Dental Implant Prosthetics

2 EDITION

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DENTAL IMPLANT PROSTHETICS, SECOND EDITION ISBN: 978-0-323-07845-0
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Library of Congress Cataloging-in-Publication Data
Misch, Carl E., author.
Dental implant prosthetics / Carl E. Misch.—Second edition.
p. ; cm.
Includes bibliographical references and index.
ISBN 978-0-323-07845-0
I. Title.
[DNLM: 1. Dental Implantation—methods. 2. Dental Implants. 3. Patient Care Planning. WU 640]
RK667.I45
617.6'93—dc23

2014000620

Executive Content Strategist: Kathy Falk
Senior Content Development Specialist: Brian Loehr
Publishing Services Manager: Catherine Jackson
Senior Project Manager: Carol O'Connell
Design Direction: Maggie Reid

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

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To my parents, MaryAnn Misch and Carl Otto Misch.
And to my children, Paula Angeline Mather, Carl Patrick Misch,
Lara Elizabeth Vandekerckhove, David John Misch, Jonathan Edward
Misch, and Angela Marie Misch.
I love you all very much.

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Forewords

Feast your mind on the writings of a master dental implant clinician and teacher.

This second edition of *Dental Implant Prosthetics* is more than an update of the widely read and referenced first edition. It is more than a juxtaposition of old and new relevant implant prosthetic thinking. It is a confluence, a continuum, and an expansion of encyclopedic knowledge by a pre-eminent implant prosthodontist, Dr. Carl E. Misch.

Dr. Misch's professional background, that includes decades of practice and teaching, encompasses both the infancy and emergence of dental implantology, its renaissance, and its current prominence in the panoply of total and advanced dental treatment. This book is a reflection of this expansive sum of accumulated knowledge.

It includes the solid footing of implant biomechanics, implant biomaterials, pretreatment prostheses, radiographic imaging, and the otherwise too often neglected subject of occlusion. It is a text. It is a learning tool. It brings us back to basics and then proceeds beyond the basics into the current realm of patient treatment. This book tells us where we have been and where we should be. It is not a glossy picture book that satisfies our eyes, but rather a book of words that are essential to the sound practice of implant dentistry.

These words teach not only the neophyte clinician but also renew the clinical platform that sustains the experienced practitioner. You are not an "experienced clinician" unless you renew and refresh why you are doing what you are doing. The end result of oral implantology is the well-planned fabrication and insertion of a viable prosthesis. The reconstructive principles described in this book fulfill the guidelines and parameters that constitute the processes of dental implant prosthetic reconstruction.

Dr. Misch has done the dental implant clinician a favor by compiling this updated edition. It is a reflection of his sense of duty to continue to educate. This book is "boot camp" for us all.

Morton L. Perel, DDS, MScD, FACD, FICD

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In 2005, I had the honor to write a brief foreword to Dr. Carl E. Misch's book *Dental Implant Prosthetics,* which has since become a classic, translated into many languages and influencing many thousands of his colleagues. A true dental "best seller" of all time.

Dr. Misch, as a member of the healing arts and sciences, has greatly benefited from the previous valuable contributions of many. Let us not forget Semmelweis, who introduced the concept of surgical cleanliness involving hands, instruments, clothing, drapes, and bandages, thereby saving hundreds of thousands of lives by preventing puerperal fever and, by extension, positively altering basic wound healing therapy. In the end, he was condemned by none other than the brilliant surgeon Virchow. It was ironic that Semmelweis died after contracting septicemia at the young age of 47, and at his own hand. In rapid order we were bombarded by the works of Lister, Pasteur, and Koch. Dentistry contributed greatly to the growing field of anesthesia, which allowed a burgeoning number of surgical procedures. Three areas, however, remained untouchable: the heart, brain, and spinal cord.

In 1896, long before the introduction of antibiotics, Dr. Louis Rehn, of the Frankfurt City Hospital, treated a patient who had been stabbed with a knife between the ribs through the pericardium and into the heart itself. Rehn acted decisively and made an incision in the fourth intercostal space, severed the fifth rib, and probed the thoracic cavity. The patient's left lung then collapsed. However, Rehn was able to clasp the pericardium, remove copious clots and blood, and visualize the still beating heart. In between beats, the wound to the right ventricle was sutured. In short order, the hemorrhage stopped and the patient survived. The principles of aseptic surgery were followed. And while some complications ensued, the patient returned to complete health and was presented by Dr. Rehn at a surgical conference in Berlin.

What does this all have to do with Dr. Misch's new edition? Carl has often personally told me that his ultimate goal in dedicating his life to dental implantology was "to advance the field" as others mentioned above clearly have. If we recognize that our patients do not necessarily want implants *per se,* but rather they want the prosthodontic results (i.e., teeth that permit function, smiles, social interactions, self-confidence, etc.), which would be in many cases supported by implants, then, and only then, will we all realize the great contribution that will be made for decades to come by the second edition of *Dental Implant Prosthetics*.

Another consideration that we should all appreciate is who will be the beneficiaries of this expanded work? Over the past 40 years, thousands of our dental colleagues have been introduced to implantology by Dr. Misch's lectures. Almost five thousand seriously committed dentists, specialists as well as generalists, have graduated from the Misch Implant Institutes in the United States and abroad. Dental educators, as well as students, rely on Dr. Misch's prosthodontic continuum not only for understanding but also for basic language, treatment planning, multiple updates, and clinical techniques.

Dr. Misch's second edition is not a prolegomena. It is a Bible.

This short commentary is submitted with great personal and professional admiration and respect.

Kenneth W.M. Judy, DDS, FACD, FICD
Co-Chairman, International Congress of Oral Implantologists

Preface

In the early 1900s, fixed partial dentures to replace missing teeth in a partially edentulous patient were vehemently opposed, and removable partial dentures were strongly encouraged. In 1911, Hunter blamed the "mausoleum of gold over a mass of sepsis" for complicating systemic conditions of anemia, gastritis, kidney disease, and lesions of the spinal cord.[1] Despite this popular belief, fixed partial dentures became the standard of care to replace missing teeth and are still taught in every dental school in North America. In fact, if a dental student does not perform a traditional fixed partial denture, they do not graduate and join the dental community.

In the 1970s, the mere mention of dental implants was controversial. Organized dentistry feared that these devices would always fail and could lead to a brain abscess or heart failure, because it was believed there was no barrier between the oral bacteria and the systemic pathways. However, in spite of this obstacle, a few hundred dentists around the world observed that patients readily accepted dental implants to support a mandibular complete denture or believed that a fixed implant prosthesis was more desirable than using removable restorations or preparing and joining adjacent teeth for fixed prostheses.

Today we are in the midst of a dental implant revolution. There are more scientific and clinical articles written on dental implants than any other topic in dentistry. From 1950 to 1985, there were approximately 500 referred articles published on dental implants. Between the years 1985 and 1995, there were more than 1500 articles published on dental implants. More recently, from 1995 to 2005, there were over 5000 articles published in referred journals on topics related to dental implants. Today, the dental implant is now accepted as a primary method to replace a single tooth or multiple adjacent missing teeth, or to support a removable or fixed prosthesis for a completely edentulous patient.

In the United States, the total sales of implant products to the dental profession from 1950 to 1985 was less than $1 million each year, and from 1985 to 1995 the sales increased to $100 million per year. The sale of implant-related products from 1995 to 2005 skyrocketed to $1 billion per year, and today is estimated at $4 billion each year. However, this dramatic increase in sales has a downside. The rapid growth of dental implants as man-made abutments to replace missing teeth has caused technology to develop quickly and often without guidelines for evaluation. The driving force behind implant treatment should not be directed by dental advertising from manufacturers. Procedures should be based on scientific and clinical studies to determine what is predictable.

Implant dentistry has become a vital part of prosthodontics for partially and completely edentulous patients. All U.S. dental undergraduate programs and all U.S. specialty programs in prosthodontics must teach implant prosthetics to gain accreditation by their governing bodies. Several dental schools now recommend that almost all mandibular dentures be retained by implants and that three-unit fixed prostheses may be replaced by single-tooth implants. More than 90% of all U.S. general dentists have restored implants or referred a patient for an implant prosthesis. However, most dentists who perform implant restorations have not completed a structured, supervised program specific for implant prostheses. Instead, the implant is restored in a similar scenario as natural teeth. However, although only a minority of practitioners take the time and effort to learn all aspects of this rapidly growing and evolving field, the majority of dentists can provide various aspects of implant treatment.

The good news is that dental implant restorations have the highest survival rate compared with any other type of prosthesis to replace missing teeth. They do not decay or require endodontic treatment. They are also less prone to fracture and resist periodontal-like disease better than a tooth. The bad news is that the treatment plan, the fabrication of the restoration, the occlusion, the maintenance, and the treatment of complications (such as screw loosening, crestal bone loss, prosthesis fracture, or implant failure) are most often unique to implant dentistry.

The second edition of *Dental Implant Prosthetics* addresses the science and discipline of implant dentistry. Compared to the first edition, this book has nearly doubled in size and has added new chapters in treatment planning and implant prosthetics. In addition, more than 2000 illustrations have been used to detail related concepts.

An underlying theme of *Dental Implant Prosthetics* is to base the treatment of missing teeth on the sciences related to implant dentistry. This book does not attempt to be an encyclopedia of all that is possible in the restoration of an implant patient. Instead, it is a text that relates one chapter to every other chapter and presents a common thread of science and past experience to the art of replacing teeth. Every chapter is carefully blended to be consistent in purpose: to provide a predictable outcome.

The first part of *Dental Implant Prosthetics* sets the stage for understanding the importance of implants to a dental restorative practice. The second part of the book covers the related basic sciences of biomechanics and biomaterials, exploring why biomechanics should be used as a basis of implant treatment planning as a way to reduce complications. Implant dentistry does not guarantee a result, nor is it without complications. However, there is a consistent theme to reduce and eliminate many complications, and this theme starts with a biomechanically based treatment plan.

Implant treatment planning, the focus of the third part of this book, has been expanded in this edition. More than 50 implant dental criteria may influence treatment planning and prognosis. A generic seven-step process for treatment planning is presented. Chapters in this part look at stress treatment theorem for implant dentistry, prosthetic options, force factors, bone density, implant body size, preimplant prosthodontics, and diagnostic casts, surgical templates, and provisionalizaion.

[1]Hunter W: The role of sepsis and antisepsis in medicine, *Dent Briefs* 16:852, 1911.

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The fourth part of this book on special treatment options looks at single tooth replacement and restoration, maxillary posterior edentulism, the edentulous mandible, and maxillary arch implant considerations. The single tooth replacement is often the first introduction to implant dentistry for restoring dentists. The posterior missing single tooth is addressed separately from the anterior missing tooth. The posterior regions missing a single tooth can be the easiest restoration. On the other hand, the maxillary anterior region can be the most difficult treatment to render in implant dentistry. The two extremes are detailed in separate chapters. The completely edentulous patient is a prime candidate for implant prostheses and is the topic of the several chapters in this section, Specific issues related to edentulism are addressed and unique treatment planning concepts are presented in a logical fashion. The principles of implant overdentures with bar and attachment support, retention, and stability are presented. The mandible and maxilla are addressed as separate chapters, since their complications are unique to each other.

Principles for fixed implant restorations are discussed in Part V. These guidelines may be used in almost every implant prosthesis for a partially edentulous patient. In addition, progressive loading is presented for softer bone types and as a concept has matured since I introduced it in the late 1980s. Occlusion also is specifically addressed for both fixed and removable prostheses.

The final part of *Dental Implant Prosthetics* presents the long-term evaluation and maintenance of dental implants.

Dental Implant Prosthetics and my other book, *Contemporary Implant Dentistry,* published by Elsevier, have been used over the years as textbooks for dental students, interrelated dental residents, postgraduate programs, implant residents, specialists, and generalists. Their translation into more than 10 languages and their widespread acceptance have provided a thinking process for oral implantology. This most recent edition attempts to help further elevate the science and discipline of implant dentistry and allow predictable treatment to replace missing teeth for the patients we treat and the doctors we train.

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About the Author



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Carl E. Misch is a Clinical Professor and Past Director of Implant Dentistry in the Department of Periodontology and Implant Dentistry at Temple University Kornberg School of Dentistry. He is also a past Clinical Professor in the Department of Periodontics/Geriatrics at the University of Michigan School of Dentistry. Dr. Misch is also a past Clinical Professor in the Department of Restorative Dentistry at the University of Detroit–Mercy School of Dentistry. He is also a past Board of Trustee member-at-large for the University of Detroit Mercy School. In addition, he is an Adjunct Professor at the University of Alabama at Birmingham, School of Engineering, Department of Biomechanics. He was Co-Director or Director of the Oral Implantology Residency Program at the University of Pittsburgh School of Dental Medicine from 1986 to 1996.

Dr. Misch graduated Magna cum laude in 1973 from the University of Detroit Dental School and received his Prosthodontic Certificate, Implantology Certificate, and Master's Degree in Dental Science from the University of Pittsburgh. He has been awarded two honoris causa PhD degrees, from the University of Yeditepe in Istanbul, Turkey, and Carol Davila University of Medicine and Pharmacy in Bucharest, Romania. Other graduate honors include 13 fellowships in dentistry, including Fellow of the American College of Dentistry, Fellow of the International College of Dentists, Fellow of the International College of Dentists, Fellow of the American Association of Hospital Dentistry, Fellow of the Academy of Dentistry International, and Fellow of the Pierre Fauchard Academy. Dr. Misch has more than 10 patents related to implant dentistry and is the co-inventor of the Biohorizons Dental Implant System.

Dr. Misch is a diplomate and past president of the American Board of Oral Implantology/Implant Dentistry and served as member of the diplomate examining committee for 7 years. He is a past president of the International Congress of Oral Implantologists, which represents more the 100 countries and is the world's largest implant organization, the American Academy of Implant Dentistry, the Academy of Implants and Transplants, and the American College of Oral Implantologists.

In 1984, Dr. Misch founded the Misch Implant Institute. Currently, training centers for the institute are located in Florida, Michigan, Nevada, and Toronto, Canada. Over the years, the Misch Implant Institute has had training centers in Korea, Italy, Brazil, Japan, the United Kingdom, Monaco and Spain. In the United States and Canada, the Institute has had centers in Florida, Georgia, Maryland, Texas, New York, Illinois, Vancouver, and Montreal. As Director, Dr. Misch has trained more than 5000 doctors in a hands-on yearly forum of education in implant dentistry. Programs are offered in both the surgical and prosthetics aspects of patient care.

Dr. Misch has now edited three editions of *Contemporary Implant Dentistry* and two editions of *Dental Implant Prosthetics*. These five textbooks have been translated into Italian, Korean, Portuguese, Turkish, Spanish, Farsi, Japanese, Chinese (Simplified), Greek, and Russian, and they are used in dental schools around the world for graduate and postgraduate programs. Dr. Misch has published more than 250 articles related to implant dentistry. During the past 30 years, Dr. Misch has lectured more than 1000 times in all 50 states of the United States and in more than 47 countries throughout the world.

Dr. Misch has six children: Paula, Carl, Lara, David, Jonathan, and Angela.

Acknowledgments

This is the fifth book I have written that shares my experience, training, and knowledge in a discipline to which I have dedicated my life. This process began with my three original mentors: Ken Judy, Leonard I. Linkow, and O. Hilt Tatum. They will always be acknowledged in my lectures, articles, and chapters. Implant dentistry needed early pioneers to blaze the trails for the profession. Their concepts of bone grafting, implant surgery, prosthetics, implant education, and leadership created a foundation 40 to 50 years ago that allowed the profession to build the current structure we have today in implant dentistry. Through the years, all three of these gentlemen have become great friends, and I continue to learn from them. I especially thank each of them for providing their personal continued guidance and support to me over the last 40 years.

There also are many people to acknowledge and thank in preparation of *Dental Implant Prosthetics*, second edition. Allow me to begin with all participating authors: Martha Warren Bidez, Lee Culp, Jack E. Lemons, Michael S. McCracken, Francine Misch-Dietsh, Girish Ramaswamy, Randolph R. Resnik, J. Todd Strong, Jon B. Suzuki, Lynn D. Terracciano-Mortilla, and Natalie Y. Wong. Each co-author was selected for his or her unique additional knowledge. Their dedication to implant dentistry and their friendship and personal support to me is greatly appreciated.

Thank you to Jill Bertelson. Since I hand write every chapter and hand write every chapter edit more than 20 times, she types and retypes every sentence in this book. She also coordinated the chapters with the publisher.

Each book takes a toll on my immediate family. During this project, my youngest son and daughter, Jonathan and Angela, bore the brunt to the time and pressures to write this book. Thank you for understanding and giving up our personal time.

I also would like to thank Brian Loehr and Kathy Falk of Elsevier/Mosby. Thank you for your patience, experience, and guidance during this process.

Thank you to Heidi Cartegena and Jennifer Luczak, my executive and private assistants, for all the coordination required in organizing this text. I would also like to thank the Dental Laboratory Team: Nemer Hussain, Tom and Beatrice Dabrowsky, LDT, BIT Dental Studios, Dillon, CO. Kim Bradshaw-Sickinger, President and CEO Micro Dental Laboratories (DTI), and Rebecca Caprroso (Tata) my surgical and prosthetic assistant.

The second edition of *Dental Implant Prosthetics* is also a reflection of the five thousand doctors I have trained around the world at the Misch International Implant Institute since 1984. Those doctors contributed by the questions asked and their desire for an organized approach to help their patients. I wish to thank each of them for their professional support.

Carl E. Misch

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CHAPTER 1

Rationale for Dental Implants*

Carl E. Misch

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The goal of modern dentistry is to restore the patient to normal contour, function, comfort, esthetics, speech, and health, whether restoring a single tooth with caries or replacing several teeth. What makes implant dentistry unique is the ability to achieve this goal regardless of the atrophy, disease, or injury of the stomatognathic system.[1] However, the more teeth a patient is missing, the more challenging this task becomes. As a result of continued research, diagnostic tools, treatment planning, implant designs, materials, and techniques, predictable success is now a reality for the rehabilitation of many challenging clinical situations.

The number of dental implants used in the United States increased more than 10-fold from 1983 to 2002, and that number increased another 10-fold from 2000 to 2010. More than 5 million dental implants are inserted each year in the United States. This number continues to increase steadily, with an expected yearly growth sustained at 12% to 15% for the next several years.[2] More than $1 billion in implant products was sold in the United States in 2010, up from $550 million of implant products sold in 2005 and compared with $10 million in 1983. When bone grafting materials are included in implant products, it is estimated the field of implant dentistry in 2010 sold $10 billion in products to provide services to patients.[3] More than 90% of interfacing surgical specialty dentists currently provide dental implant treatment on a routine basis in their practices, 90% of prosthodontists restore implants routinely, and more than 80% of general dentists have used implants to support fixed and removable prostheses compared with fewer than 50% of specialists and fewer than 25% of general dentists 20 years ago.[4–8]

Despite these figures demonstrating implants are incorporated into dentistry more than ever before, there is still much room for continued growth. Utilization of dental implants varies widely in different countries of the world. For example, it is estimated that the number of implants each year per 10,000 people is 230 for Israel (the greatest number); 180 for South Korea and Italy; 140 for Spain and Switzerland; 100 for Germany; and 60 each for Brazil, the Netherlands, and the United States (Figure 1-1). Japan and France (50), Canada and Australia (40), and Taiwan and United Kingdom at 20 per year use implants less often. The six countries with greatest use of implants (Europe and South Korea) accounted for more than half the total market growth from 2002 to 2007. A long-term growth of 12% to 15% is expected in the future in most countries using implants at this time.

The percentage of teeth replaced with an implant, rather than traditional fixed or removable prostheses, also dramatically varies by country. In Israel, Italy, and South Korea, 30% to 40% of teeth replaced incorporate an implant. In Spain, Switzerland, Germany, and Sweden, 20% to 26% of restorations to replace teeth are supported by an implant. Brazil and Belgium come in at 13% to 16% of restorations use and implant. Surprisingly, the United States, Japan, France, and Canada use implants in 10% or fewer of the teeth replaced.[8] In other words, in a 2011 report, only one of 10 teeth replaced in the United States uses an implant for an abutment (Figure 1-2).

The increased need and use of implant-related treatments in the future result from the combined effect of several factors, including (1) aging population living longer, (2) tooth loss related to age, (3) consequences of fixed prosthesis failure,

*Note: This chapter is written in terms for dentists, staff, and the lay public.

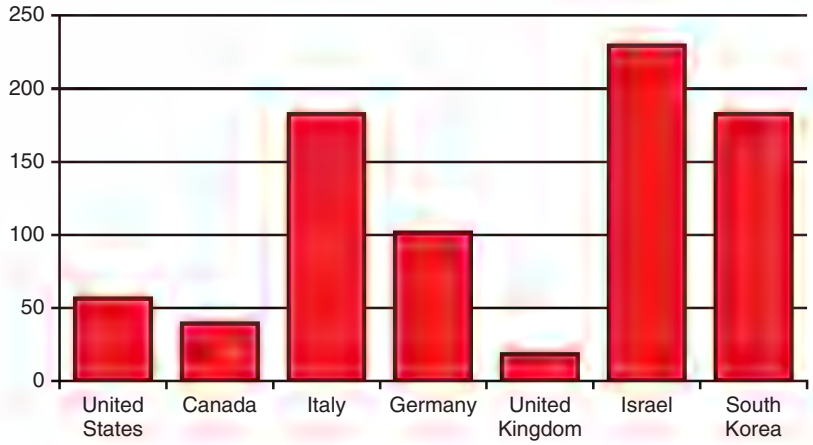


FIGURE 1-1. Implant use to replace teeth varies by country. Estimated implant use per 10,000 people per year is greatest in Israel, South Korea, and Italy.

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(4) anatomical consequences of edentulism, (5) poor performance of removable prostheses, (6) consequences of removable partial dentures, (7) psychological aspects of tooth loss and needs and desires of aging baby boomers, (8) predictable long-term results of implant-supported prostheses, (9) advantages of implant-supported restorations, and (10) increased public awareness.

Effects of an Aging Population

According to the literature, age is directly related to every indicator of tooth loss.[9,10] Therefore, the aging population is an important factor to consider in implant dentistry. Although some famous individuals in the past have lived past the age of 80 years (e.g., Ramses II, King Louis XIV), the average life span remained below 40 years until the 18th century. For example, when Alexander the Great conquered the ancient world, he was only 17 years old. However, life expectancy at that time was only 22 years of age. From 1000 BC to 1800 AD, life span remained less than 30 years (Figure 1-3). Since 1960, the increase in life expectancy has been more rapid than at any other time in history (Figure 1-4). In 1980, 30% of the U.S. population was older than age 45 years, 21% was older than 50 years, and 11% was older than 65 years. In 1995, 15 years later, these individuals were older than age 60 years. The group older than age 65 years is projected to increase from 12% in 2000 to more than 20% of the population within the next 15 years[11] (Figure 1-5).

In addition, not only is the percentage of the population over 65 years of age increasing, but the overall population is also increasing. The population in 2000 was 282 million and is projected to increase 49% to 420 million by 2050. Considering the effect of both a population increase and a greater percentage of that population being older than age 65 years, a dramatic overall increase in geriatric patient numbers can be expected. In 2003, 35 million people were older than age 65 years. This number is expected to increase 87% by 2025, resulting in almost 70 million people being older than age 65 years in the United States[12] (Figure 1-6). Because older people are more likely to be missing teeth, the need for implant dentistry will dramatically increase over the next several decades.

Life expectancy has increased significantly past the age of retirement. In 1965, the average life span was 65 years; in 1990, it was 78 years. Life expectancy in 2001 was 85 years for a nonsmoking individual of normal weight.[13] A 65-year-old woman can now expect to live 25 more years 40% of the time and 30 more years 19% of the time[14–16] (Figure 1-7). Women represent two thirds of the population older than age 65 years and are more likely to use implants to replace their teeth compared with men.[17] It is not unusual for a 70-year-old patient to ask, "Is it worth it for me to spend more than $30,000 to repair my mouth at my age?" The response should be very positive because the patient's life expectancy may extend for two more decades, and his or her current oral situation will normally become worse if not corrected.

Social pleasures, including dining and dating, continue throughout advanced life. In the past, geriatric dentistry meant

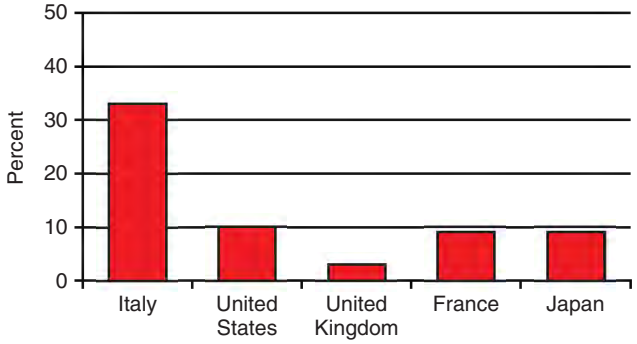


FIGURE 1-2. Implant versus nonimplant tooth replacement (by %) varies greatly by country. In the United States, only one of every 10 teeth replaced incorporates an implant.

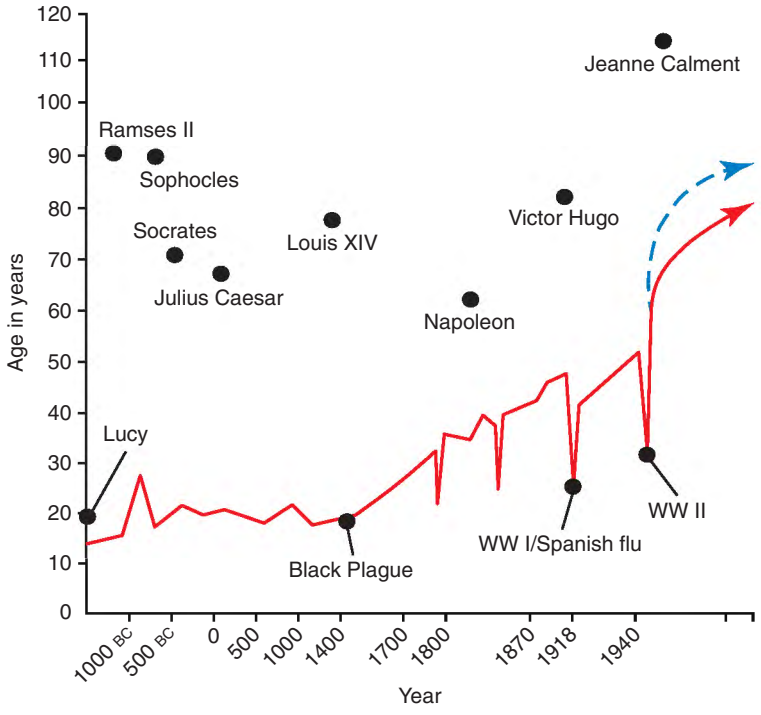


FIGURE 1-3. Average life expectancy remained approximately 20 to 30 years for several hundred years of human civilization. Since the late eighteenth century, there has been a gradual increase in life span. (Redrawn from *Le Figaro Magazine*, Paris, 2004.)

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inexpensive treatment emphasizing nonsurgical approaches. The poverty rate for elderly adults, however, is less than 10%, and retiree median income has grown 8% in recent years. The median net worth of retirees is 15 times the net worth of those younger than age 35 years and three times as high as "working families" ages 35 to 44 years.[17,18] Close to 20% of today's retirees have a net worth of more than a quarter of a million dollars.

Today, the full scope of dental services for elderly patients is increasing in importance to both the public and the profession because of the increasing age of our society. Treatment alternatives that consider fixed prostheses with implant support should be presented to almost any patient. Only when all treatment options are discussed can a person's desires related to the benefit of implant dentistry be truly appreciated.

Dental services for elderly patients clearly represent a growing demand for the dental profession. In 2000, 28.8% of all income from a dentist came from patients age 60 years and older—a group that represented only 12% of income in 1988. When the dentist is older than age 40 years, income from those older patients represents 64.3% of the dentist's income; in 1988, it was 30.3%.[19] Clearly, the demographics of our population have dramatically changed the economics of dental practice.

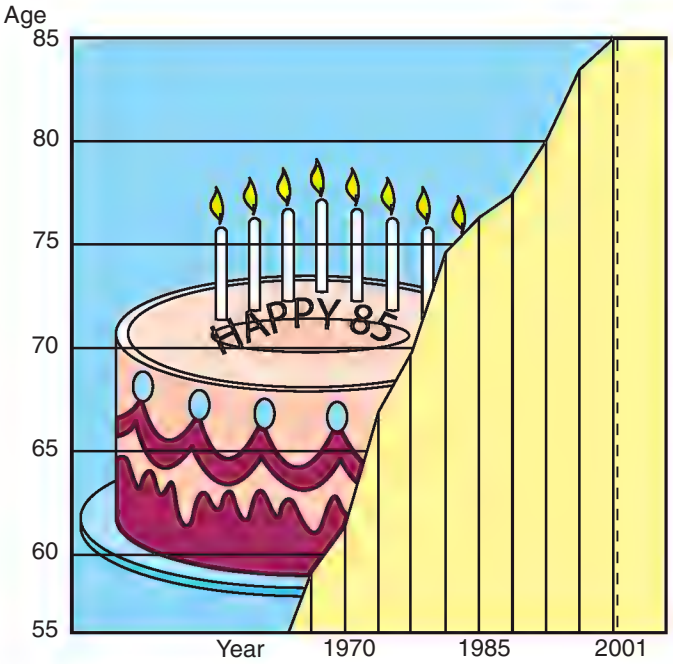


FIGURE 1-4. Life expectancy has increased more rapidly since 1960 than at any other time in history. Because tooth loss is directly related to age, a growing number of adults are missing teeth.

Age-Related Tooth Loss

Single-Tooth Edentulism (Single-Tooth Loss)

Adult patients often have one or more crowns as a consequence of previous larger restorations required to repair the integrity of the tooth. Longevity reports of crowns have yielded very disparate results. The mean life span at failure has been reported as 10.3 years. Other reports range from a 3% failure rate at 23 years to a 20% failure rate at 3 years. It has been estimated that a $425 crown for a 22-year-old patient will cost $12,000 during the patient's lifetime to replace or repair.[20]

The primary cause of failure of the crown is caries followed by endodontic therapy.[21–29] The tooth is at risk for extraction as a result of these complications, which are the leading causes of single posterior tooth loss in adults (Figure 1-8).

As a consequence, the posterior regions of the mouth often require the replacement of a single tooth.[30–32] The first molars are the first permanent teeth to erupt in the mouth and, unfortunately, are often the first teeth lost as a result of decay, failed endodontic therapy, or fracture (usually after endodontics). They are important teeth for maintenance of the arch form and proper occlusal schemes (Figure 1-9).

Fixed Partial Dentures (Dental Bridges)

The most common choice to replace posterior missing teeth is a fixed partial denture (FPD). The adjacent teeth next to the missing tooth are prepared, and crowns are inserted that are connected to the missing tooth (pontic) (Figure 1-10). This three-tooth restoration can be fabricated within 1 to 2 weeks and satisfies the criteria of normal contour, comfort, function, esthetics, speech, and health. Because of these benefits, FPD has been the treatment of choice for the past 6 decades. Bone and soft tissue considerations in the missing tooth site in the posterior regions are few. Every dentist is familiar with the procedure, and it is widely accepted by the profession, patients, and dental insurance companies.

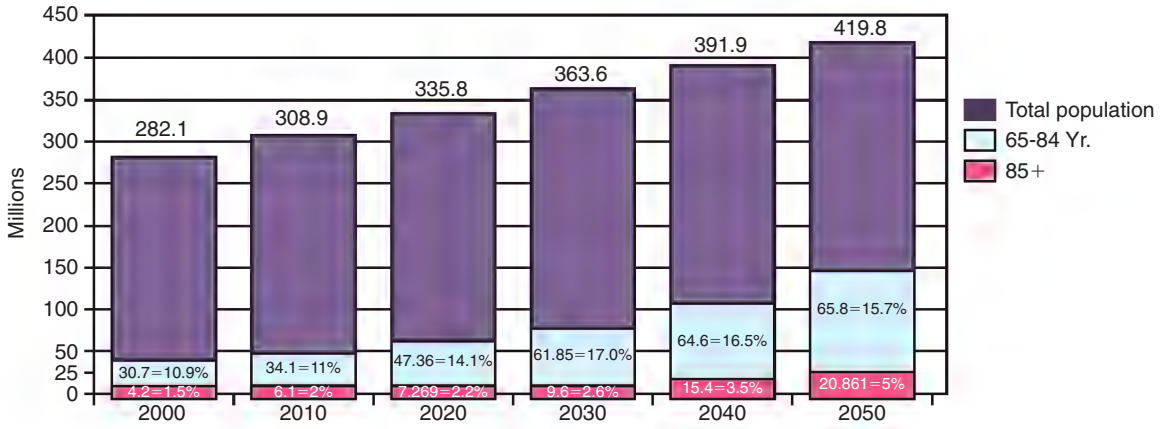


FIGURE 1-5. By 2050, 20.7% of the population will be older than age 65 years. In addition to the increasing percentage of 65-year-old adults, the population is also increasing. As a result, 34.9 million people were older than 65 years in 2000, and 86.6 million people will reach this milestone by 2050.

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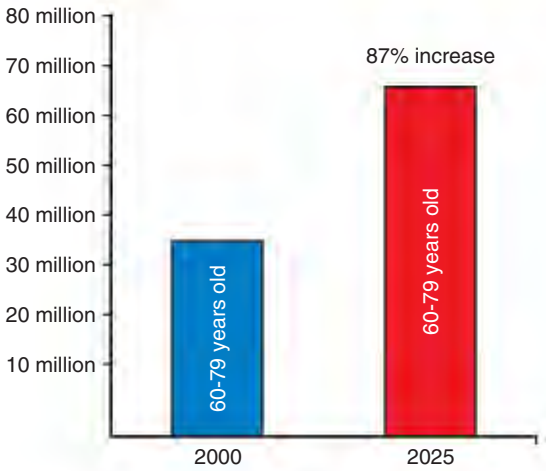


FIGURE 1-6. The adult population older than the age of 60 years old will increase by 87% from the year 2000 to the year 2025.

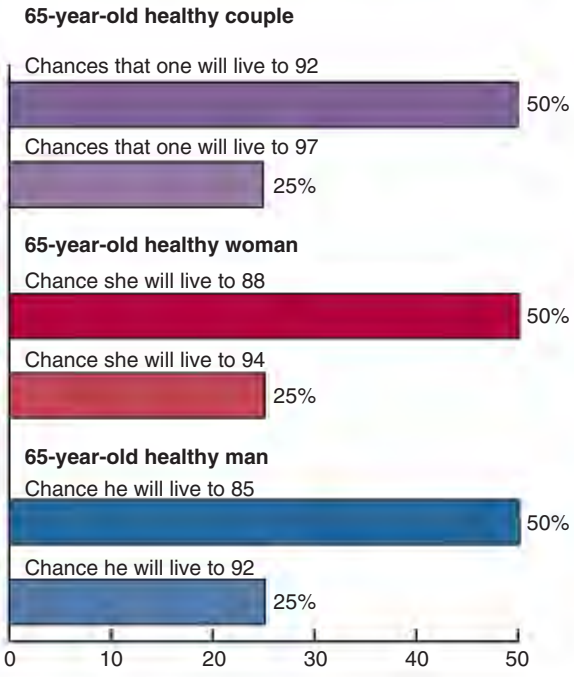


FIGURE 1-7. When a person reaches age 65 years, he or she often feels an investment in health is less appropriate. A 65-year-old healthy woman will live 23 more years 50% of the time and 29 more years 25% of the time. Her present oral condition will become worse during this extended time frame if treatment is not rendered.



FIGURE 1-8. A posterior endodontically treated tooth has an increased risk of failure or fracture compared with a vital tooth.



FIGURE 1-9. A posterior missing tooth is a frequent occurrence in a general practice. The most common single tooth missing is a first molar.

Almost 30% of the 50- to 59-year-old adults examined in a U.S. National Survey exhibited either single or multiple edentulous spaces bordered by natural teeth. In 1990, more than 4 million FPDs were placed in the United States.[21,22,32] Treatments to replace single teeth with a fixed prosthesis represent 7% of the annual dental reimbursement from insurance companies and more than $3 billion each year. Less than half of our population in the United States has dental insurance, and of those who do, only 50% of treatment costs are reimbursed. Hence, the entire three-unit FPD costs in the United States may approach more than $10 billion each year.

A three-unit FPD presents survival limitations to the restoration and, more importantly, to the abutment teeth.[27,29] The survival rate of a FPD is lower than for a single crown restoration. In an evaluation of 42 reports since 1970, Creugers et al. calculated a 74% survival rate for FPDs for 15 years.[25] Mean life spans of 9.6 to 10.3 years have been reported by Walton et al.[27] and Schwartz et al.,[21] respectively. However, reports are very inconsistent, with as little as 3% loss over 23 years to 20% loss over 3 years.[21–29,32]

The incidence of failure is greater for a FPD compared with a single crown and places the abutment teeth at more risk. Caries (decay) and endodontic (root canal) failure of the abutment teeth are the most common causes of prostheses failure.[27,28] Whereas the caries risk for a crown at 5 years is 1%, the caries risk for a FPD is over 20%. The pontic acts as a plaque reservoir in a FPD and the abutment teeth often decay (Figure 1-11). As a result of structural failure from decay or failed endodontic therapy, the abutment teeth are at increased risk of loss. Up to 15% of abutment teeth for a FPD require endodontic therapy compared with 3% of nonabutment teeth that have crown preparations[25] (Box 1-1). In addition, the prepared and crowned

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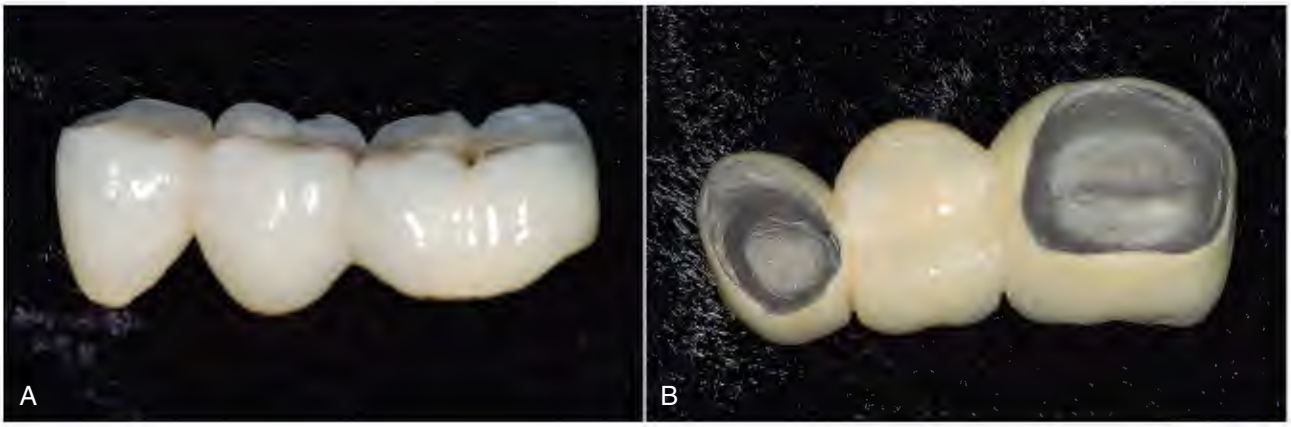


FIGURE 1-10. **A,** A three-unit fixed partial denture is the most common method to replace missing teeth in the posterior regions of the jaws. **B,** To replace the missing teeth, the teeth adjacent to the space are crowned, and the missing tooth is attached to the crowns.

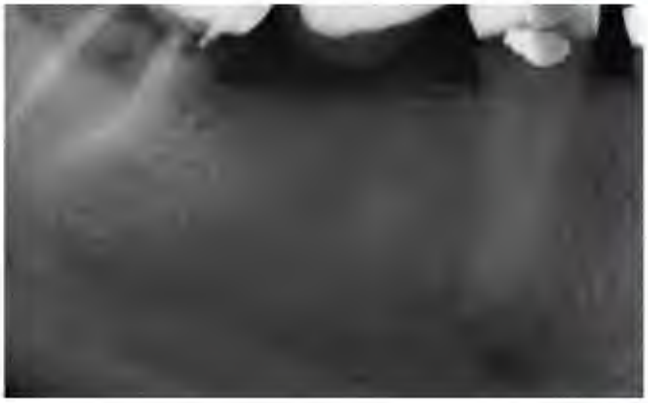


FIGURE 1-11. The abutment teeth of a fixed partial denture often decay at the margin next to the pontic because it acts as a plaque reservoir and rarely has adequate daily hygiene.



FIGURE 1-12. Almost 80% of the time when a posterior tooth is missing, the adjacent teeth have no or only minimal restorations.

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BOX 1-1 Fixed Partial Denture versus Crown Complications

Caries: 22%–27% vs. 1%
Endodontic related (e.g., failure, fracture): 11%–15% vs. 3%
Unretained restoration: 7%–11% vs. 2%
Porcelain fracture: 7%–10% vs. 3%

BOX 1-2 Single-Tooth Replacement—Fixed Partial Denture

- Estimated mean life span of a fixed partial denture (FPD) (50% survival) is reported at 15 years
- Caries and endodontic problems are the most common causes of FPD failure (>20%)
- Loss of FPD abutment teeth at 8% to 12% within 10 years and 30% within 15 years
- 80% of teeth adjacent to missing teeth have no or minimal restoration

abutments may be sensitive to cold from hyperemia related to the trauma of a tooth preparation.

Unfavorable outcomes of FPD failure include both the need to replace the failed prosthesis and the loss of an abutment and the need for additional pontics (replacement teeth) and abutment teeth in the replacement bridge. Approximately 8% to 12% of the abutment teeth holding a FPD are lost within 10 years.[8] The abutment teeth of a FPD may be lost at rates as high as 30% within 14 years.[26] The most common reason for single-tooth loss is endodontic failure or fracture of a tooth (usually after endodontic therapy). Because 15% of abutment teeth require endodontics and root canal therapy may have a 10% failure rate at the 8-year mark, abutment teeth are at increased risk of loss.

Almost 80% of abutments prepared for a three-unit FPD have no existing or only minimal restorations[33,34] (Figure 1-12). Rather than removing sound tooth structure and crowning two or more teeth—thus increasing the risk of decay and endodontic therapy (and splinting teeth together with pontics, which have the potential to cause additional tooth loss)—a dental implant may replace the single tooth (Box 1-2).

Single-Tooth Implants

A primary treatment option to replace a posterior single missing tooth is a single-tooth implant (Figure 1-13). For years, patients

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FIGURE 1-13. A single-tooth implant in the posterior region of the mouth is most often the treatment of choice.



FIGURE 1-14. A single-tooth implant to replace a missing tooth has the highest success rate, and the adjacent teeth are less likely to decay, require endodontics, or result in additional tooth loss.



FIGURE 1-15. A postoperative picture of a 10-year-old single-tooth implant replacing the second premolar.

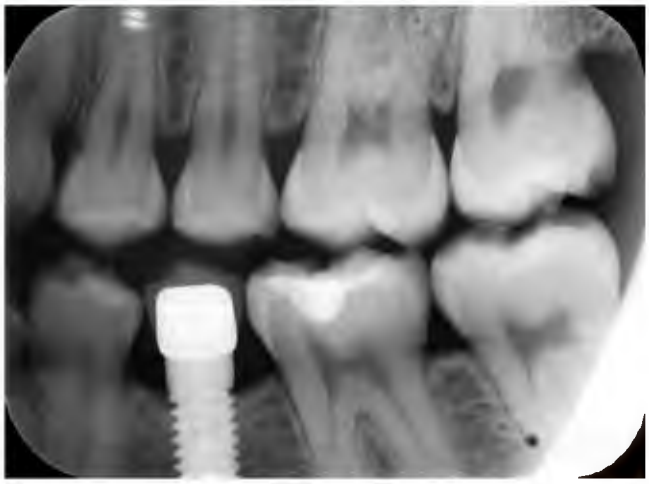


FIGURE 1-16. A bitewing radiograph of a single tooth implant after 10 years. The adjacent teeth had no additional restoration during this time frame.

were advised to put their desires aside and accept the limitations of a FPD. However, many believe the most natural method to replace a tooth is to use an implant rather than preparing adjacent teeth and joining them together with a prosthesis. The primary reasons for suggesting the FPD were its clinical ease, reduced cost, and reduced treatment time. However, if this concept were expanded, extractions would replace endodontics, and removable partial dentures would be used instead of fixed prostheses. The primary reason to suggest or perform a treatment should not be related to treatment time, costs, or difficulty of the procedure but instead should consider the best possible long-term solution for each individual.

From 1993 to the present, single-tooth implant survival reports have validated this procedure as the most predictable method of tooth replacement. There are more refereed reports in the literature for single-tooth implant replacement than for any other method of tooth replacement,[35] and all reports demonstrate a higher survival rate for single-tooth implants. In 1995, Haas et al. reported on 76 single-tooth implants over a 6-year period and found a 97% survival rate and a 2.6% implant loss.[36] Fugazzotto evaluated 1472 implants over a 13-year period and found a 97% survival rate during that period.[37] In 2008, Misch et al. reported on more than 1300 implants over a 10-year period and found over a 99% survival rate.[34] As important, the adjacent teeth survival and restoration rate was greater than with any other treatment method to replace a tooth (Figure 1-14).

Goodacre et al. performed a Medline literature review from 1980 to 2001 and found the single-tooth implant success rate to be in the range of 97%—higher than any other implant restoration.[35] In comparison, FPD failure rates may be as high as 20% within 3 years, and 50% rates at 10 to 15 years are expected. As a result, the single-tooth implant exhibits the highest survival rates presented for single-tooth replacement. As important, reports indicate less restoration or loss of an adjacent tooth, which is a considerable advantage[33,34] (Figures 1-15 and 1-16). Despite some limitations and obvious clinical challenges, the single-tooth implant represents the treatment of choice from both a health and value standpoint.[38]

When adjacent teeth are healthy or when the patient refuses their preparation for the fabrication of a traditional three-unit fixed partial restoration, a posterior single-tooth implant is an excellent solution. Health-related advantages of this modality over a fixed partial restoration are listed in Box 1-3 and include a decreased risk of decay and periodontal disease, decreased risk of abutment tooth loss from endodontic failure or caries, and improved esthetics (because the adjacent teeth may remain unrestored). In fact, even when the adjacent teeth require crowns, a single-tooth implant is often the treatment of choice because a crown decays less often than abutments for a FPD

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BOX 1-3 Single-Tooth Implants—Advantages

- High success rates (above 97% for 10 years)
- Decreased risk of caries of adjacent teeth
- Decreased risk of endodontic problems on adjacent teeth
- Improved ability to clean the proximal surfaces of the adjacent teeth
- Improved esthetics of adjacent teeth
- Improved maintenance of bone in the edentulous site
- Decreased cold or contact sensitivity of adjacent teeth
- Psychological advantage
- Decreased risks of adjacent tooth loss



FIGURE 1-17. Even when teeth adjacent to the missing tooth require crowns, an implant is the treatment of choice because single crowns on teeth adjacent to implants have fewer complications and increased longevity compared with abutments for a three-unit fixed partial denture.

(Figure 1-17). Psychological advantages, especially with congenitally missing teeth or the loss of a tooth after a crown restoration, are significant as well. These advantages are so significant to the health and periodontal condition of the adjacent teeth and maintenance of the arch form that the single-tooth implant has become the treatment of choice in most situations.

Economic considerations may play in disfavor of the implant restoration only during the first several years. Compared with a FPD, a single-tooth implant becomes more advantageous economically, not only for health considerations but also financially after the break-even point of 7 years, at which time the patient will not need a replacement prosthesis. As a result, the future savings will offset the initial higher cost, especially because the adjacent teeth are more likely to survive longer and replacement of a restoration is unnecessary.[39,40]

Partial Edentulism (Tooth Loss)

The prevalence of partial edentulism is also of interest because a growing number of implants are used in these patients. A 1988 to 1991 survey in the United States found that only 30% of patients had all 28 teeth. Partially dentate patients had an average of 23.5 teeth.[9,32,41] In the 1999 to 2004 follow-up survey, the average number of missing teeth was fewer than two of 28 teeth for the 20- to 39-year-old group. However, this number rapidly increased to an average of nine teeth missing in adults older than age 60 years.[42] The average missing teeth in the

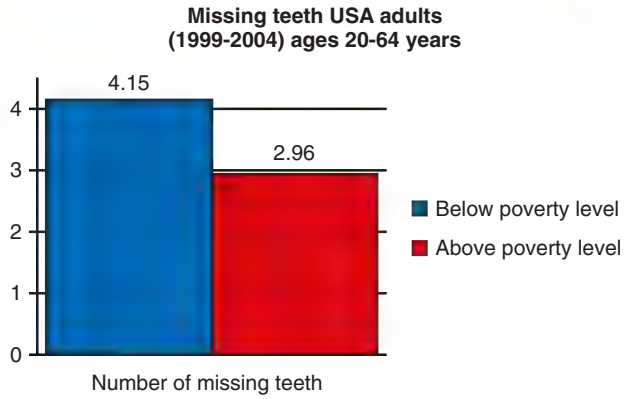


FIGURE 1-18. The number of teeth missing in the U.S. adult population is not affected very much by economic factors.

population below the poverty level was four teeth compared with three missing teeth above the poverty level (Figure 1-18). Hence, income was not a major factor for the number of teeth loss. Partially edentulous seniors older than age 60 years have lost an average of 10 teeth, with older seniors having lost three more teeth than the younger seniors. Statistics for partial edentulism are similar for both men and women.

The greatest transition from an intact dental arch to a partially edentulous condition in the 1987 study occurred in the 35- to 54-year-old group.[19,32] The growth rate of this portion of the population was approximately 30% in 1982 and is continuing to increase, more than any other age group. For example, in 1982, this 35- to 54-year-old group increased from 39 million Americans to 79 million in 2005. Although the number of teeth missing per patient may seem to decrease, the overall number of missing teeth will continue to increase as a result of the aging population. Therefore, the need for implant services in partially edentulous patients will dramatically increase during the next several decades.[14]

The most common missing teeth are molars.[31] Partial free-end edentulism is of particular concern because in these patients, teeth are often replaced with removable partial prostheses. This condition is rarely found in persons younger than age 25 years. Mandibular free-end edentulism is greater than its maxillary counterpart in all age groups. Unilateral free-end edentulism is more common than bilateral edentulism in both maxillary and mandibular arches in the younger age groups (ages 25 to 44 years). About 13.5 million persons in these younger age groups have free-end edentulism in either arch (Figure 1-19).

In 45- to 54-year-old patients, 31.3% have mandibular free-end edentulism, and 13.6% have free-end edentulism in the maxillary arch. Approximately 9.9 million persons in the 45- to 54-year-old group have at least one free-end edentulous quadrant, and almost half of these have bilateral partial edentulism.[10] The pattern of posterior edentulism evolves in the 55- to 64-year-old group, in whom 35% of mandibular arches show free-end edentulism compared with 18% of maxillary arches. As a result, approximately 11 million individuals in this age group are potential candidates for implants. An additional 10 million show partial free-end edentulism at age 65 or older.

Additional studies have documented that in the population of noninstitutionalized U.S. civilians, one of five had a removable prosthesis of some type.[43–45] The total number of potential patients in the U.S. survey with at least one quadrant of

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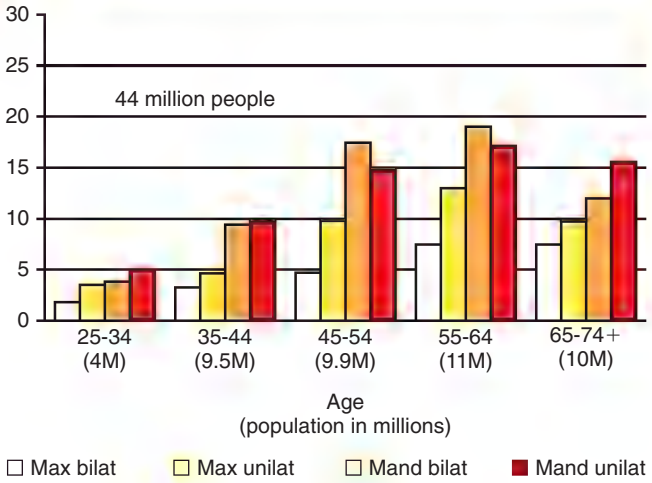


FIGURE 1-19. There are more than 44 million people in the United States missing at least one quadrant of posterior teeth (most often in the mandible).

posterior missing teeth is more than 44 million people.[10] If each of these arches requires three implants to support a fixed prosthesis, 132 million implants would be required.

Removable Partial Dentures

Removable soft tissue–borne partial dentures have one of the lowest patient acceptance rates in dentistry. Half of patients with a removable partial denture chew better without the device. A 44-year Scandinavian study revealed that only 80% of patients were wearing such prostheses after 1 year. The number further decreased to only 60% of the free-end partial dentures worn by the patients after 4 years. This rate was reduced to only 35% at 10 years.[46–50] In another study, few partial dentures survived more than 6 years.[51] Although one of five U.S. adults have worn a removable dental prosthesis of some type, 60% reported at least one problem with it.[44]

Reports of removable partial dentures indicate the health of the remaining dentition and surrounding oral tissues often deteriorates.[46,52] In a study that evaluated the need for repair of an abutment tooth as the indicator of failure, the "success" rates of conventional removable partial dentures were 40% at 5 years and 20% at 10 years.[48] Patients wearing the partial dentures often exhibit greater mobility of the abutment teeth, greater plaque retention, increased bleeding upon probing, higher incidence of caries, speech inhibition, taste inhibition, and noncompliance of use.[49–52] A report by Shugars et al. found abutment tooth loss for a removable partial denture may be as high as 23% within 5 years and 38% within 8 years.[26] Aquilino et al. reported a 44% abutment tooth loss within 10 years for a removable partial denture[53] (Box 1-4).

The natural abutment teeth, on which direct and indirect retainers are designed, must submit to additional lateral forces. Because these teeth are often compromised by deficient periodontal support, many partial dentures are designed to minimize the forces applied to them. The result is an increase in mobility of the removable prosthesis and greater soft tissue support. These conditions protect the remaining teeth but accelerate the bone loss in the edentulous regions.[54] It should be noted that bone loss is accelerated in the soft tissue support regions in patients wearing the removable device compared with the case in patients not wearing the device (Figure 1-20).

BOX 1-4 Problems with Removable Partial Dentures

- Low survival rate—60% at 4 years
- 35% survival rate at 10 years
- Repair of abutment teeth rate—60% at 5 years and 80% at 10 years
- Increased mobility, plaque, bleeding upon probing, and caries of abutment teeth
- 44% abutment tooth loss within 10 years
- Accelerated bone loss in edentulous region if wearing removable partial denture

Therefore, alternative therapies that improve oral conditions and maintain bone are often warranted.

Total Edentulism

Complete edentulism is not an eventual, healthy occurrence in an adult population. Rather, it is most often the result of repeated tooth extractions from the combined pathologic processes of dental caries, periodontal disease, or a method to reduce the costs associated with dental treatment.[55–57] Similar to other pathologic outcomes of disease, the occurrence of total loss of teeth is directly related to the age of the patient. The rate of edentulism increases by 4% per 10 years in early adult years and increases to more than 10% per decade after age 70 years.[57]

The average total edentulous rate around the world is 20% of the adult population at age 60 years, although there is wide disparity from the countries with the highest and lowest rates.[57] For example, from the 65- to 74-year-age group, the total edentulous rate in Kenya and Nigeria was 4%, but the Netherlands and Iceland have a 65.4% and 71.5% rate, respectively. The edentulous Canadian rate was 47% at 65 to age 69 years and 58% from ages 70 to 98 years (with Quebec at 67% for those older than age 65 years compared with Ontario with a 41% rate).

One of the factors influencing total edentulism is the level of education. In data from the Canadian Health Promotion Survey from 1990, whereas the least educated population had an edentulous rate of 50%, those with a college education had a low 4% rate.[58] The United States showed a similar pattern in the period 1988 to 1994, with an edentulous rate of 22% for those with less than 8 years of education, 12% for those with 9 to 11 years of school, 8% for those with 12 years of school, and 5% for individuals with more than 12 years of education.[41]

Although income is often related to education, it plays less of a role in the rate of edentulism. The complete tooth loss in the U.S. adult below the poverty level from 1999 to 2004 was 9.28% and 4.41% above the poverty level, only a 5% difference (Figure 1-21). Countries with higher income levels do not necessarily have less tooth loss. For example, whereas Iceland and the Netherlands have the greatest complete tooth loss by age 70 years with a gross domestic product (GDP) of $17,000, Kenya and Gambia have one of the least complete edentulusm rate with a GDP of less than $2500 (Figure 1-22). An interesting note is that an increasing number of dentists in a country (per 10,000 inhabitants) does not reduce the complete edentulous rate. In fact, countries with the most dentists often have a higher complete edentulous rate (Figure 1-23).

A 1999 to 2002 survey found that total edentulism in the United States of both arches occurred in 7.7% of the adult

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FIGURE 1-20. Panoramic radiograph demonstrating that more bone is maintained below the anterior periodontal diseased teeth compared with the basal bone loss and severe atrophy of the posterior edentulous segment. Wearing of a mandibular class I removable partial denture has escalated the posterior bone loss. Even periodontal involved teeth may maintain more bone than a removable partial denture because the denture may cause basal bone loss.

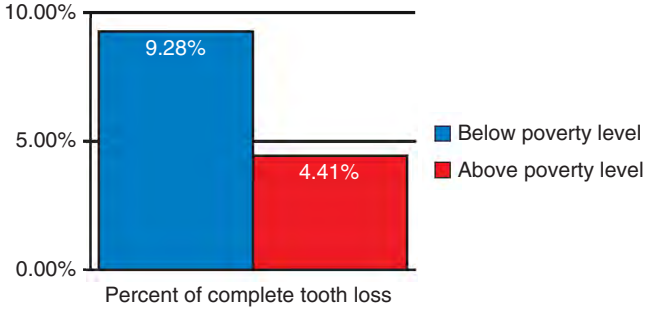


FIGURE 1-21. Complete edentulism in the United States averages over 9% in the 20- to 64-year-old age group below the poverty level and 4.4% above the poverty level, a difference of less than 5%.

population in the United States, or almost 20 million people.[41] The present younger population is benefiting from today's advanced knowledge and restorative techniques. Total edentulism has been noted in 5% of employed adults ages 40 to 44 years, gradually increasing to 26% at age 65 years and almost 44% in seniors older than age 75 years[9] (Figure 1-24). As expected, older persons are more likely to be missing all their teeth. Gender was not found to be associated with tooth retention or tooth loss after adjustments were made for age.

The maxillary (upper) arch may be completely edentulous, opposing at least some teeth in the mandible (lower jaw). This condition occurs 35 times more often than the reverse situation. At age 45 years, 11% of the population has maxillary total edentulism opposing teeth, which increases to 15% by 55 years of age and then remains relatively constant.[45] Therefore, a total of approximately 12 million individuals in the United States have total edentulism in one arch, representing 7% of the adult population overall.

The percentages of one or two arch total edentulism translate into more than 30 million people or about 17% of the entire U.S. adult population.[45] To put these numbers in perspective, 30 million people represent approximately the entire U.S. African American population, the U.S. Hispanic population, the whole population of Canada, or the total population in the United States older than 65 years of age.

Although the edentulism rate is decreasing every decade, the elderly population is rising so rapidly that the adult population in need of one or two complete dentures will actually *increase* from 33.6 million adults in 1991 to 37.9 million adults in 2020. The total numbers of edentulous arches are estimated at 56.5 million in 2000, 59.3 million in 2010, and 61 million in 2020.[59] Complete edentulism, therefore, remains a significant concern, and affected patients often require implant dentistry to solve several related problems. If four implants were used to help support each complete edentulous arch, a total of 226 million implants would be required. Yet only 10 million implants were inserted in 2010 for all patient treatment. Almost 70% of dentists spend less than 1% to 5% of their treatment time on edentulous patients, leaving a great unfulfilled need for implant dentistry.

When the posterior partially edentulous figures are added to the complete edentulous percentages, more than 30% of the adult U.S. population are candidates for a complete or partial removable prosthesis. The need for additional retention, support, and stability and the desire to eliminate a removable prosthesis are common indications for dental implants. As a result, 74 million adults (90 million arches) are potential candidates for dental implants. Because a minimum of five appointments is required to implant and restore a patient, every U.S. dentist would need approximately 20 appointments every month for 20 years to treat the present posterior partial and complete edentulous population with implant-supported prostheses.[60] The population's evolution to an increased average age, combined with the existing population of partially and completely edentulous patients, guarantees implant dentistry's future for several generations of dentists.

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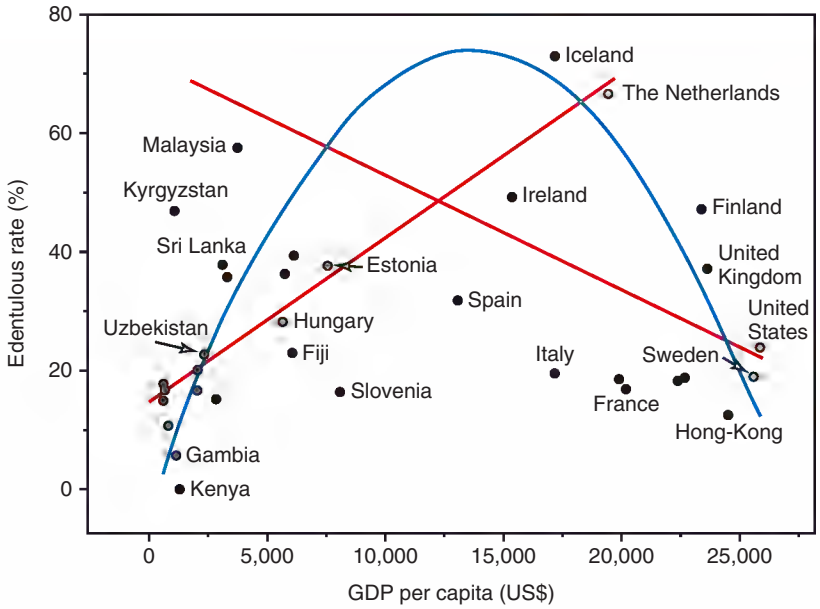


FIGURE 1-22. Gross domestic product (GDP) around the world is not related to the edentulous rate. Many of the richest countries have a greater rate of complete edentulism by 70 years of age than the poorer countries.

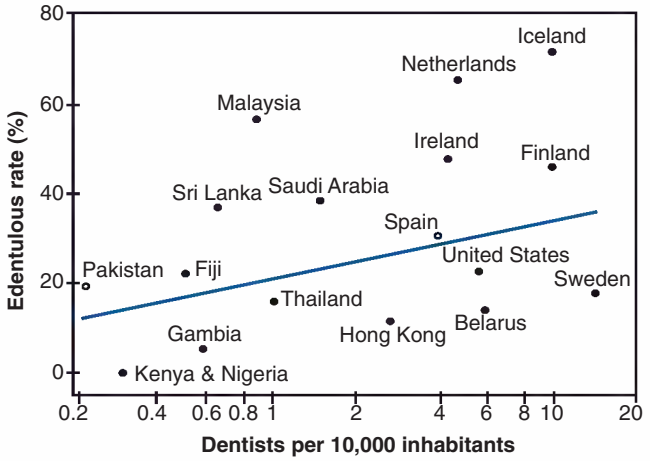


FIGURE 1-23. The incidence of complete edentulism averages 20% of the adult population around the world. It is interesting to note that often the greater the number of dentists per population, the greater the rate of edentulism. (Adapted from Mojon P: The world without teeth: demographic trends. In Feine JS, Carlsson GE, editors: *Implant overdentures: the standard of care for edentulous patients*, Carol Stream, IL, 2003, Quintessence.)

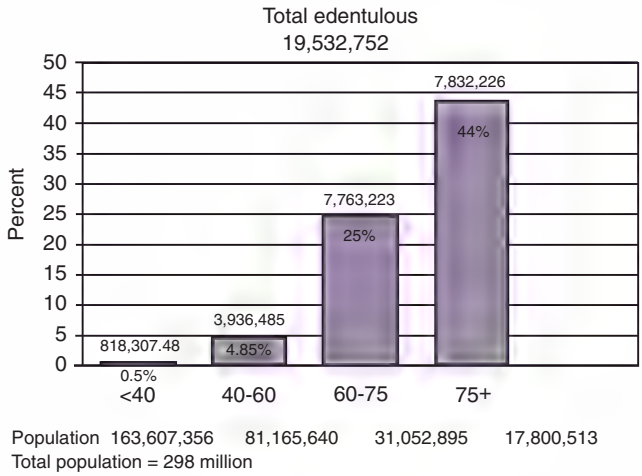


FIGURE 1-24. The U.S. population completely edentulous rate ranges from 0.5% for 40-year-old adults to 44% for those older than age 75 years. As a result, 20 million people (10.5% of the population) in the United States have no teeth. An additional 12 million people (7% of the adult population) have no maxillary teeth opposing at least some mandibular teeth.

Anatomical Consequences of Edentulism

There are many negative consequences for completely edentulous patients. They include continued bone loss of the jaws, soft tissue consequences that support the prostheses, facial esthetic consequences of the bone loss, decreased masticatory performance, and diet-related health issues and psychological aspects of a total tooth loss (Box 1-5).

BOX 1-5 Consequences of Complete Edentulism

- Continued bone loss of the jaws
- Negative soft tissue changes of the jaws
- Negative facial esthetic changes
- Decreased masticatory dynamics
- Negative diet effects on health
- Psychological issues

Bone Loss

Basal bone forms the dental skeletal structure, contains most of the muscle attachments, and begins to form in the fetus before teeth develop. Alveolar bone (bone around teeth) first appears when Hertwig's root sheath of the tooth bud evolves[61] (Figure 1-25). The alveolar bone does not form in the absence of primary or secondary tooth development (Figure 1-26). The close relationship between the tooth and the alveolar process continues throughout life.

Wolff's law (1892) states that bone remodels in relationship to the forces applied.[62] Every time the function of bone is

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modified, a definite change occurs in the internal architecture and external configuration.[63] In dentistry, the consequences of complete edentulism and remaining bone volume was noted by J. Misch in 1922, when he described the skeletal structure of a 90-year-old woman without teeth for several decades[64] (Figure 1-27).

Bone needs stimulation to maintain its form and density. Roberts et al. report that a 4% strain to the skeletal system maintains bone and helps balance the resorption and formation phenomena.[65] Teeth transmit compressive and tensile forces to the surrounding bone. These forces have been measured as a piezoelectric effect in the imperfect crystals of durapatite that compose the inorganic portion of bone.[66] When a tooth is lost, the lack of stimulation to the residual bone causes a decrease in trabeculae and bone density in the area, with loss in external width, then height, of the bone volume.[67] There is a 25% decrease in width of bone during the first year after tooth loss and an overall 4-mm decrease in height during the first year after extractions for an immediate denture.[68] In a longitudinal 25-year study of edentulous patients, lateral cephalograms demonstrated continued bone loss during this time span, with a fourfold greater loss observed in the mandible.[69,70] In 1963, Atwood introduced five different stages of bone loss in an anterior mandible after tooth loss[71] (Figure 1-28). However, because initially the mandibular height of bone is twice that of the maxilla, maxillary bone loss is also significant in long-term edentulous patients.

A tooth is necessary for the development of alveolar bone, and stimulation of this bone is required to maintain its density and volume. A removable denture (complete or partial) does not stimulate and maintain bone; rather, it accelerates bone loss. Even periodontally involved teeth stimulate and maintain bone volume better than missing teeth and replacement with a removable partial denture (see Figure 1-20). The load from mastication of a soft tissue prosthesis is transferred to the bone surface only, not the bone structure. As a result, blood supply is reduced and total bone volume loss occurs.[70] This issue, which is of utmost importance, has been observed but not addressed in the past by traditional dentistry.

Dentists most often overlook the insidious bone loss that will occur after tooth extraction. The patient is often not educated about the anatomical changes and the potential consequences of continued bone loss. The bone loss accelerates when the patient wears a poorly fitting soft tissue–borne prosthesis. Patients do not understand that bone is being lost over time and at a greater rate beneath poorly fitting dentures. Patients do not return for regular visits for evaluation of their condition; instead, they return after several years when denture teeth are worn down or can no longer be tolerated. In fact, the average denture wearer sees a dentist every 14.8 years after having a complete denture. Hence, the traditional method of tooth replacement (dentures) often affects bone loss in a manner not sufficiently considered by the dentist and the patient. The doctor should inform the patient that a denture replaces more bone and soft tissue than teeth, and every 5 years a reline or new denture is suggested to replace the additional bone loss by atrophy that will occur (Figure 1-29).

Preventive dentistry has traditionally emphasized methods to decrease tooth loss or the surrounding bone supporting a tooth. This bone loss is often monitored by the millimeter. No therapy had been promoted and accepted by the profession to avoid the bone changes resulting from tooth loss. The bone changes after total tooth loss may be measured by the centimeter. Today the profession must consider the loss of both teeth and bone. The loss of teeth causes remodeling and resorption of the surrounding residual bone and eventually leads to atrophic edentulous ridges.

Almost every woman past the age of 14 years is aware of osteoporosis after menopause. Diet and exercise are encouraged over their entire lifetimes to decrease this risk. Yet osteoporosis primarily affects bone density, not bone volume. The only place in the body bone volume is lost to an extreme is in the jaws after tooth loss. Yet nobody in the public and very few in the profession ever address this issue. It is malpractice if a dentist does not monitor the bone loss around teeth by the millimeter with a probe. Yet the centimeter bone loss of the edentulous regions are often ignored.[72]

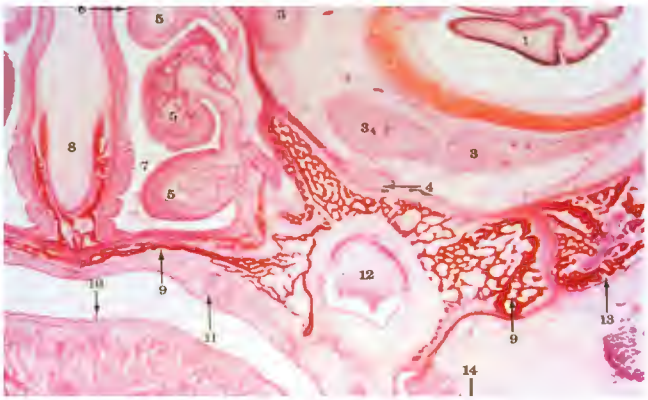


FIGURE 1-25. The alveolar bone forms as a result of the formation of Hertwig's root sheath, which forms the tooth root.

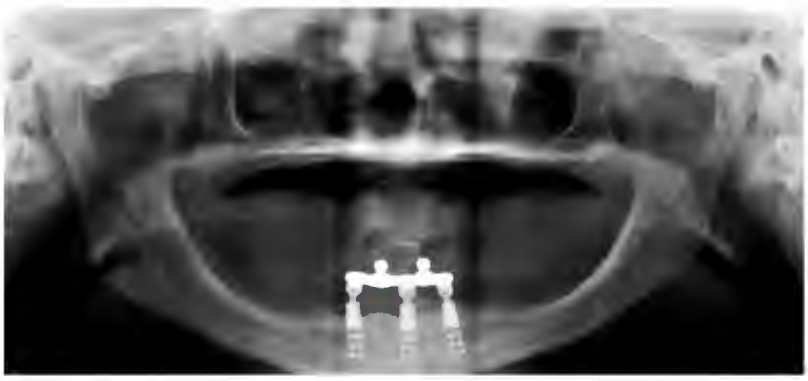


FIGURE 1-26. When no primary or secondary tooth root is present, the alveolar process does not form. For example, this panoramic radiograph is from a 35-year-old patient with ectodermal dysplasia with complete anodontia (tooth loss) of both primary and secondary teeth. The basal bone developed, but not the alveolar process. Three anterior implants in the mandible help retain the lower denture.

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FIGURE 1-27. After the initial extraction of teeth, the average first-year bone loss is more than 4 mm in height and 30% in crestal bone width. Although the rate of bone loss is slower after the first year, the bone loss is continuous throughout life. This picture is from a book written by Julius Misch in 1922, demonstrating long-term complete edentulism and bone loss.[64]

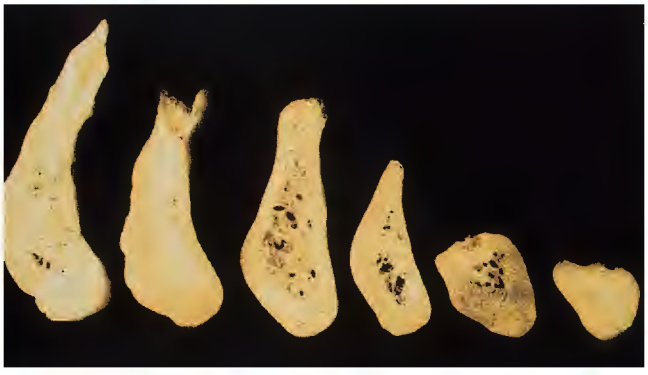


FIGURE 1-28. Atwood described five different stages of resorption in the anterior mandible. Stage 1 represents the tooth and surrounding alveolar process and basal bone. Stages II and III illustrate the initial residual ridge after tooth loss. Stages IV to VI primarily describe a continuous loss in height of anterior residual bone.

Although the patient often is not aware or informed of the potential consequences, over time consequences will occur. The rate and amount of bone loss may be influenced by such things as gender, hormones, metabolism, parafunction, and ill-fitting dentures. Yet almost 40% of denture wearers have been wearing an ill-fitting prosthesis for more than 10 years.[73] Patients wearing dentures day and night place greater forces on the hard and soft tissues, which accelerates bone loss. Nonetheless, 80% of dentures are worn both day and night.[74] Masticatory forces generated by short facial types (brachiocephalics) can be three to four times those of long facial types (dolichocephalics). Short facial–type patients are at increased risk for developing severe atrophy [75,76] (Box 1-6).

Atrophic edentulous ridges are associated with anatomical problems that often impair the predictable results of traditional dental therapy. Several of these anatomical problems are listed

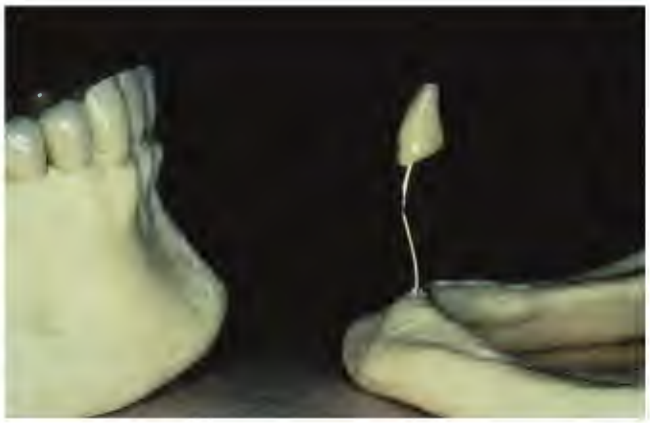


FIGURE 1-29. A dentate mandible on the *left* and a long-term edentulous mandible on the *right*. Note the amount of bone loss in height. Loss of bone height in the mandible may be measured by the centimeter and often is ignored. Such bone loss is often more significant than the bone loss (in millimeters) from periodontal disease. The patient should understand that a denture often replaces more bone than teeth to restore the proper dimensions of the face.

BOX 1-6 Rate and Amount of Bone Loss Influenced By

- Gender
- Hormones
- Metabolism
- Parafunction
- Ill-fitting dentures
- Facial type (brachiocephalic vs. dolichocephalic)
- Time period dentures are worn

in Box 1-7. Loss of bone in the maxilla or mandible is not limited to alveolar bone; portions of the basal bone may also be resorbed (Figures 1-30 and 1-31), especially in the posterior aspect of the mandible, where severe resorption may result in more than 80% bone loss.[70] The contents of the mental foramen or mandibular canal eventually become dehiscent and serve as part of the support area of the prosthesis.[77] As a result, acute pain and transient to permanent paresthesia of the areas supplied by the mandibular nerve are possible. The body of the mandible also is at increased risk of fracture, even under very low impact forces (Figure 1-32). The mandibular fracture causes the jaw to shift to one side and makes stabilization and an esthetic result most difficult to obtain during treatment of the fracture. The complete anterior ridge and even the nasal spine may be resorbed in the maxilla, causing pain and an increase in maxillary denture movement during function.[70]

Soft Tissue Consequences

As bone loses width, then height, then width and height again, the attached gingiva gradually decreases. A very thin attached tissue usually lies over the advanced atrophic mandible or is entirely absent. The increasing zones of mobile, unkeratinized gingiva are prone to abrasions caused by the overlaying prosthesis. In addition, unfavorable high muscle attachments and hypermobile tissue often complicate the situation (Figure 1-33). The loss of bone first causes decreased bone width. The

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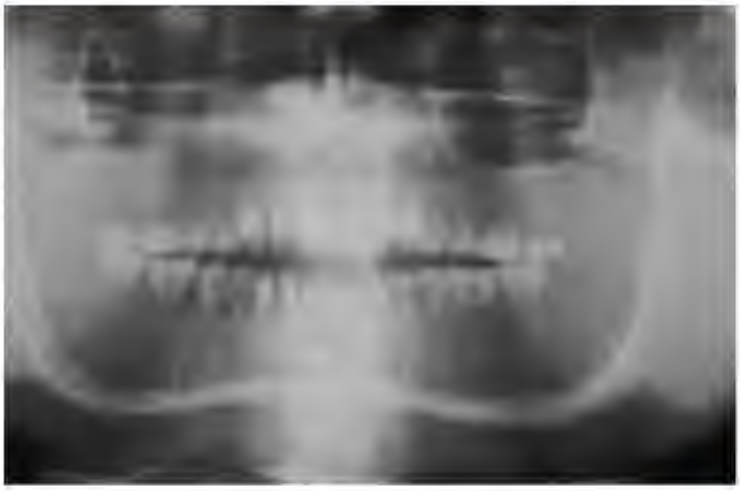


FIGURE 1-30. This panoramic radiograph demonstrates a denture may restore the vertical dimension of the face, but the bone loss of the jaws can continue until the basal bone is paper thin in the maxilla and the mandible becomes the size of a toothpick.



FIGURE 1-31. Lateral cephalogram of a patient demonstrates the restored vertical dimension of occlusion with a denture. However, because of the advanced basal bone loss in the mandible, the superior genial tubercles are positioned above the residual anterior ridge. The body of the mandible is only a few millimeters thick, and the mandibular canal is completely dehiscent (one posterior body of the mandible is superimposed on top of the other in this view). In the maxillary anterior ridge, only the nasal spine remains (not the original alveolar ridge), and the posterior maxillary bone is paper thin because of basal bone loss at the crest and the pneumatization of the maxillary sinus. (This is a different patient from the one in Figure 1-30.)

BOX 1-7 Consequences of Bone Loss in Fully Edentulous Patients

- Decreased width of supporting bone
- Decreased height of supporting bone
- Prominent mylohyoid and internal oblique ridges with increased sore spots
- Progressive decrease in keratinized mucosa surface
- Prominent superior genial tubercles with sore spots and increased denture movement
- Muscle attachment near the crest of the ridge
- Elevation of prosthesis with contraction of mylohyoid and buccinator muscles serving as posterior support
- Forward movement of prosthesis from anatomical inclination (angulation of mandible with moderate to advanced bone loss)
- Thinning of mucosa with sensitivity to abrasion
- Loss of basal bone
- Paresthesia from dehiscent mandibular neurovascular canal
- More active role of tongue in mastication
- Effect of bone loss on esthetic appearance of lower third of face
- Increased risk of mandibular body fracture from advanced bone loss
- Loss of anterior ridge and nasal spine, causing increased denture movement and sore spots during function

remaining narrow residual ridge often causes discomfort when the thin overlying tissues are loaded under a soft tissue–borne removable prosthesis. The continued atrophy of the posterior mandible eventually causes prominent mylohyoid and internal oblique ridges covered by thin, movable, unattached mucosa. The anterior residual alveolar process also continues to resorb, and the superior genial tubercles (which are 20 mm below the crest of bone when teeth are present) eventually become the most superior aspect of the anterior mandibular ridge. There is little to prevent the prosthesis from moving forward against the lower lip during function or speech. This condition is further compromised by the vertical movement of the distal aspect of the prosthesis during contraction of the mylohyoid and buccinator muscles and the anterior incline of the atrophic mandible compared with that of the maxilla.[78]

The thickness of the mucosa on the atrophic ridge is also related to the presence of systemic disease and the physiologic changes that accompany aging. Conditions such as the patient's age, hypertension, diabetes, anemia, and nutritional disorders have deleterious effects on the vascular supply and soft tissue quality under removable prostheses. These disorders result in a decreased oxygen tension to the basal cells of the epithelium (Box 1-8). Surface cell loss occurs at the same rate, but the cell formation at the basal layer is slowed. As a result, thickness of the surface tissues gradually decreases. Therefore, sore spots and uncomfortable removable prostheses result.

The tongue of a patient with edentulous ridges often enlarges to accommodate the increase in space formerly occupied by teeth. At the same time, it is used to limit the movements of the removable prostheses and takes a more active role in the

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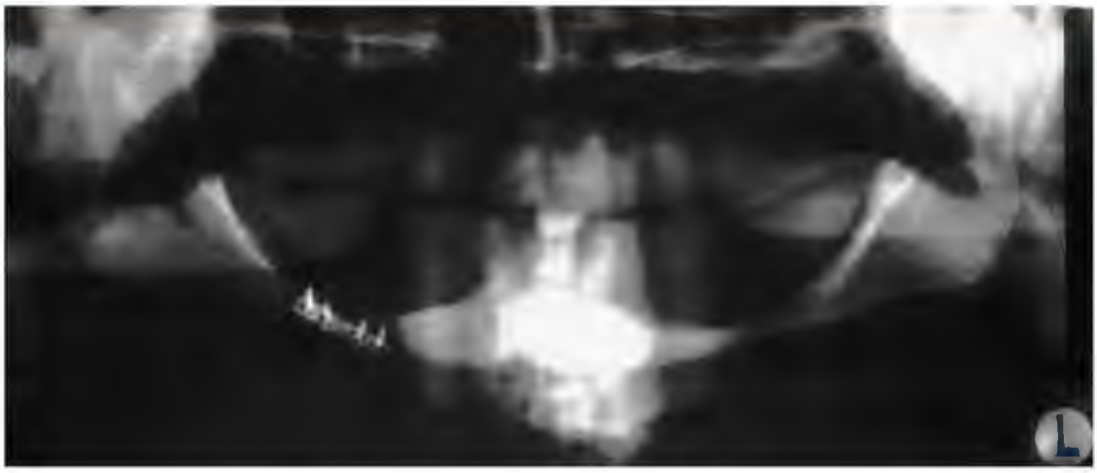


FIGURE 1-32. Resorption of an edentulous mandible may result in dehiscence of the mandibular canal and associated paresthesia. The patient may fear that a tumor is growing against the nerves. The body of the mandible may continue to resorb until minor trauma causes fracture as in this panoramic radiograph (e.g., during mastication, the bump of a baby's head held closely to the face, an accidental bump from the elbow).

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FIGURE 1-33. A patient with moderate to severe atrophy usually has the intraoral muscles above the residual ridge, including the floor of the mouth and the mentalis and buccinator muscles. The tongue is also larger in size and plays a more active role in mastication.

BOX 1-8 Conditions That Have an Effect on Vascular Supply and Soft Tissue Quality Under Removable Prostheses

- Patient's age
- Hypertension
- Diabetes
- Anemia
- Nutritional disorders

mastication process. As a result, the removable prosthesis decreases in stability. The decrease in neuromuscular control, often associated with aging, further compounds the problems of traditional removable prosthodontics. The ability to wear a denture successfully may be largely a learned, skilled performance. An aged patient who recently became edentulous may lack the motor skills needed to adjust to the new conditions (Box 1-9).

BOX 1-9 Soft Tissue Consequences of Edentulism

- Attached, keratinized gingiva is lost as bone is lost
- Unattached mucosa for denture support causes increased soft spots
- Thickness of tissue decreases with age and systemic disease that causes more sore spots for dentures
- Tongue increases in size, which decreases denture stability
- Tongue has more active role in mastication, which decreases denture stability
- Decreased neuromuscular control of jaw in elderly adults

Esthetic Consequences

The facial changes that naturally occur in relation to the aging process can be accelerated and potentiated by the loss of teeth. Every dentist is aware that the dental skeletal position will affect facial esthetics. Yet the face is more supported by the bone than the teeth (Figure 1-34). Several esthetic consequences result from the loss of alveolar bone. A decrease in facial height from a collapsed vertical dimension causes several facial changes (Figure 1-35). The loss of labiomental angle and deepening of vertical lines in the area create a harsh appearance. As the vertical dimension progressively decreases, the occlusion evolves toward a pseudo class III malocclusion. As a result, the chin rotates forward and creates a prognathic facial appearance (Figure 1-36). These conditions result in a decrease in the horizontal labial angle at the corner of the lips; the patient appears unhappy when the mouth is at rest (Figures 1-37 and 1-38). People with short facial types have higher bite forces, greater bone loss, and more dramatic facial changes with edentulism compared with others.

A thinning of the vermilion border of the lips results from the poor lip support provided by the prosthesis and the loss of muscle tone. The maxillary retruded position is related to the loss of the premaxillary ridge and the loss of tonicity of the

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FIGURE 1-34. Esthetic aspects of the inferior third of the face are not only related to the position of the teeth but even more important is the position and amount of bone in the jaws and include the muscles that attach to the bone.

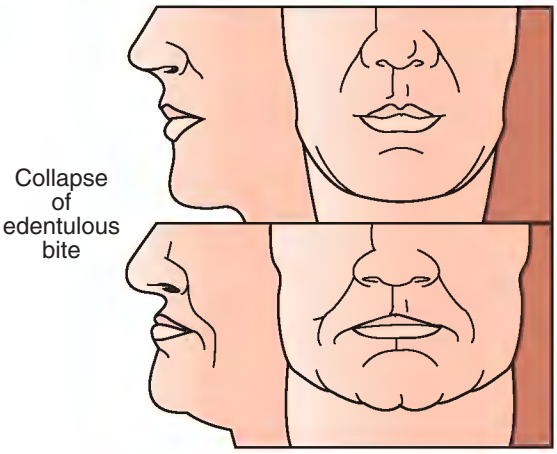


FIGURE 1-35. A patient often wears a denture for more than 15 years. The loss of bone height during this time is associated with many extraoral facial changes as a closed bite, a mandible that rotates forward, a receding maxilla, a reverse smile line, increased number and depth of lines in the face, more acute angle between the nose and the face, loss of vermilion border in the lips and jowls, and witch's chin from loss of muscle attachment.



FIGURE 1-36. Loss of bone height can lead to a closed bite with rotation of the chin anterior to the tip of the nose. The top picture is a patient with the teeth and jawbone. The bottom picture represents the face of someone without teeth and advanced bone loss.

muscles involved in facial expression. In a study of 179 white patients at different stages of jaw atrophy, the collapse of the lips and circumoral musculature was evaluated by Sutton et al.[79] The contraction of the orbicularis oris and buccinator muscles in a patient with moderate to advanced bone atrophy displaces the modiolus and muscles of facial expression medially and posteriorly. As a result, a narrowing of the commissure, inversion of the lips, and hollowing of the cheeks were very characteristic findings. Women often use one of two techniques to hide this cosmetically undesirable appearance: either no lipstick and minimal makeup so that little attention is brought to this area of the face or lipstick drawn on the skin over the vermilion border to give the appearance of fuller lips.

A deepening of the nasolabial groove and an increase in the depth of other vertical lines in the upper lip are related to normal aging but are accelerated with bone loss. This usually is accompanied by an increase in the columella–philtrum angle. This can make the nose appear larger than if the lip had more support (Figures 1-39 and 1-40). Men often grow a moustache to minimize this effect. The maxillary lip naturally becomes longer with age as a result of gravity and loss of muscle tone, resulting in less of the anterior teeth shown when the lip is at rest. This has a tendency to "age" the smile because the younger the patient, the more the teeth show in relation to the upper lip at rest or when smiling. Loss of muscle tone is accelerated in edentulous patients, and the lengthening of the lip occurs at a younger age and is longer (showing less teeth) than dentate patients of a similar age. The upper lip often rolls over the incisal edge of the maxillary dentures, which further decreases the size of the vermilion border.

The attachments of the mentalis and buccinator muscles to the body and symphysis of the mandible also are affected by bone atrophy. The tissue sags, producing "jowls" or a "witch's chin." This effect is cumulative because of the loss in muscle tone with the loss of teeth, the associated decrease in bite force, and the loss of bone in the regions where the muscles used to attach (Box 1-10). Patients are unaware that these hard and soft tissue changes are from the loss of teeth. Among denture wearers, 39% have been wearing the same prosthesis for more than 10 years.[74] The profession is unable to evaluate patients unless they return yearly. Therefore, the consequences of tooth loss must be explained to partially or completely edentulous patients during the early phases of treatment.

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FIGURE 1-37. Panoramic radiograph of a complete edentulous patient with severe bone loss. A hydroxyapatite graft in the premaxilla and mandible was attempted to help stabilize a denture.



FIGURE 1-38. This patient (same as Figure 1-37) has severe bone loss in the maxilla and mandible. Although she is wearing her 15-year-old dentures, the facial changes are significant. The loss of muscle attachments lead to ptosis of the chin (witch's chin), loss of vermilion border (lipstick is applied to the skin), reverse lip line (decrease in horizontal angles), increased vertical lines in the face and lips, increased lip angle under the nose, and a lack of muscle tonicity in the masseter and buccinator muscles.

BOX 1-10 Esthetic Consequences of Bone Loss

- Decreased facial height
- Loss of labiomental angle
- Deepening of vertical lines in lip and face
- Chin rotates forward—gives a prognathic appearance
- Decreased horizontal labial angle of lip—makes patient look unhappy
- Loss of tone in muscles of facial expression
- Thinning of vermilion border of the lips from loss of muscle tone
- Deepening of nasolabial groove
- Increase in columella–philtrum angle
- Increased length of maxillary lip, so less teeth show at rest and smiling—ages the smile
- Ptosis of buccinator muscle attachment—leads to jowls at side of face
- Ptosis of mentalis muscle attachment—leads to "witch's chin"

BOX 1-11 Negative Effects of Complete Dentures

- Bite force is decreased from 200 psi for dentate patients to 50 psi for edentulous patients
- 15-year denture wearers have reduced bite force to 6 psi
- Masticatory efficiency is decreased
- More drugs are necessary to treat gastrointestinal disorders
- Food selection is limited
- Healthy food intake is decreased
- The life span may be decreased
- Reduced prosthesis satisfaction
- Speech difficulty
- Psychologic effects

Negative Consequences of Complete Dentures

There are many other negative consequences related to a complete denture and edentulous patients, including masticatory function, systemic consequences, patient satisfaction, and speech and psychologic effects (Box 1-11).

Masticatory Function

The difference in maximum occlusal forces recorded in a person with natural teeth and one who is completely edentulous is dramatic. In the first molar region of a dentate person, the average force has been measured at 150 to 250 psi.[80] A patient who grinds or clenches the teeth may exert a force that approaches 1000 psi. The maximum occlusal force in an edentulous patient is reduced to less than 50 psi. The longer patients are edentulous, the less force they are able to generate. Patients wearing complete dentures for more than 15 years may have a maximum occlusal force of less than 6 psi.[81]

As a result of decreased occlusal force and the instability of the denture, masticatory efficiency also decreases with tooth loss. Ninety percent of the food chewed with natural teeth fits through a no. 12 sieve; this is reduced to 58% in the patient wearing complete dentures.[82] A study of 367 denture wearers (158 men and 209 women) found that 47% exhibited a low masticatory performance.[83] The 10-fold decrease in force and

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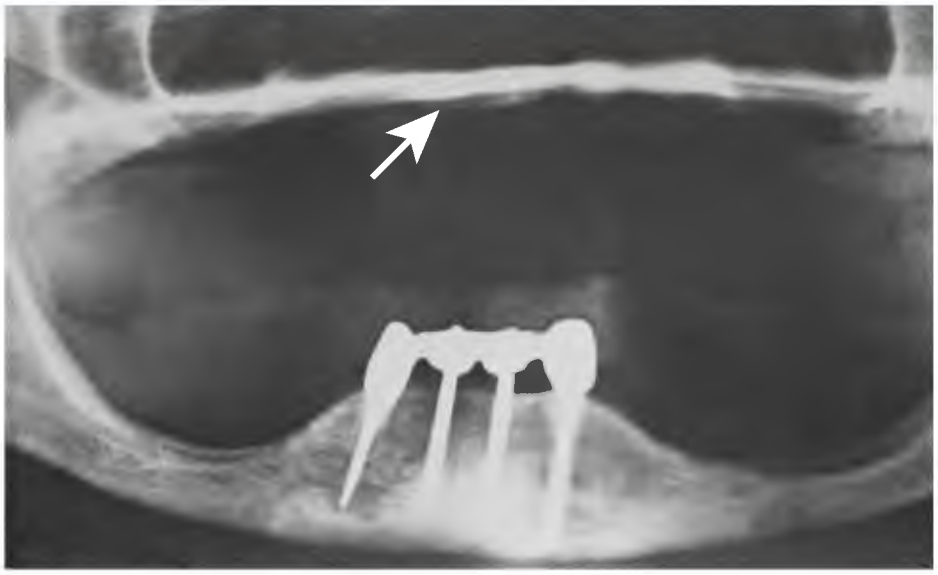


FIGURE 1-39. Panoramic radiograph of a 68-year-old woman. The maxillary arch has severe atrophy and almost complete basal bone loss, including most of the nasal spine. Implants were inserted in the anterior mandible 15 years before this film. The anterior bone has been maintained. The posterior mandible has continued to resorb, and the mandibular canal is dehiscent on one side.

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FIGURE 1-40. Profile view (same patient as in Figure 1-39). Note the maxillary bone loss effect on the lack of vermilion border of the lip, deep labial folds, and the columella–philtrum angle. Yet the lower lip has a normal vermillion border and the muscles to the anterior lower jaw are still attached, providing a normal contour.

the 40% decrease in efficiency affect the patient's ability to chew. In persons with dentures, 29% are able to eat only soft or mashed foods, 50% avoid many foods, and 17% claim they eat more efficiently without the prosthesis.[84] Lower intakes of fruits, vegetables, and vitamin A by women were noted in this group. Denture patients also take significantly more drugs (37%) compared with those with superior masticatory ability (20%), and 28% take medications for gastrointestinal disorders. The reduced consumption of high-fiber foods could induce gastrointestinal problems in edentulous patients with deficient masticatory performance. In addition, the coarser bolus may impair proper digestive and nutrient extraction functions.[85]

Mandibular discomfort was listed in a study by Misch and Misch with equal frequency as movement (63.5%), and surprisingly, 16.5% of the patients stated they never wear the mandibular denture.[84] In comparison, the maxillary denture was uncomfortable half as often (32.6%), and only 0.9% were seldom able to wear the prosthesis. Function was the fourth most common problem reported by these 104 denture wearers. Half of the patients avoided many foods, and 17% claimed they were able to masticate more effectively without the prostheses. The psychological effects of the inability to eat in public can be correlated with these findings. Other reports agree that the major motivating factors for patients to undergo treatment were related to the difficulties with eating, denture fit, and discomfort.

Systematic Consequences

The literature includes several reports suggesting that compromised dental function causes poor masticatory performance and swallowing poorly chewed food, which in turn may influence systemic changes favoring illness, debilitation, and shortened life expectancy.[86–90] In a study evaluating the ability to eat fruit, vegetables, and other dietary fiber in edentulous subjects, 10% claimed difficulty, and blood tests demonstrated reduced levels of plasma ascorbate and plasma retinol compared with dentate subjects. These two blood tests are correlated to an increased risk of dermatologic and visual problems in aging adults.[91] In another study, the masticatory performance and efficiency in denture wearers were compared with those of dentate individuals.[92] This report noted that when appropriate corrections were made for different performance norms and levels, the chewing efficiency of a denture wearer was less than one sixth of a person with teeth.

Several reports in the literature correlate a patient's health and life span to dental health.[93–97] Poor chewing ability may be a cause of involuntary weight loss in old age, with an increase

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in mortality rate.[98] In contrast, persons with a substantial number of missing teeth were more likely to be obese.[93] After conventional risk factors for strokes and heart attacks were accounted for, there was a significant relationship between dental disease and cardiovascular disease, the latter still remaining as the major cause of death.[86–100] It is logical to assume that restoring the stomatognathic system of these patients to a more normal function may indeed enhance the quality and length of their lives.[93,99–102]

Satisfaction of Prosthesis

A dental survey of edentulous patients found that 66% were dissatisfied with their mandibular complete dentures. Primary reasons were discomfort and lack of retention causing pain and discomfort.[103] Past dental health surveys indicate that only 80% of the edentulous population are able to wear both removable prostheses all the time.[104] Some patients wear only one prosthesis, usually the maxillary; others are only able to wear their dentures for short periods. In addition, approximately 7% of patients are not able to wear their dentures at all and become "dental cripples" or "oral invalids." They rarely leave their home environment, and when they feel forced to venture out, the thought of meeting and talking to people when not wearing their teeth is unsettling.

Speech Effects

A report of 104 completely edentulous patients seeking treatment was performed by Misch and Misch.[84] Of the patients studied, 88% claimed difficulty with speech, with one fourth having great difficulty. The lower prosthesis rests upon the buccinator muscle and mylohyoid muscle when the posterior mandible resorbs. When the patient opens his or her mouth, the contraction of these muscles acts like a trampoline and propels the lower denture off the ridge. As a result, the teeth often click when the patient talks, not from too much of the vertical dimension restored but from the lack of stability and retention of the prosthesis. Speech problems may be associated with a concern for social activities. Awareness of movement of the mandibular denture was cited by 62.5% of these patients, although the maxillary prosthesis stayed in place most of the time at almost the same percentage.

Psychological Aspects of Tooth Loss

The psychological effects of total edentulism are complex and varied and range from very minimal to a state of neuroticism (Box 1-12). Although complete dentures are able to satisfy the esthetic needs of many patients, some believe their social lives are significantly affected.[105,106] They are concerned with kissing and romantic situations, especially if a new partner in a relationship is unaware of their oral handicap. Fiske et al., in a study of interviews with edentulous subjects, found tooth loss was comparable to the death of a friend or loss of other important parts of a body in causing a reduction of self-confidence ending in a feeling of shame or bereavement.[105]

The psychological needs of edentulous patients are expressed in many forms. For example, in 1970, Britons used approximately 88 tons of denture adhesive[107](Figure 1-41). In 1982, more than 5 million Americans used denture adhesives (Ruskin Denture Research Associates: AIM study, unpublished data, 1982), and a report shows that in the United States, more than $200 million is spent each year on denture adhesives, representing 55 million units sold.[108] The patient is willing to accept the unpleasant taste, need for recurring application, inconsistent denture fit, embarrassing circumstances, and continued expense for the sole benefit of increased retention of the prosthesis. Clearly, the lack of retention and psychological risk of embarrassment in the denture wearer with removable prostheses is a concern the dental profession must address.

Advantages of Implant-Supported Prostheses

The use of dental implants to provide support for prostheses offers many advantages compared with the use of removable soft tissue–borne restorations (Box 1-13). A primary reason to consider dental implants to replace missing teeth is the maintenance of alveolar bone. Dental implants placed in the anterior mandible help retain a lower denture and are a benefit over a complete denture (Figure 1-42). But the posterior bone loss will continue and may eventually lead to significant complications. Instead, when enough implants are inserted, the restoration is not only retained, but it also is completely supported and stabilized off the tissue and bone. The implants also stimulate and maintain the bone of the entire mandibular as well as serve as an anchor for the prosthetic device. As a result, dental implants are one of the better preventive maintenance procedures in dentistry (Figure 1-43).

Stress and strain may be applied to the bone surrounding the implant. As a result, the decrease in trabeculation of bone that occurs after tooth extraction is reversed. There is an increase in bone trabeculae and density when the dental implant is inserted and functioning. The overall volume of bone is also maintained with a dental implant. Even grafts of iliac bone to

BOX 1-12 Psychological Effects of Tooth Loss

- Range from minimal to neuroticism
- Romantic situations affected (especially in new relationships)
- "Oral invalids" unable to wear dentures
- More than $200 million each year is spent on denture adhesive to decrease embarrassment
- Dissatisfaction with appearance; low self-esteem
- Avoidance of social contact



FIGURE 1-41. Denture adhesive is often used to help retain a denture. It does not provide support or stability but only helps retain a denture. It does not prevent bone loss.

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FIGURE 1-42. A panoramic radiograph with two anterior implants. Although retention and oral stability are gained for the denture, it does not stop the posterior bone loss. The bone loss in the maxilla will also continue.

BOX 1-13 Advantages of Implant-Supported Prostheses

- Maintain bone
- Restore and maintain occlusal vertical dimension
- Maintain facial esthetics (muscle tone)
- Improve esthetics (teeth positioned for appearance vs. decreasing denture movement)
- Improve phonetics
- Improve occlusion
- Improve or regain oral proprioception (occlusal awareness)
- Increase prosthesis success
- Improve masticatory performance or maintain muscles of mastication and facial expression
- Reduce size of prosthesis (eliminate palate, flanges)
- Provide fixed versus removable prostheses
- Improve stability and retention of removable prostheses
- Increase survival times of prostheses
- No need to alter adjacent teeth
- More permanent replacement
- Improve psychological health
- Improved health related to diet



FIGURE 1-43. Bone loss in an edentulous patient may be dramatically stopped by using enough implants to completely support, retain, and stabilize the prosthesis.

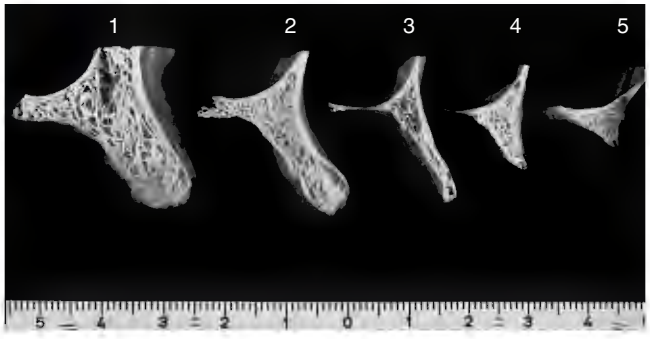


FIGURE 1-44. The maxillary bone also continues to resorb over time. The bone on the far right will have difficulty supporting a maxillary denture.

the jaws, which usually resorb without dental implant insertion within 5 years, are instead stimulated and maintain overall bone volume and implant integration. An endosteal implant can maintain bone width and height as long as the implant remains healthy.[109] As with a tooth, periimplant bone loss may be measured in tenths of a millimeter and may represent a more than 20-fold decrease in lost structure compared with the resorption that occurs with removable prostheses.

The benefit of bone maintenance is especially noteworthy in the maxillary edentulous arch. Rather than using implants only in the edentulous mandibular arch, because the primary mechanical denture problems and complaints are in this arch, the maxillary arch should also be addressed. After implant prostheses are placed to support and retain the mandibular restoration, the bone in the maxillary region continues to be lost, and eventually the patient may complain of loss of retention and inability of the maxillary denture to function[110] (Figure 1-44). The loss of facial esthetics is most often first noted in the maxillary arch, with the loss of vermilion border of the lip, increased length of the maxilla lip, and lack of facial bone support. Implants should be used to treat the continued bone loss and prevent the later complications found in the maxillary arch (Figures 1-45 to 1-50).

A mandibular denture often moves when the mylohyoid and buccinator muscles contract during speech or mastication. The maxillary teeth are often positioned for lower denture stability rather than where natural teeth usually reside. With implants, the maxillary teeth may be positioned to enhance esthetics and phonetics rather than in the neutral zones dictated by traditional denture techniques to improve the stability of a lower prosthesis.

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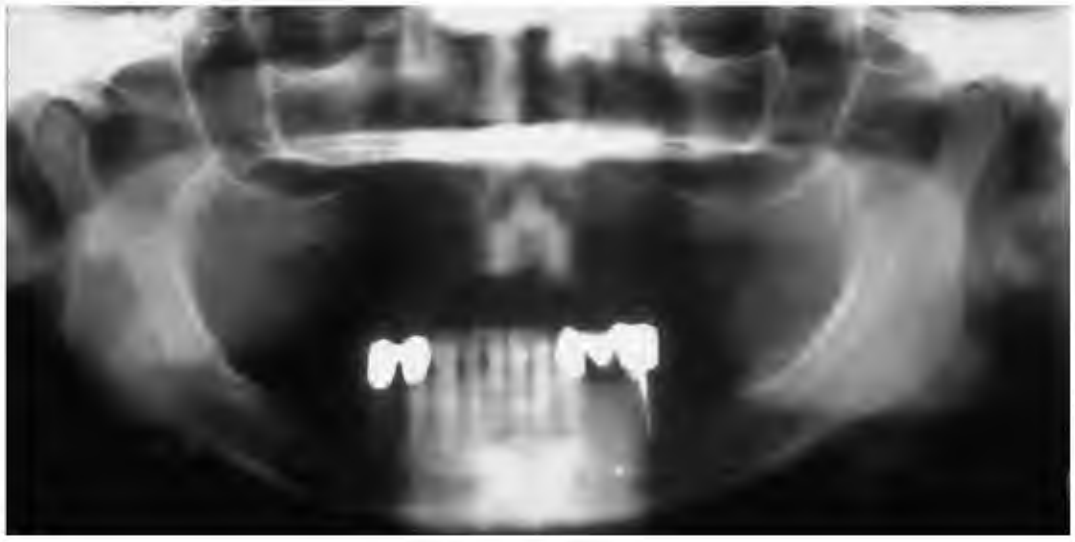


FIGURE 1-45. A panoramic radiograph of an edentulous maxillary arch with moderate-size sinuses and a resorbed anterior maxilla.

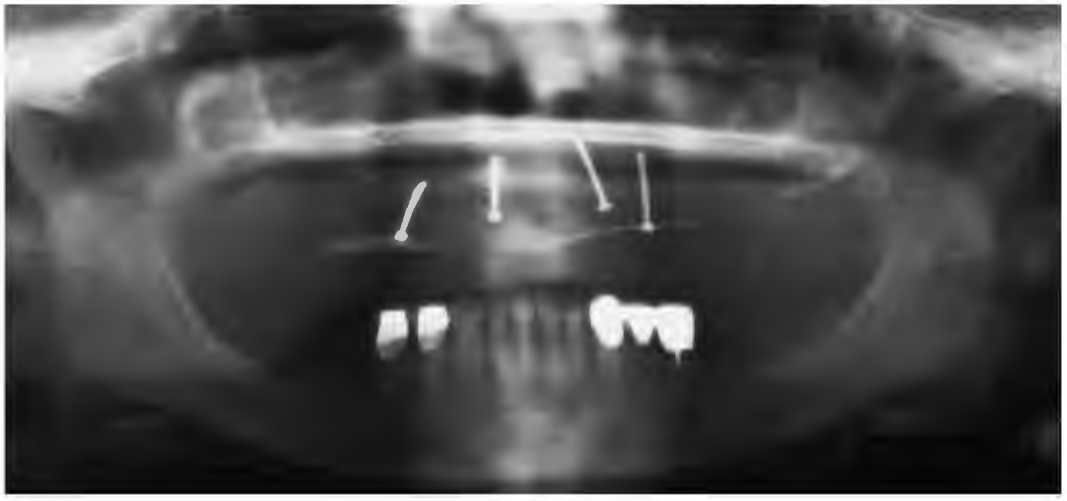


FIGURE 1-46. An iliac crest bone graft was inserted into the maxilla, and bilateral sinus grafts were also made to the posterior regions.

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FIGURE 1-47. The lateral cephlometric radiograph of the patient shown in Figure 1-44. Note the gain in bone height from the graft.

The features of the inferior third of the face are closely related to the supporting skeleton. When vertical bone is lost, the dentures only act as "oral wigs" to improve the contours of the face. The dentures become bulkier as the bone resorbs, making it more difficult to control function, stability, and retention. With implant-supported prostheses, the vertical dimension may be restored, similar to natural teeth. In addition, the implant-supported prosthesis allows a cantilever of anterior teeth for ideal soft tissue and lip contour and improved appearance in all facial planes. This happens without the instability that usually occurs when an anterior cantilever is incorporated in a traditional denture. The facial profile may be enhanced for the long term with implants rather than deteriorating over the years, as can occur with traditional dentures.

Occlusion is difficult to establish and stabilize with a completely soft tissue–supported prosthesis. Because the mandibular prosthesis may move as much as 10 mm or more during function,[111,112] proper occlusal contacts occur by chance, not by

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FIGURE 1-48. Maxillary implants were inserted after the graft matured, and a maxillary fixed prosthesis was fabricated.

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FIGURE 1-49. A profile of the patient after restoration. Note the support of the maxillary lip and presence of the vermilion border of the lip.



FIGURE 1-50. The high smile line of the patient with the final restoration in place.

design. But an implant-supported restoration is stable. The patient can more consistently return to centric relation occlusion rather than adopt variable positions dictated by the prosthesis' instability. Proprioception is awareness of a structure in time and place. The receptors in the periodontal membrane of the natural tooth help determine its occlusal position. Although endosteal implants do not have a periodontal membrane, they provide greater occlusal awareness than complete dentures. Whereas patients with natural teeth can perceive a difference of 20 microns between the teeth, implant patients can determine a 50-micron differences with rigid implant bridges compared with 100 microns in those with complete dentures (either one or two).[113] As a result of improved occlusal awareness, the patient functions in a more consistent range of occlusion. With an implant-supported prosthesis, the direction of the occlusal loads is controlled by the restoring dentist. Horizontal forces on removable prostheses accelerate bone loss, decrease prosthesis stability, and increase soft tissue abrasions. Therefore, the decrease in horizontal forces that are applied to implant restorations improves the local parameters and helps preserve the underlying soft and hard tissues.

In a randomized clinical trial by Kapur et al., the implant group of patients demonstrated a higher level of eating enjoyment and improvement of speech, chewing ability, comfort, denture security, and overall satisfaction.[114] The ability to eat several different foods among complete denture versus mandibular overdenture patients was evaluated by Awad and Feine.[115] The implant overdenture was superior for eating not only harder foods, such as carrots and apples, but also softer foods, such as bread and cheese. Geertman et al. evaluated complete denture wearers with severely resorbed mandibles before and after mandibular implant overdentures. The ability to eat hard or tough foods significantly improved.[116,117]

Researchers at McGill University evaluated blood levels of patients who had complete dentures and 30 maxillary dentures and mandibular implant prostheses 6 months after treatment. Within this rather short period, implant patients had higher vitamin B_{12} hemoglobin (related to iron increase) and albumin levels (related to nutrition). These patients also had greater

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body fat in their shoulders and arms, with decreased body fat in their waists.[118]

The success rate of implant prostheses varies, depending on a host of factors that change for each patient. However, compared with traditional methods of tooth replacement, the implant prosthesis offers increased longevity, improved function, bone preservation, and better psychological results. According to 10-year survival surveys of fixed prostheses on natural teeth, decay is indicated as the most frequent reason for replacement; and survival rates are approximately 75%.[27] In a partially edentulous patient, independent tooth replacement with implants may preserve intact adjacent natural teeth as abutments, further limiting complications such as decay or endodontic therapy, which are the most common causes of fixed prosthesis failure. A major advantage of the implant-supported prosthesis is that the abutments cannot decay and never require endodontics. The implant and related prosthesis can attain a 10-year survival rate of more than 90%.

The maximum occlusal force of a traditional denture wearer ranges from 5 to 50 lb. Patients with an implant-supported fixed prosthesis may increase their maximum bite force by 85% within 2 months after the completion of treatment. After 3 years, the mean force may reach more than 300% compared with pretreatment values. As a result, an implant prosthesis wearer may demonstrate a force similar to that of a patient with a fixed restoration supported by natural teeth. Chewing efficiency with an implant prosthesis is greatly improved compared with that of a soft tissue–borne restoration. The masticatory performance of dentures, overdentures, and natural dentition was evaluated by Rissin et al.[82] The traditional denture showed a 30% decrease in chewing efficiency; other reports indicate a denture wearer has less than 60% of the function of people with natural teeth. The tooth-supported overdenture loses only 10% of chewing efficiency compared with natural teeth. These findings are similar with implant-supported overdentures. In addition, rigid, implant-supported fixed bridges may function the same as natural teeth. Beneficial effects such as a decrease in fat, cholesterol, and the carbohydrate food groups have been reported, as well as significant improvement in eating enjoyment and social life.[119–127]

Stability and retention of an implant-supported prosthesis are great improvements over soft tissue–borne dentures (Figure 1-51). Mechanical means of implant retention are far superior to the soft tissue retention provided by dentures or adhesives and cause fewer associated problems. The implant support of the final prosthesis is variable, depending on the number and position of implants; yet all treatment options demonstrate significant improvement.



FIGURE 1-51. Implant prostheses *(bottom)* can maintain bone, improve function and psychologic health, and reduce the bulk of the soft tissue–borne prostheses *(top)*.

Phonetics may be impaired by the instability of a conventional denture. The buccinator and mylohyoid muscles may flex and propel the posterior portion of the denture upward, causing clicking, regardless of the vertical dimension.[112] As a result, a patient in whom the vertical dimension already has collapsed 10 to 20 mm may still produce clicking sounds during speech. Often the tongue of the denture wearer is flattened in the posterior areas to hold the denture in position. The anterior mandibular muscles of facial expression may be tightened to prevent the mandibular prosthesis from sliding forward. The implant prosthesis is stable and retentive and does not require these oral manipulations. The implant restoration allows reduced flanges or palates of the prostheses. This is of special benefit to new denture wearers, who often report discomfort with the bulk of the restoration. The extended soft tissue coverage also affects the taste of food, and the soft tissue may be tender in the extended regions. The palate of a maxillary prosthesis may cause gagging in some patients, which can be eliminated in an implant-supported overdenture.

Patients treated with implant-supported prostheses judge their overall psychological health as improved by 80% compared with their previous state while wearing traditional, removable prosthodontic devices. They perceived the implant-supported prosthesis as an integral part of their body.[116,128–132] For example, Raghoebar et al. evaluated 90 edentulous patients in a randomized multicenter study.[131] Five years after treatment, a validated questionnaire targeted patient esthetic satisfaction, retention, comfort, and the ability to speak and eat with either a complete mandibular denture, complete mandibular denture with vestibuloplasty, or mandibular two-implant overdenture. Implant overdentures had significantly higher ratings, but no significant difference was found between the two complete-denture groups. Geertman et al. reported similar results comparing chewing ability of conventional complete dentures with mandibular implant overdentures.[116,117]

Summary

The goal of modern dentistry is to return patients to oral health in a predictable fashion. Partial and complete edentulous patients may be unable to recover normal function, esthetics, comfort, or speech with a traditional removable prosthesis. The patient's function when wearing a denture may be reduced to one sixth of that level formerly experienced with natural dentition; however, an implant prosthesis may return the function to near normal limits. The esthetics of edentulous patients are affected as a result of muscle and bone atrophy. Continued bone resorption leads to irreversible facial changes. An implant prosthesis allows normal muscle function, and the implant stimulates the bone and maintains its dimension in a manner similar to healthy natural teeth. As a result, the facial features are not compromised by lack of support as often required for removable prostheses. In addition, implant-supported restorations are positioned in relation to esthetics, function, and speech, not in neutral zones of soft tissue support. The soft tissues of the edentulous patients are tender from the effects of thinning mucosa, decreased salivary flow, and unstable or unretentive prostheses. The implant-retained restoration does not

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require soft tissue support and improves oral comfort. Speech is often compromised with soft tissue–borne prostheses because the tongue and perioral musculature may be compromised to limit the movement of the mandibular prosthesis. The implant prosthesis is stable and retentive without the efforts of the musculature.

Implant prostheses often offer a more predictable treatment course than traditional restorations. Thus, the profession and the public are becoming increasingly aware of this dental discipline. Manufacturers' sales have increased from a few million dollars to more than several billion dollars per year. Almost every professional journal now publishes refereed reports on dental implants. All U.S. dental schools now teach implant dentistry to all interfacing specialties. Implant dentistry has finally been accepted by organized dentistry. The current trend to expand the use of implant dentistry will continue until every restorative practice uses this modality for abutment support of both fixed and removable prostheses on a regular basis as the primary option for all tooth replacement.[133]

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CHAPTER 2

Generic Root Form Component Terminology

Carl E. Misch

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An *endosteal* implant is an alloplastic material surgically inserted into a residual bony ridge, primarily as a prosthodontic foundation.[1] The prefix *endo* means "within," and *osteal* means "bone."[2] The major subcategory of endosteal implants covered in this text are root form implants. The term *endosseous* is also used in the literature, and because the term *osseous* also indicates bone, either term is acceptable. However, *endosteal*, *periosteal*, and *transosteal* are preferred. Many endosteal implant designs have been used in the past, including tapered pegs, pin shapes, and plate forms.[3,4] Today an endosteal implant in the shape of a single rooted tooth is the design most often used in the restoration of partial or complete edentulous patients.

Implant dentistry is the second oldest discipline in dentistry (oral surgery [exodontia] is the oldest). Root form implant history dates back thousands of years and included ancient civilizations. For example, 4000 years ago the Chinese carved bamboo sticks in the shape of pegs and drove them into the bone for fixed tooth replacement. The Egyptians used precious metals with a similar peg design 2000 years ago. A skull was found in Europe with a ferrous metal tooth inserted into a skull with a tooth peg design that dated back to the time of Christ. Incas from Central America around 600 AD took pieces of sea shells and, similar to the ancient Chinese, tapped them into the bone to replace missing teeth[5] (Figure 2-1). In other words, history demonstrates it has always made sense to replace a tooth with an implant, with the approximate shape of a tooth. In reality, if the lay public were given a choice to replace a missing tooth with an implant or to grind down several adjacent teeth and connect them with a prosthesis to replace a missing tooth and then attempt to make the adjacent teeth look similar to the condition before their preparation, the implant would be the obvious choice.

Maggiolo introduced the more recent history of implant dentistry in 1809 with use of gold in the shape of a tooth root.[6] In 1887, Harris reported the use of teeth made of porcelain into which lead-coated platinum posts were fitted.[7] Many materials were tested, and in the early 1900s, Lambotte fabricated implants of aluminum, silver, brass, red copper, magnesium, gold, and soft steel plated with gold and nickel.[8] He identified the corrosion of several of these metals in body tissues related to electrolytic action. The first root form design that differed significantly from the shape of a tooth root was the Greenfield latticed-cage design in 1909, made of iridoplatinum[9] (Figure 2-2). This was also the first two-piece implant, which separated the abutment from the endosteal implant body at the initial placement. The surgery was designed to use a calibrated trephine bur to maintain an inner core of bone within the implant body. The implant crown was connected to the implant body with an antirotational internal attachment after several weeks. Reports indicate this implant had a modicum of success. Seventy-five years later, this implant design was reintroduced by Straumann in Europe and later by Core-Vent in the United States.[10,11]

Surgical cobalt-chromium-molybdenum alloy was introduced to oral implantology in 1938 by Strock (Boston, MA) when he replaced a single maxillary left incisor tooth[12] with a root form, one-piece implant that lasted more than 15 years. A direct bone–implant interface to titanium was initially called *bone fusing* and was first reported in 1940 by Bothe and coworkers.[13] In 1946, Strock designed the first titanium, two-piece screw implant that was initially inserted without the permucosal post (Figure 2-3). The abutment post and individual crown were added after complete healing.[14] The desired implant interface described by Strock was a direct bone–implant connection, which was called *ankylosis.* The first submerged implant placed by Strock was still functioning 40 years later.[15]

Brånemark began extensive experimental studies in 1952 on the microscopic circulation of bone marrow healing. These studies led to a dental implant application in the early 1960s in which a 10-year implant integration was established in dogs



FIGURE 2-1. Dated 600 AD, this mandible was found in Central America. The Incas implanted three carved, implanted incisors made from carved sea shells. Calculus formation on these three implants indicate this was not a burial ceremony but a fixed, functional, and esthetic tooth replacement. (Courtesy of the Peabody Museum of Archaeology and Ethnology, Harvard University, 33-19-20/254.0, 95240002.)

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FIGURE 2-2. Greenfield (Kansas City, KS) developed a two-stage implant insertion. This was also the first antirotational abutment design.

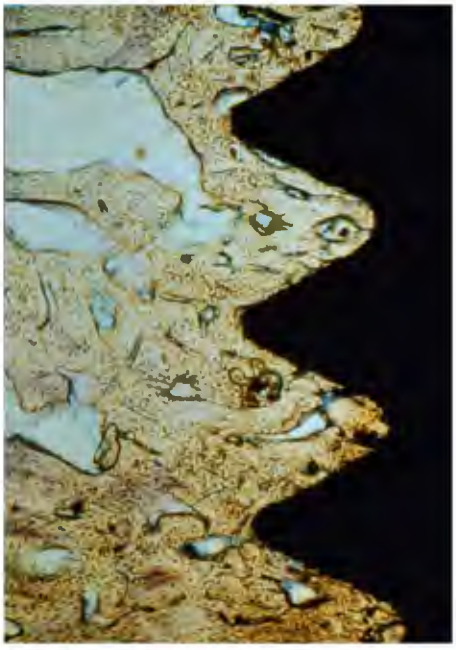


FIGURE 2-4. Osseointegration, as coined by Brånemark, described a direct bone–implant interface under the power of a light microscope.



FIGURE 2-3. Al Strock (Boston, MA) invented a two-piece cylinder and two-piece screw-type implant in 1938.

without significant adverse reactions to hard or soft tissues. Implant clinical studies in humans with the Brånemark philosophy began in 1965, were followed for 10 years, and were reported in 1977.[16] The term *osseointegration* (rather than *bone fusing* or *ankylosis*) was defined by Brånemark as a direct contact of living bone with the surface of an implant at the light microscopic level of magnification[17] (Figure 2-4). The terms *bone fusing, ankylosis,* and *osseointegration* may be interchangeable and may address the microscopic bone–implant interface. The percentage of direct bone–implant contact was not initially addressed and has been found to be highly variable.

Rigid fixation is the clinical result of a direct bone interface but has also been reported with a fibrous tissue interface.[18] *Rigid fixation* is a clinical term that implies no observable movement of the implant when a force of 1 to 500 g is applied. Today the term *osseointegration* has become common in the implant discipline and describes not only a microscopic condition but also the clinical condition of rigid fixation. The prefix *osteo* (e.g., *osteo*blast, *osteo*tomy) also is widely used by the profession and may describe this condition as *osteointegration*.

The osseointegration concepts of Brånemark have been promoted more than those of any other previous person in dental history. The documentation of past clinical case studies, research of surgery and bone physiology, healing of soft and hard tissues, and restorative applications from Brånemark's laboratory were unprecedented. Adell et al. published the Brånemark 15-year clinical case series report in 1981 on the use of implants in completely edentulous jaws.[17] Approximately 90% of the reported anterior mandibular implants that were in the mouths of patients after the first year of loading were still in function 5 to 12 years later. Lower survival rates were observed in the anterior maxilla. In the initial Brånemark clinical reports, no implants were inserted into partially edentulous patients or the posterior regions of the mouth of edentulous patients, and all reported prostheses were cantilevered fixed restorations (Figure 2-5).

The use of dental implants in the treatment of complete and partial edentulism has become an integral treatment modality in restorative dentistry.[19–21] The 1988 National Institutes of Health consensus panel on dental implants recognized that restorative procedures using implants differ from those of traditional dentistry and stressed the necessity for advanced education.[22] During the past 15 years, implant dentistry has become a routine method to replace teeth in a restorative practice.

Many practitioners are taught the use of a specific manufacturer's implant system rather than the theory and

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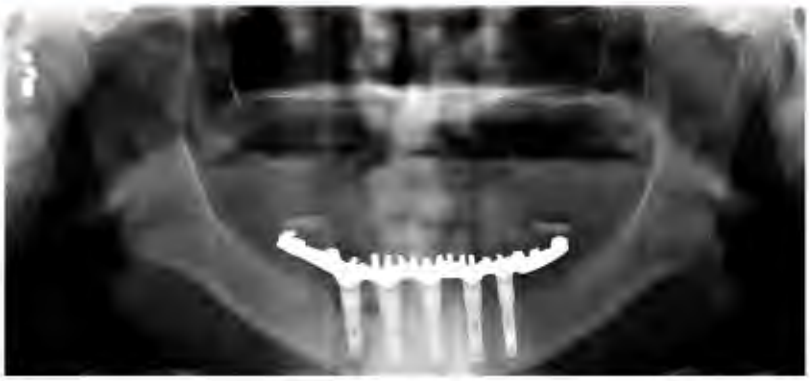


FIGURE 2-5. The Brånemark treatment approach placed a cantilevered fixed prosthesis supported by four to six anterior implants.

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comprehensive practice of implant dentistry. The increasing number of manufacturers entering the field use trade names for their implant components (often unique to a particular system), and such names have proliferated to the point of creating confusion. Several different terms or abbreviations now exist that describe similar basic components.[23–28]

To make conditions worse, in the team approach to implant treatment, the widening referral base often requires that the restoring practitioner be knowledgeable regarding many implant systems. With the required knowledge of multiple systems and the lack of uniformity in component names, communication is hampered among manufacturers, dentists, staff, laboratory technicians, students, and researchers. In addition, the incorporation of implant dentistry into the curriculum of most predoctoral and postdoctoral programs further emphasizes the need for standardization of terms and components in implant dentistry.[29]

Generic Prosthetic Component Terminology

A generic language for endosteal implants was developed by Misch and Misch in 1992.[30] The order in which these terms is presented follows the chronology of insertion to restoration. In formulating the terminology, five commonly used implant systems in the United States were referenced. Fifteen years later, the dramatic evolution of the U.S. implant market has resulted in changes in nearly all the implant lines and component designs.[31–33] In 2000, the U.S. market alone had to choose from more than 1300 different implant designs and 1500 abutments in various materials, shapes, sizes, diameters, lengths, surfaces, and connections. More than ever, a common language is needed. In pharmacology, the variety of pharmaceutical components makes it impossible to list them all by proprietary names, but a list by category of drugs is useful. Likewise, implant components still can be classified into broad application categories, and practitioners should be able to recognize a certain component category and know its indications and limitations.

This book incorporates a generic terminology, first introduced by Misch and Misch for endosteal implants, that blends a continuity and familiarity of many implant systems with established definitions from the terms of the *Illustrated Dictionary of Dentistry* and the glossaries from *Terms of the Academy of Prosthodontics, American Academy of Implant Dentistry,* and *International Congress of Oral Implantologists.*[1,2,34,35]



FIGURE 2-6. An implant body *(gray color)* is usually separate from the implant abutment *(gold color)*. They are most often connected together with an abutment screw. (*Left,* internal hex BioHorizons Dental Implants; *right,* external hex BioHorizons Dental Implants, Birmingham, AL).

Generic Implant Body Terminology

Root form implants are a category of endosteal implants designed to use a vertical column of bone, similar to the root of a natural tooth. Although many names have been applied, the 1988 National Institutes of Health consensus statement on dental implants and the American Academy of Implant Dentistry recognized the term *root form.*[1,22,35]

The most common root form design has a separate *abutment and implant body,* which permits only the implant body placement during bone healing (Figure 2-6). A second procedure is required to attach the implant abutment. The design and surgical philosophy is to achieve clinical rigid fixation that corresponds to a microscopic direct bone-to-implant interface without intervening fibrous tissue occurring over any significant portion of the implant body after healing.

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Over the years, three different surgical approaches have been used for the two-piece implant systems: one stage, two stage, and immediate restoration (loading) (Figure 2-7). The *two-stage* surgical process places the implant body below the soft tissue until the initial bone healing has occurred. During a *second-stage surgery,* the soft tissues are reflected to attach a *permucosal element or abutment.* During a *one-stage surgical* approach, the implant body and the permucosal element above the soft tissue are both placed until initial bone maturation has occurred. The abutment of the implant then replaces the permucosal element without the need for a secondary soft tissue surgery. The *immediate restoration* approach places the implant body and the prosthetic abutment at the initial surgery. A restoration (most often transitional) is then attached to the abutment (often out of occlusal contacts in partially edentulous patients) within 2 weeks of the surgical appointment.

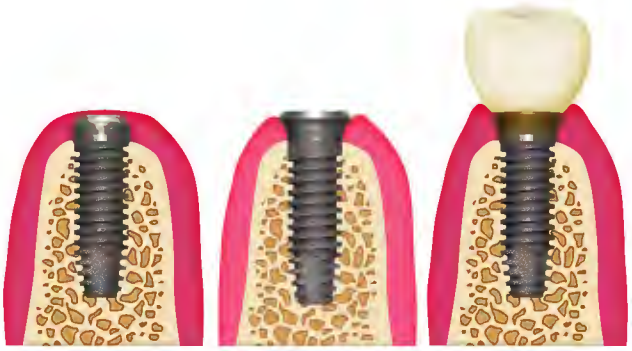


FIGURE 2-7. There are three different surgical approaches for two-piece implant systems: **(A)** two stage (healing submerged, then uncover surgery), (**B)** one stage (implant with permucosal healing, no uncover surgery), and **(C)** immediate restoration (restoration placed at the time of the surgical placement).

An implant body especially designed for one surgical method may also be selected. For example, a permucosal element may already be attached to the implant body by the manufacturer to facilitate a one-stage surgical approach. An implant body also may have a prosthetic abutment, which may be part of the implant body, for the one-piece implant to be inserted and restored at the initial surgery. The latter was the original concept first introduced.[12]

There are three primary types of root form body endosteal implants based on design: cylinder, screw, or combination[30] (Figure 2-8). *Cylinder* root form implants depend on a coating or surface condition to provide microscopic retention to the bone. Most often the surface is either coated with a rough material (e.g., hydroxyapatite, titanium plasma spray) or a macro retentive design (e.g., sintered balls). Cylinder implants are usually pushed or tapped into a prepared bone site. They can be a paralleled wall cylinder or a tapered implant design. *Screw* root forms are threaded into a slightly smaller prepared bone site and have the macroscopic retentive elements of a thread for initial bone fixation. They may be machined, textured, or coated. There are three basic screw-thread geometries: V-thread, buttress (or reverse buttress) thread, and power (square) thread designs.[36] Threaded implants are primarily available in a parallel cylinder or tapered design. Micro or macro thread features; variable



FIGURE 2-8. Implant body designs generally relate to three different categories: cylinder implants *(first six in top row)*; screw design implants *(middle row)*; or a combination *(bottom row),* which usually are pressed into position and have a macro body design similar to a thread form. (Courtesy Charles English.)

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thread pitch, depth, and angle; and self-tapping features can be combined to create a myriad of implant designs in this category. The threaded implants may also have a microscopic connection to the bone as a result of its surface condition. *Combination* root forms have macroscopic features from both the cylinder and screw root forms. The combination root form designs also may benefit from microscopic retention to bone through varied surface treatments (machined, textured, and the addition of coatings).[37–45] As a general rule, the combination implant designs have a press-fit surgical approach (as the cylinder implants) and a macroscopic implant design for occlusal loads (as a series of plateaus or holes in the body). Root forms also have been described by their means of insertion, healing, surgical requirements, surface characteristics, and interface.[28,46]

Implant Body Regions

The implant body may be divided into a crest module (cervical geometry), a body, and an apex (Figure 2-9). Each section of an implant body has features that are of benefit in the surgical or prosthetic application of the implant.

Implant Body

An *implant body* is primarily designed for either surgical ease or prosthetic loading to the implant–bone interface. Years ago, the implant body was the primary design feature. A round implant permits round surgical drills to prepare the bone. A smooth-walled cylinder or combination implant allows the implant to be pressed or tapped into position, similar to a nail into a piece of wood. A tapered cylinder fits into the top section of the osteotomy before engagement of the bone for further ease of placement.

A cylinder or press-fit implant design system offers the advantage of ease of placement even in difficult access locations. The cover screw of the implant also may be attached to the implant before implant placement. For example, in the very soft D4 bone of the posterior regions of the maxilla, the surgeon must rotate a threaded implant design into place. Very soft bone may strip during a threaded implant insertion. This may result in lack of initial fixation, and the implant will not be rigid. A tapered cylinder implant may be pressed by hand into soft bone and can be initially fixated more easily. The speed of implant rotation during insertion and the amount of apical force in implant insertion in soft bone are less relevant for a press-fit cylinder. The cylinder system also presents some benefits for the single-tooth implant application, especially if adjacent to teeth with tall clinical crowns. Thread extenders are needed for the screw implant placement in these situations, as well as additional tools to insert the cover screw of the implant. In dense bone, cylinder systems also are easier and faster to place because bone tapping is not required.

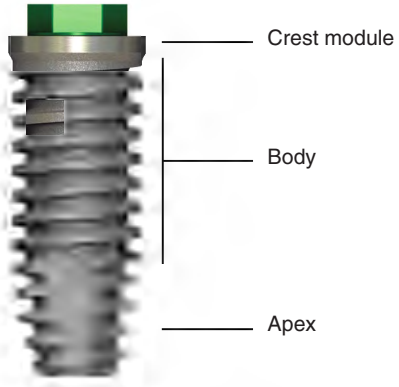


FIGURE 2-9. An implant body is the portion of the dental implant that is designed to be placed into the bone to anchor prosthetic components. The implant body has a crest module, a body, and an apex.

Most cylinder implants are essentially smooth-sided and bullet-shaped implants that require a bioactive or increased surface area coating for retention in the bone. When these materials are placed on an implant, the surface area of bone contact increases more than 30%. The greater the functional surface area of the bone–implant contact, the better the support system for the prosthesis.

A solid screw implant body is the most common design reported in the literature. A *solid screw body* is defined as an implant of a circular cross-section without penetrating any vents or holes. A number of manufacturers provide this design (e.g., Nobel Biocare, Biomet, Zimmer, Straumann, BioHorizons). The thread may be V-shaped, buttress, reverse buttress, or square (power thread) in design. The V-shaped threaded screw has the longest history of clinical use.[16,17] The most common outer thread diameter is 3.75 mm, with a 0.38-mm thread depth and a 0.6-mm thread pitch (distance). The various body lengths usually range from 7 to 16 mm, although lengths from 5 to 56 mm are available. Similar body designs are offered in a variety of diameters (narrow, standard, wide) to respond to the mechanical, esthetic, and anatomical requirements in different regions of the mouth.[31]

A solid screw implant body permits the osteotomy and placement of the implant in dense cortical bone as well as in fine trabecular bone. However, surgery may be modified to accommodate both extremes in bone density. For example, a bone tap may be required in the hardest bone types. The solid screw permits the implant removal at the time of surgery if placement is not ideal. It also permits implant removal at the stage II surgery if angulation or crestal bony contours are not deemed adequate for long-term prosthesis success. The solid screw implant body may be machined or roughened to increase the functional surface area or to take advantage of biochemical properties related to the surface coating (e.g., bone bonding or bone growth factors).

A threaded implant body is primarily designed to increase the bone–implant surface area and to decrease the stresses at the interface during occlusal loading compared with a cylinder implant body design. The functional surface area of a threaded implant is greater than a cylinder implant by a minimum of 30% and may exceed 500%, depending on the thread geometry.[36] This increase in functional implant surface area decreases the stress imposed on the implant–bone interface. The threaded implant body also increases the mechanical retention in the bone at the initial implant insertion. This is especially noteworthy in the softest bone types or when the implant is less than 10 mm long.

Crest Module

The *crest module* of an implant body is that portion designed to retain the prosthetic component in a two-piece implant system. It also represents the transition zone from the implant body design to the transosteal region of the implant at the crest of the ridge. The abutment connection area usually has a platform on which the abutment is seated; the platform offers physical resistance to axial occlusal loads. An antirotation feature also is included on the platform (external hex) or extends within the

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implant body (internal hex, octagon, Morse taper or cone screw, internal grooves or cam tube, and pin slots). Whereas the implant body has a design to transfer stress and strain to the bone during occlusal loads (e.g., threads or large spheres), the crest module often is designed to reduce bacterial invasion. (e.g., smoother to impair plaque retention if crestal bone loss occurs). Its smoother dimension varies greatly from one system to another (0.5–5 mm). When the crest module is smooth, polished metal, it is often called a *cervical collar*.

A high-precision fit of the external or internal antirotational component (flat to flat dimension) is paramount to the stability of the implant body–abutment connection.[47–49] The prosthetic connection to the crest module is received by slip fit or friction fit with a butt or bevel joint. All prosthetic connections aim at providing a precise mating of the two components with minimal tolerance.

Implant Apex

The *implant apex* portion is often tapered to permit ease of initial placement into the osteotomy. An antirotational feature of an implant may also be included, which has flat sides or grooves along the apical region of the implant body or an apical hole. When bone grows against the flat or groove regions or within the hole, the bone is placed in compression with rotational loads. For example, when the abutment screw is threaded into the crest module to attach the abutment, a rotational force of 30 N-cm may be applied to the entire implant system. The rotational force creates a shear load to bone, and bone is weakest to shear. As a result, it may break the implant–bone interface along the implant body and result in implant instability. A compressive load along the apex design as a result of a flat side or apical hole resists the rotational load.

The apical end of each implant should be flat rather than pointed. This allows for the entire length of the implant to incorporate design features that maximize desired strain profiles. Additionally, if an opposing cortical plate is perforated, a sharp, V-shaped apex may irritate or inflame the soft tissues if any soft tissue movement occurs (e.g., the inferior border of the mandible).

Implant Components

Implant Surgery: Stage I

At the time of insertion of a two-stage *implant body* (stage I surgery), a *first-stage cover screw* is placed into the top of the implant to prevent bone, soft tissue, or debris from invading the abutment connection area during healing (Figures 2-10 to 2-12).

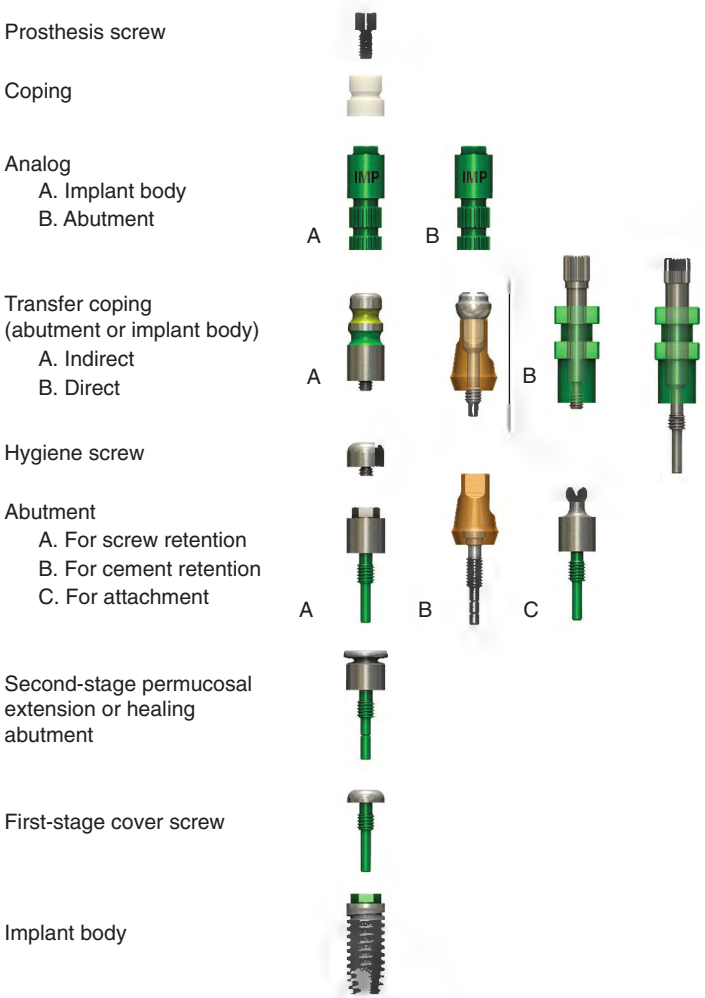


FIGURE 2-10. Implant components frequently have terms that are different for each company, but a generic language exists that applies to any product. This language permits improved communication between referring doctors and laboratories, which often must be familiar with several different systems. These generic terms are listed from bottom to top in the order of use.

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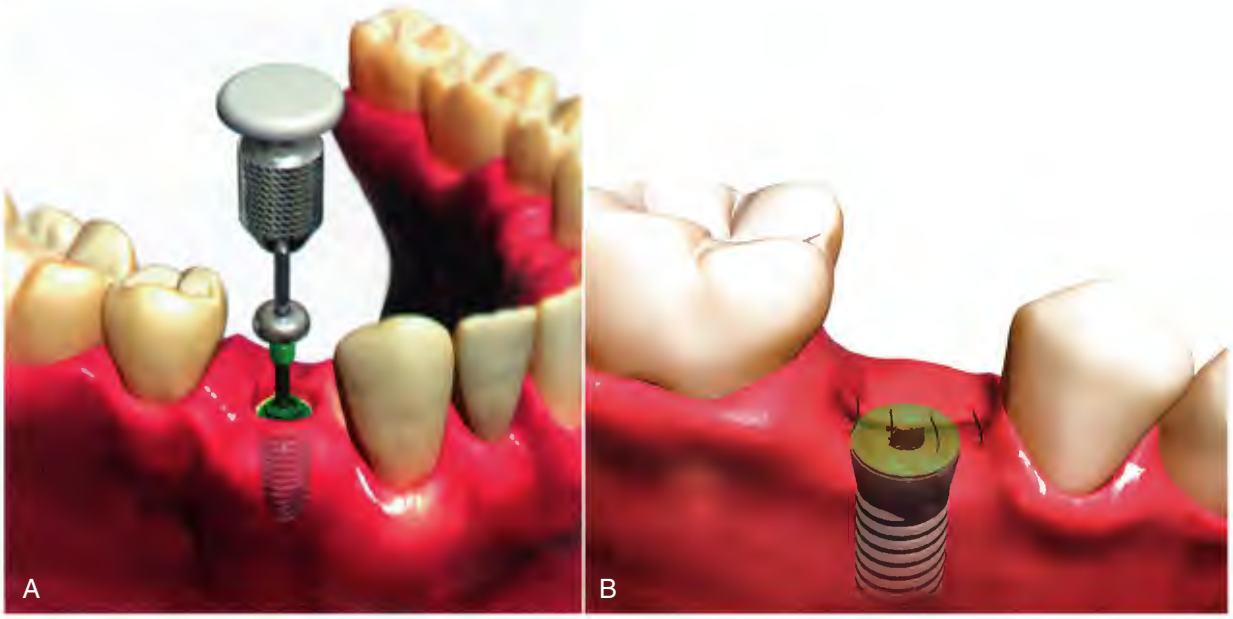


FIGURE 2-11. **A,** A first-stage cover screw is inserted into the implant body before obtaining primary closure of the soft tissue at stage I surgery. **B,** The tissue covers the first-stage cover screw during bone integration of the implant.

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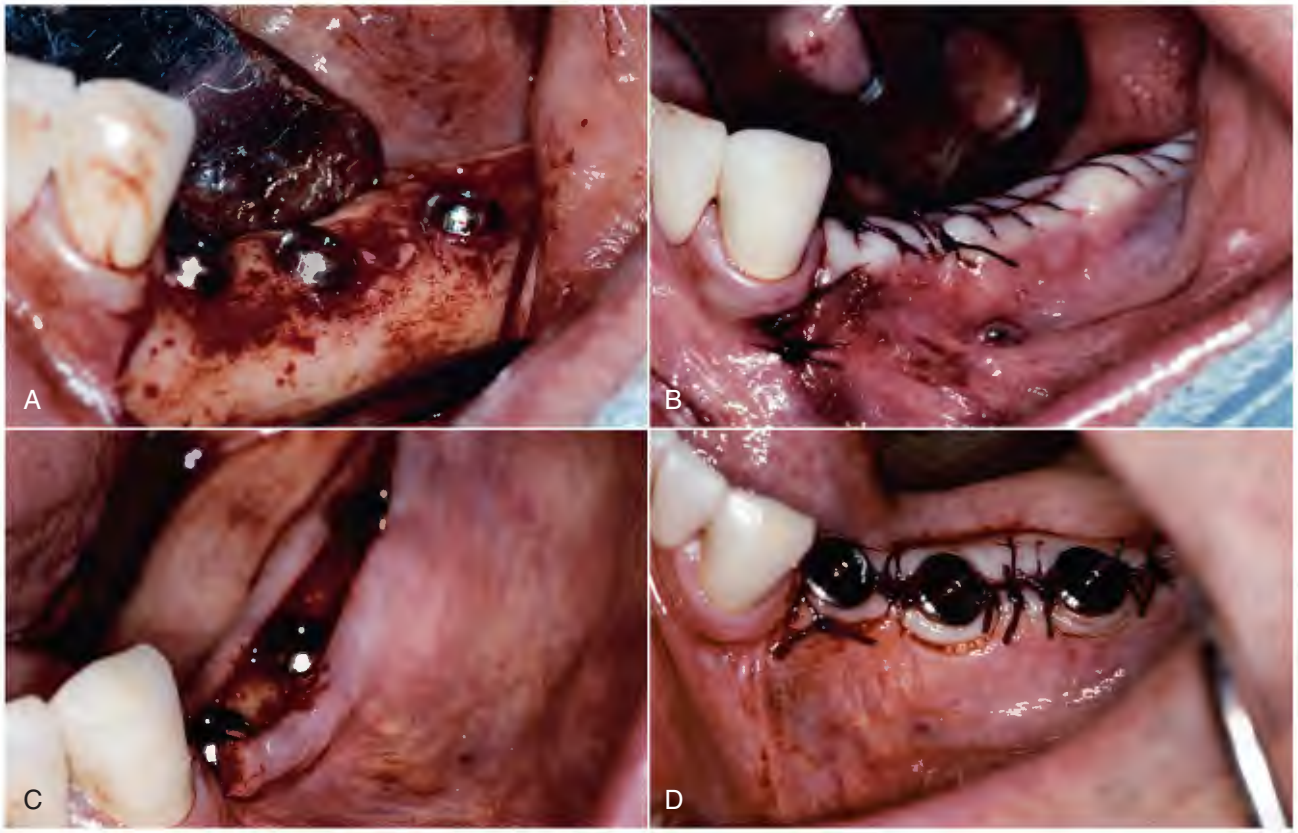


FIGURE 2-12. **A,** A posterior mandible with three implants and first-stage cover screws inserted. **B,** Primary closure of the soft tissue at implant stage I surgery decreases the risk of postoperative infection and implant movement during initial healing. **C,** A second-stage surgery uncovers the implants after initial integration. **D,** A permucosal extension is inserted into the implant body and the sutures sutured around them.

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Implant Surgery: Stage II

After a prescribed healing period sufficient to allow a supporting bone interface to develop, a second-stage procedure may be performed to expose the two-stage implant or to attach a transepithelial portion[35] (Figure 2-13). This transepithelial portion is termed a *permucosal extension* because it extends the implant above the soft tissue and results in the development of a permucosal seal around the implant. This implant component has also been called a *healing abutment* because stage II uncover surgery often uses this device for initial soft tissue healing. The *permucosal extension* is available in multiple heights to accommodate soft tissue variations. It also can be straight, flared, or anatomical to assist in the initial contour of the soft tissue healing.

In the case of a one-stage surgical procedure, the surgeon may have placed the *permucosal extension* at the time of implant insertion or may have selected an implant body design with a cervical collar of sufficient height to be supragingival (Figure 2-14). In this approach, the second-stage surgery is eliminated, and the soft tissue heals at the same time as the bone interface (Figure 2-15).

In the case of immediate restoration, the abutment may be inserted at the initial surgery, and a prosthesis delivered at the same time (Figures 2-16). Hence, the permucosal extension may not be used at all.

Prosthetic Attachments

The *abutment* is the portion of the implant that supports or retains a prosthesis or implant superstructure.[35] A *superstructure* is defined as a metal framework that attaches to the implant abutment(s) and provides either retention for a removable prosthesis[1] (e.g., a cast bar retaining an overdenture with attachments) or the framework for a fixed prosthesis. There are a myriad of options related to abutment design and material. The expansion of implant dentistry, its applications for esthetic dentistry, and the creativity of manufacturers in this very competitive market are responsible for the explosion of implant abutment styles available today.

Three main categories of implant abutments are described, according to the method by which the prosthesis or





FIGURE 2-13. The permucosal extension (PME) attaches to the implant body and allows the soft tissue to heal and mature around the future implant abutment. The PME may be the same size as the crest module of the implant body *(left)* or slightly larger *(right)* and helps develop the emergence contour of the implant crown.

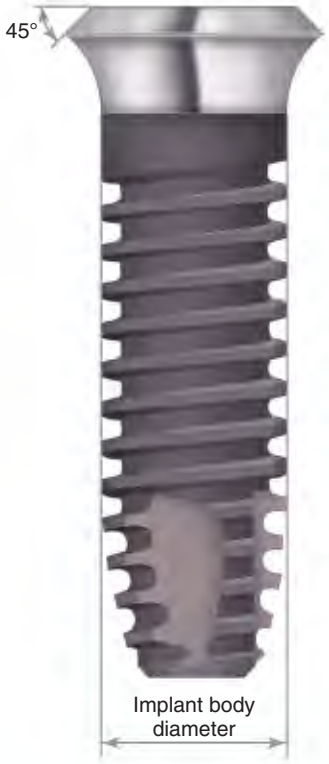


FIGURE 2-14. A one-stage implant body design has an extended crest module, which extends through the tissue at the initial surgery. A separate permucosal element is not required with this design. (BioHorizons Dental Implants, Birmingham, AL.)



FIGURE 2-15. The one-stage implant body design may be used with a one-stage surgical approach in which the soft tissue around the implant heals while the bone is healing. A second-stage surgery is eliminated with this approach.

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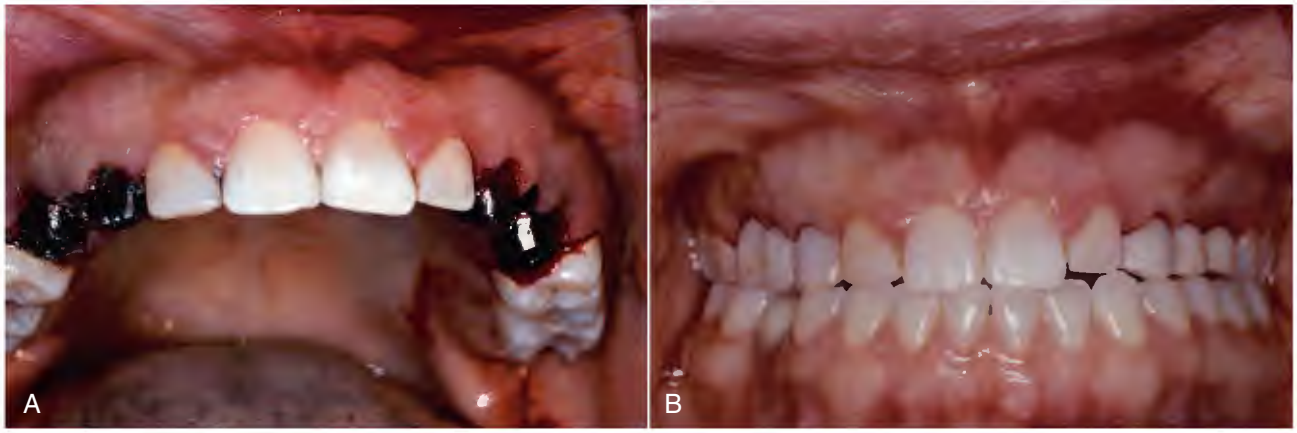


FIGURE 2-16. **A,** The prosthetic abutment may be inserted into the implant body at the initial surgery. **B,** A transitional prosthesis (usually out of occlusion in partially edentulous patients) is attached to the abutments during the initial surgery.

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superstructure is retained to the abutment: (1) an *abutment for screw retention* uses a screw to retain the prosthesis or superstructure (Figure 2-17, *A*), (2) an *abutment for cement retention* uses dental cement to retain the prosthesis or superstructure (Figure 2-17, *B*), and (3) an *abutment for attachment* uses an attachment device to retain a removable prosthesis (e.g., an O-ring attachment) (Figure 2-17, *C*). The *abutment for cement, screw, and attachment* may be screwed or cemented into the implant body, but this aspect is not delineated within the generic terminology (however, it is most always screw retained).

Each of the three abutment types may be further classified as straight or angled abutments, describing the axial relationship between the implant body and the abutment. An *abutment for screw retention* uses a *hygiene cover screw* placed over the abutment to prevent debris and calculus from invading the internally threaded portion of the abutment retention during prosthesis fabrication between prosthetic appointments.

In the *abutment for cement* category, the doctor may choose from one- and two-piece abutments; UCLA type (plastic castable, machined or plastic castable, gold sleeve castable); two-piece esthetic; two-piece anatomical; two-piece shoulder; preangled (several angulations); and ceramic, zirconia, or computer-assisted custom designs (Figure 2-18). The abutment for screw category also has been enlarged with one- and two-piece overdenture abutments of different contours and heights.

Many manufacturers classify the prosthesis as *fixed* whenever cement retains the prostheses, *fixed or removable* when screws retain a fixed prosthesis, and *removable* when the restoration is removed by the patient. This description implies that only screw-retained prostheses may be removed. This is not an accurate description because a fixed, cemented prosthesis also may be removed by the dentist (especially when a temporary cement is used). The generic language in this chapter separates prostheses into either fixed or removable in a method similar to traditional prosthetics.

Prosthesis Fabrication

Direct Prosthetic Option

The implant abutment may be restored as a natural tooth restoration. The abutment (usually prefabricated) is inserted into the implant body (usually screw retained rather than cemented as with a post in an endodontic-treated tooth). After preparation of the abutment in the mouth, an impression is made of the abutment. A stone cast is poured, and an individual die of the abutment is trimmed. The restoration is fabricated very similar to a tooth. This prosthetic approach may be called a direct prosthetic option (Figures 2-19 and 2-20).

The advantages of the direct prosthetic option are (1) familiar to restoring dentists, (2) no laboratory analog components are required, (3) splinting crowns together is less complicated because manufacturer precision for analogs is not required and transfer of components is not required (Figure 2-21), and (4) reduced cost because analogs and laboratory fees for abutments are eliminated.

The disadvantages of the direct prosthetic option are that (1) the abutments are prepared in the mouth, (2) retraction cord placement is required in esthetic zones or when additional abutment height is required for prosthesis retention, and (3) a different transitional restoration is often fabricated than the option during implant body healing because the abutment is inserted.

Indirect Prosthetic Option

Two basic indirect implant restorative techniques are used to make a master impression, and each uses a different design transfer coping based on the transfer technique performed. An impression is necessary to transfer the position and design of the *implant body or abutment* to a master cast for prosthesis fabrication. A *transfer coping* may be used in traditional prosthetics to position a die in an impression.[35] Most implant manufacturers use the terms *transfer* and *coping* to describe the component used in the implant body for the final impression. Therefore, a transfer coping is used to position an analog in an impression or cast and is defined by the portion of the implant it transfers to the master cast, either the *implant body transfer coping* or the *abutment transfer coping* (Figure 2-22).

An *indirect-transfer coping* uses an impression material requiring elastic properties.[35] The *indirect-transfer coping* is screwed into the abutment or implant body and remains in place when a traditional "closed-tray" impression is set and removed from the mouth. The *indirect-transfer coping* is removed from the *implant body* in the mouth, connected to an implant body analog, and then reinserted into the closed-tray impression; hence, the transfer is "indirect." The *indirect-transfer coping* usually has undercuts to engage the elastic impression material when reinserted, is slightly tapered to allow ease in removal

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FIGURE 2-17. An abutment for screw retention is used for a screw-retained bar or fixed prosthesis *(top)*. **B,** Abutments for cement retention may be one piece *(far left)* or two pieces, which are retained by a separate abutment screw *(center)*. **C,** Abutments for attachment are used for removable prostheses that are implant retained *(bottom)*. These may be used for complete dentures and partial dentures. (Courtesy BioHorizons, Birmingham, AL.)

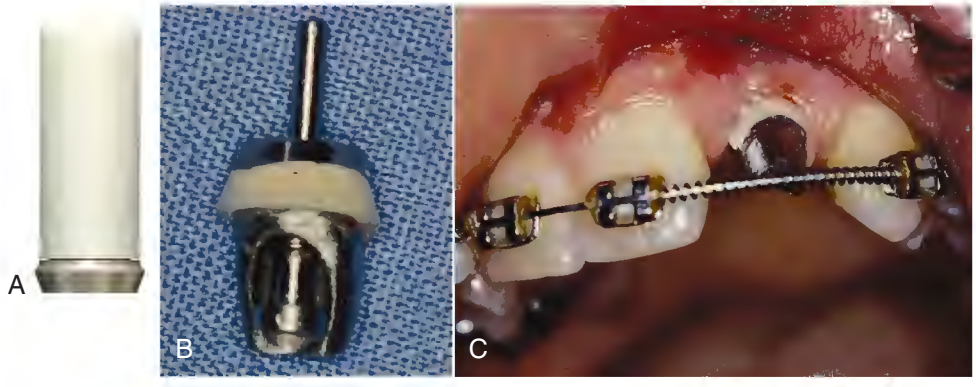


FIGURE 2-18. **A,** A custom abutment can be fabricated to address specific angulation or esthetic requirements. **B,** On a custom abutment, porcelain may be built between the crown margin and the abutment-to-implant position. This buildup allows the crown margin to be above the bone, yet the subgingival region has pink or tooth-colored porcelain and a customized shape to improve esthetics. **C,** A custom abutment with tooth-colored ceramic and ideal emergence profile from the implant body. If the tissue shrinks in the future, the crown will appear longer, but the titanium color of the abutment will not be visible.

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FIGURE 2-19. A direct prosthetic option places the final abutment into the implant body, prepares it for the restoration, and makes a final impression with a closed impression tray technique similar to the restoration of a natural tooth.

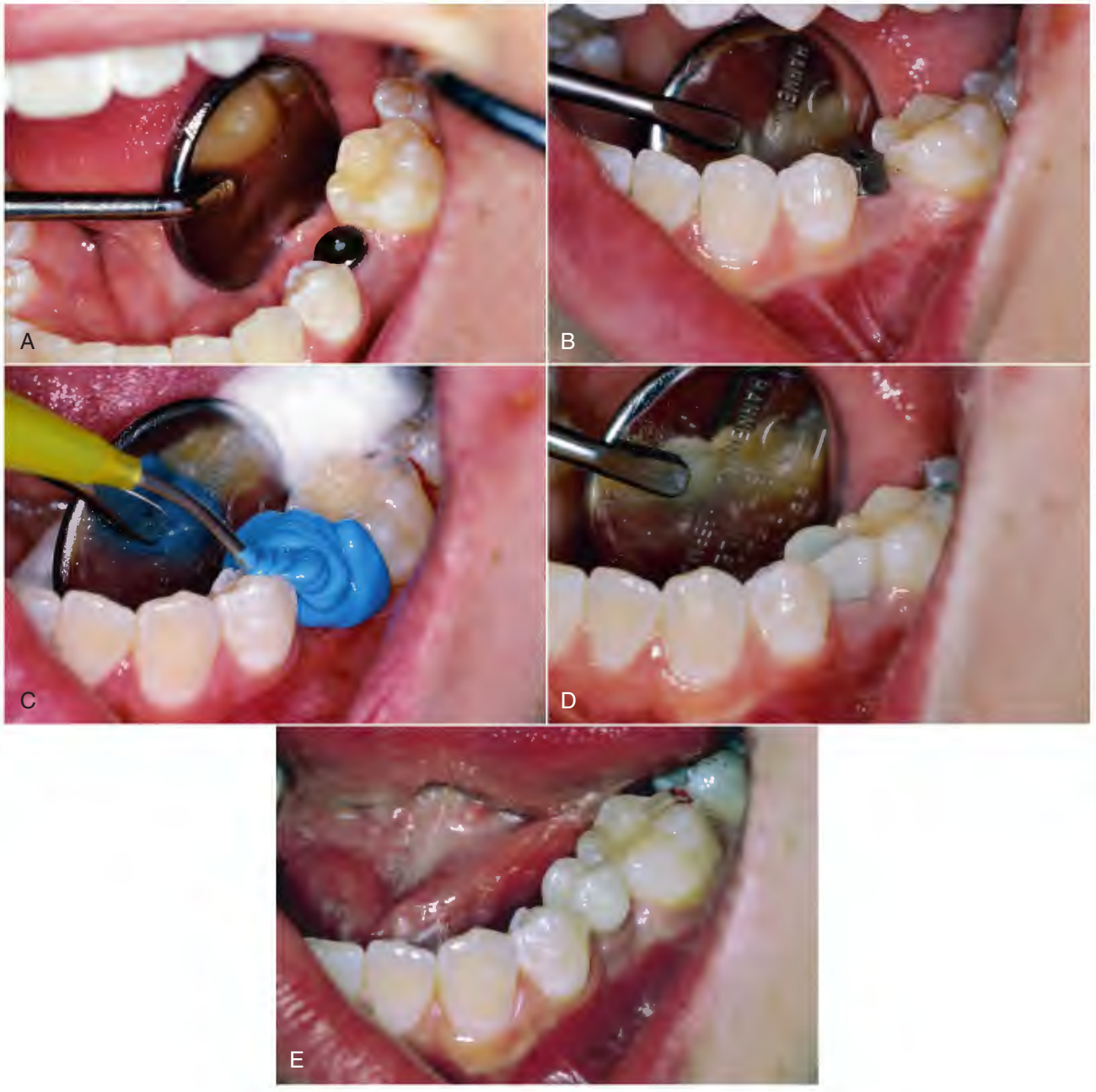


FIGURE 2-20. **A,** A permucosal extension in the implant replacing the mandibular second premolar. **B,** An abutment for cement retention is inserted and prepared for the final crown. **C,** A final impression is made of the abutment and surrounding teeth. **D,** A transitional prosthesis is fabricated. **E,** The final crown is cemented in place.

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FIGURE 2-21. The direct prosthetic option is advantageous when implants are splinted together for the final restoration.

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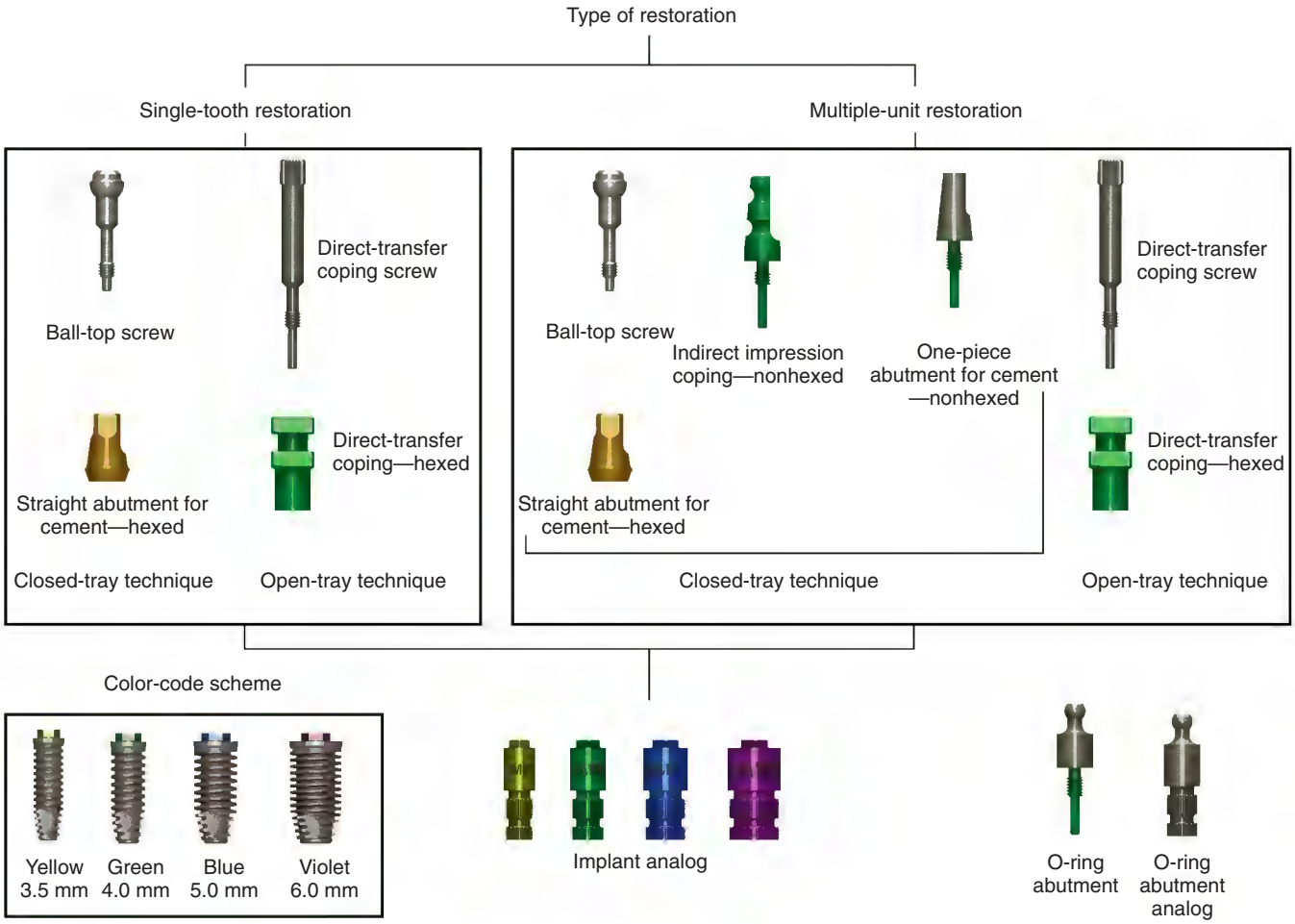


FIGURE 2-22. An indirect transfer *(far left and center)* is inserted into an implant body or abutment for screw retention, and a closed-tray impression is made. The impression is removed, and the transfers are connected to an analog and reinserted into the impression. A direct-impression transfer *(far right)* uses an open tray to make the impression. The direct-transfer coping screw must be unthreaded before the impression is removed from the mouth. (Courtesy BioHorizons, Birmingham, AL.)

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from the impression, and often has flat sides or smooth undercuts to facilitate reorientation in the impression after it is removed (Figures 2-23 to 2-25).

A *direct-transfer coping* usually consists of two pieces, which includes a hollow transfer component (often square) and a long central screw to secure it to the *abutment* or *implant body*. An "open-tray" impression tray is used to permit direct access to the long central screw securing the direct-transfer coping. After the impression material is set, the *direct-transfer coping screw* is unthreaded to allow removal of the impression from the mouth. The square coping remains in the impression; hence, the transfer is "direct." *Direct-transfer copings* take advantage of impression materials having rigid properties and eliminate the error of permanent deformation of impression materials because the transfer coping remains within the impression until the master model is poured and separated (Figure 2-26). They are also less likely to be rotated or moved during the model fabrication compared with the indirect techniques (Box 2-1).



FIGURE 2-23. An indirect impression transfer *(left)* usually has undercuts in the design to help secure it in position when it is reinserted into the impression with the analog. It may be inserted into an abutment for screw *(pictured)* or into the implant body. A closed-tray impression is made of this transfer coping *(right)*.

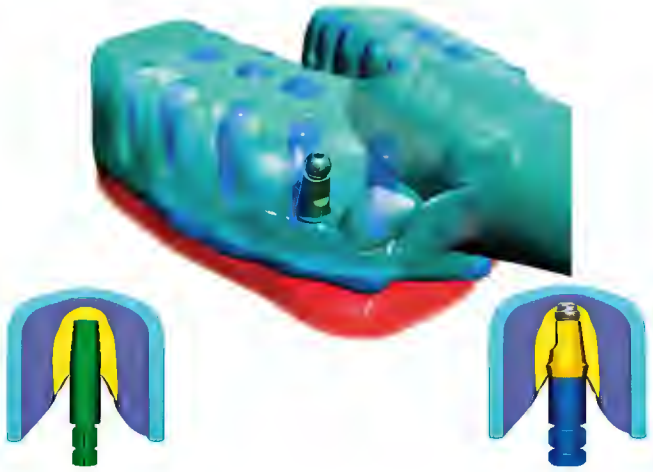


FIGURE 2-24. A closed-tray impression *(top)* may be with the final abutment and a long ball-top fixation screw for the indirect prosthetic option. This allows the transfer of the antirotational hex component of the implant crest module *(right)*. After being removed from the mouth, the transfer coping is removed, attached to an analog, and reinserted into the impression before it is poured in stone. A one-piece indirect transfer does not engage the antirotational feature of the crest module and does not transfer the component to the implant analog *(left)*.

Laboratory Fabrication

An *analog* is defined as something that is analogous or similar to something else.[35] An *implant analog* is used in the fabrication of the master cast to replicate the retentive portion of the implant body or abutment (*implant body analog, implant abutment analog*). After the master impression is obtained, the corresponding analog (e.g., *implant body, abutment for screw*) is attached to the *transfer coping,* and the assembly is poured in stone to fabricate the master cast (see Figures 2-25, *D*, to 2-25, *I*).

A prosthetic coping is a thin covering[35] usually designed to fit the implant abutment for screw retention. It serves as the connection between the abutment and the prosthesis or superstructure. A prefabricated coping usually is a metal component machined precisely to fit the abutment. A castable coping usually is a plastic pattern cast in the same metal as the superstructure or prosthesis. A screw-retained prosthesis or superstructure is secured to the implant body or abutment with *a prosthetic screw* (Figure 2-27).

Summary

Generic terminology has been developed to facilitate communication among implant team members. Regardless of the implant system used, the generic term is descriptive of the function of the component rather than its proprietary name. The surgery phase of treatment most often uses an *implant body* with a *first-stage cover screw*. The second-stage surgery removes the *first-stage cover screw* and inserts a *permucosal extension*. The restoring dentist removes the *permucosal extension* and places the *abutment* or makes an implant body impression.

The implant body impression may use a *direct* or *indirect* technique. The laboratory uses *analogs* to fabricate the prosthesis. The prosthesis is most often cement retained in partially edentulous patients and uses an *abutment for cement* retention. Regardless of the implant system selected, the staff and laboratory should be familiar with generic, descriptive terminology.

BOX 2-1

Indirect Transfer
- Removed from implant body and then reinserted into the impression (indirect transfer)
- Often has flat sides and undercut areas to allow reorientation in the impression after it is removed from the mouth

Direct Transfer
- Consists of two pieces
  - Hollow transfer component
  - Long central screw
- Less likely to be misplaced or moved during model fabrication
- Square coping remains in the impression (direct transfer)

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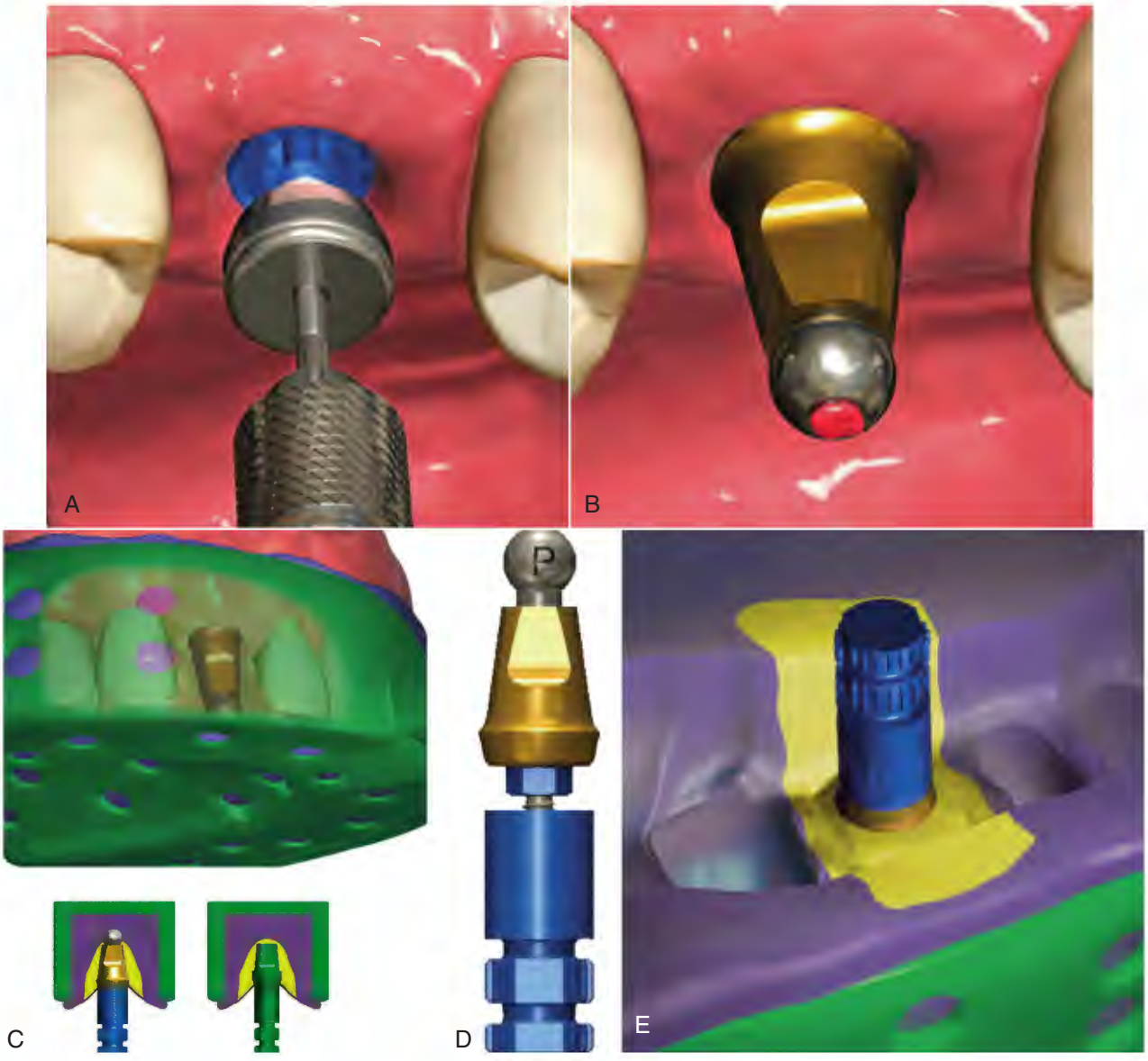


FIGURE 2-25. **A,** After soft tissue healing, the permucosal extension is removed from the implant body. **B,** An "indirect" impression transfer coping is inserted into the implant body. **C,** A "closed-tray" impression is made of the indirect impression transfer coping. **D,** The indirect impression transfer coping is removed from the mouth and attached to the implant body analog. (Two-piece transfer and ball-top screw allow the hex of the implant crest module to be transferred to the analog.) **E,** The implant body analog and indirect impression transfer is reinserted into the impression.

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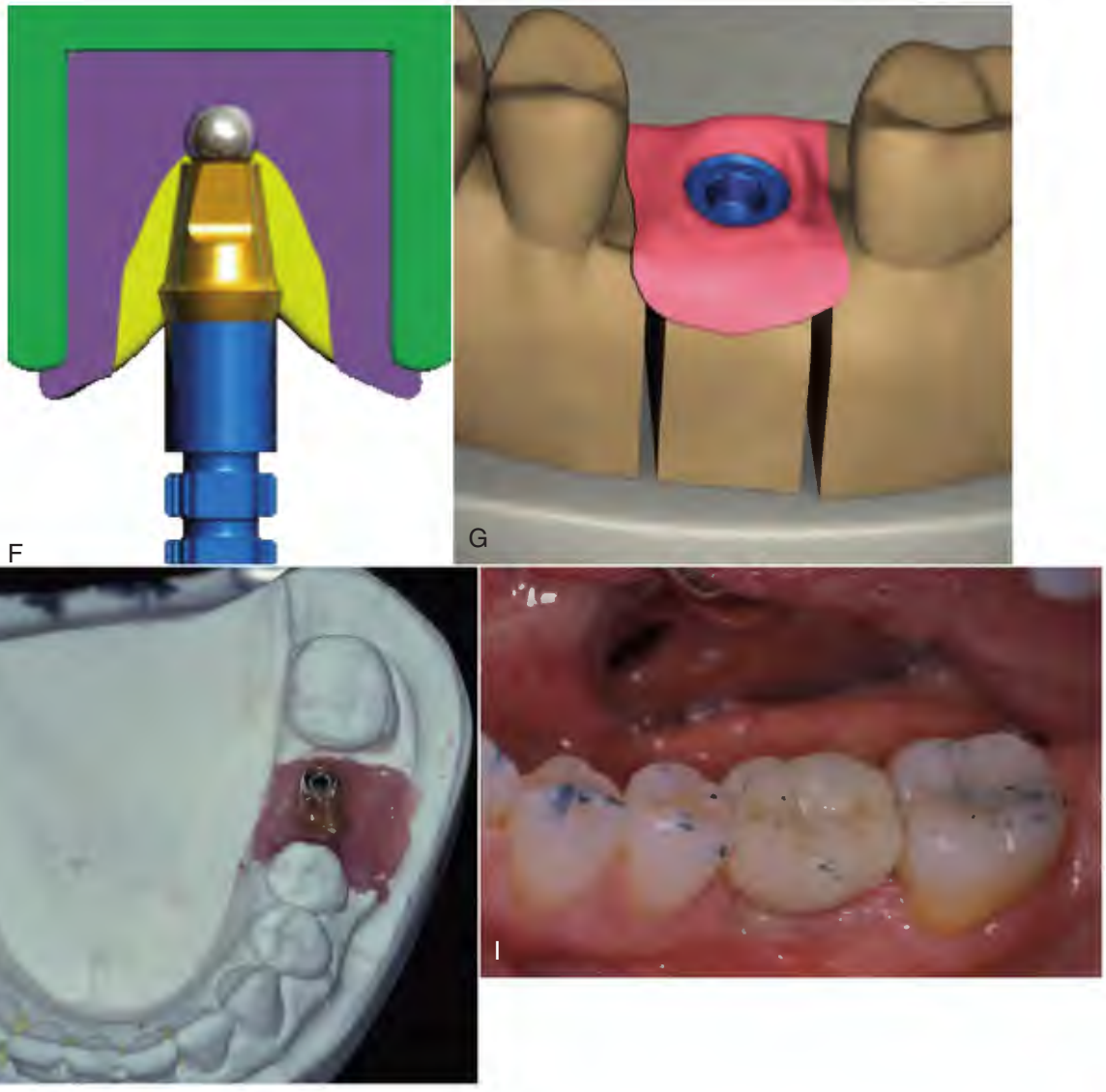


FIGURE 2-25, cont'd. **F,** The indirect impression transfer is reinserted into the impression. **G,** A working model is made with dental stone. A soft tissue replica may be used around the implant body. **H,** A patient model with implant abutment inserted into the implant analog replacing the first molar. **I,** The prosthesis is made and inserted into the mouth.

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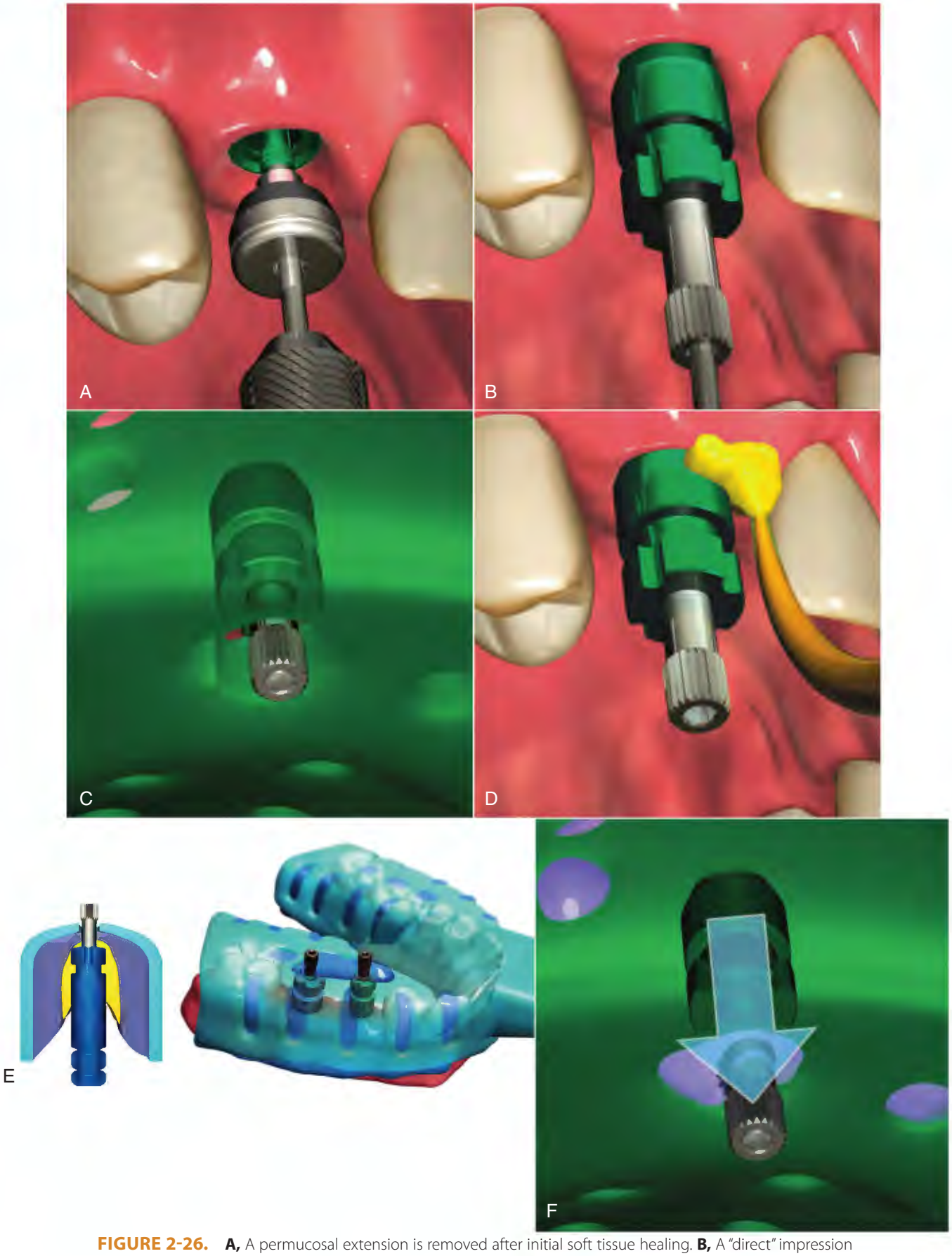


FIGURE 2-26. **A,** A permucosal extension is removed after initial soft tissue healing. **B,** A "direct" impression transfer coping is inserted into the implant body. **C,** An "open" impression tray with an opening over the impression transfer is positioned over the implant to verify its position. **D,** An impression is made of the impression transfer coping and **(E)** allowed to set. **F,** After the impression sets, the screw is unthreaded and removed from the transfer coping.

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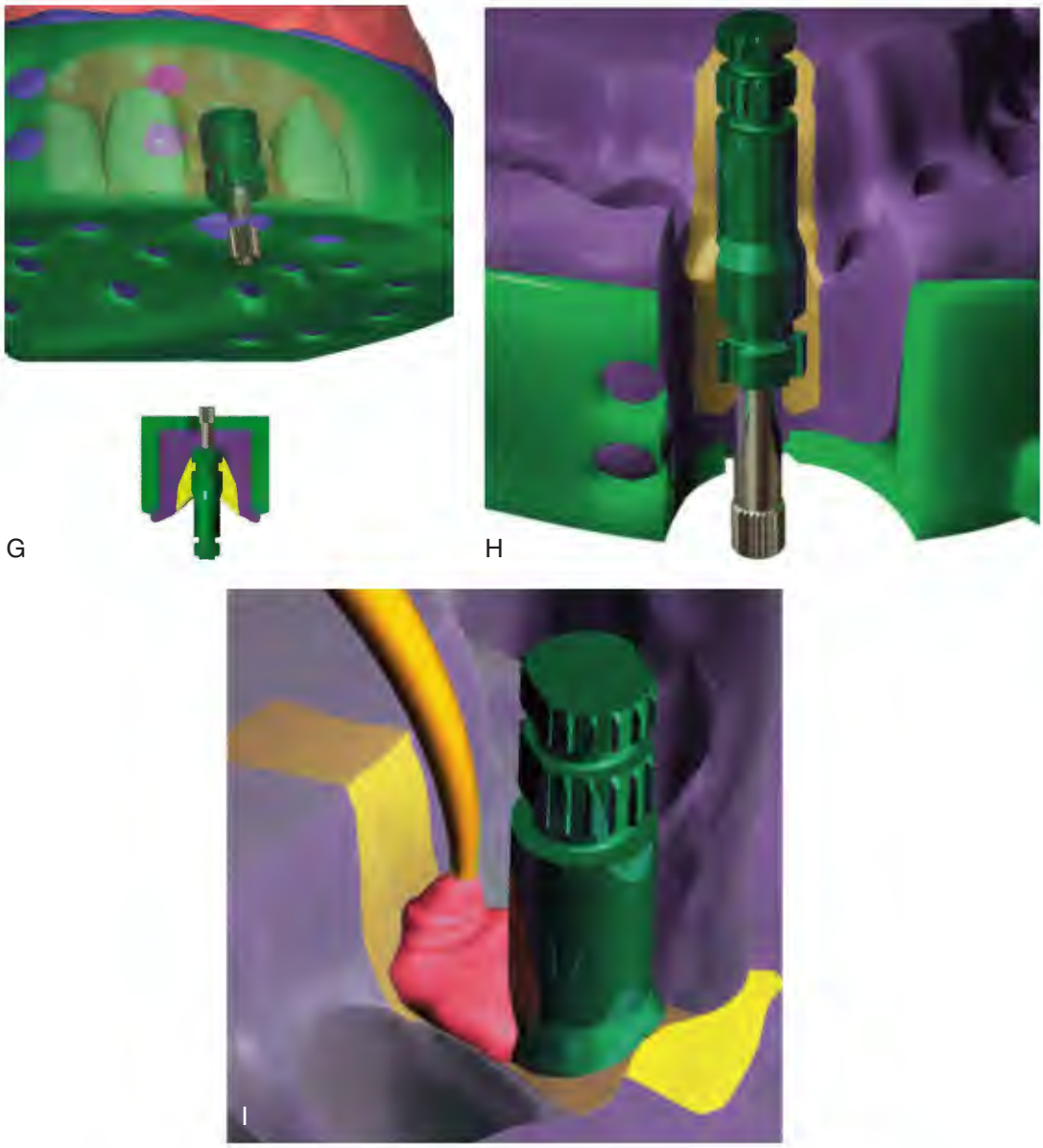


FIGURE 2-26, cont'd. **G,** An implant analog is attached to the transfer coping while it remains in the impression. **H,** The implant body analog is a direct transfer because the transfer coping is never removed from the impression. **I,** A soft tissue replica material is often used around the implant transfer before the stone model is poured.

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FIGURE 2-27. **A,** A patient demonstration model with a 5-mm implant body in the first molar position and a 4-mm implant in the canine posterior. **B,** An indirect-impression transfer coping is inserted into the first molar (two piece with ball-top screw), and a direct-impression transfer is inserted into the canine implant. **C,** An impression tray is modified for a direct (open-tray) impression in the canine implant and an indirect (closed-tray) impression for the molar implant. **D,** Impression is made and allowed to set. The direct-transfer coping screw is removed from the canine impression transfer. **E,** The patient model demonstrates the indirect-impression transfer remains in the model, while the direct-impression transfer resides in the impression. **F,** An indirect-transfer coping is removed from the patient and attached to an implant body analog.

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FIGURE 2-27, cont'd. **G,** The indirect-transfer coping and attached implant body analog is reinserted into the impression in the region of the molar implant. **H,** The impression with the molar indirect-transfer coping and implant body analog and canine direct-impression transfer and implant body analog in position. **I,** The working cast after it is removed from the impression. The indirect transfer in the molar position remains in the cast. **J,** A working cast with a soft tissue replica and stone model, with implant body analogs in position. **K,** The abutments are inserted into the implant body analogs and prepared for the final prosthesis. **L,** The final restorations are fabricated. The molar is a screw-retained crown, and the canine is cement retained.

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CHAPTER 3

An Implant Is Not a Tooth: A Comparison of Periodontal Indices

Carl E. Misch

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Dental implants are primarily used to replace teeth in a partial or complete edentulous patient or to retain removable prostheses. Therefore, the typical purpose of a dental implant is to act as an abutment for a prosthetic device, similar to a natural tooth root and crown. The restoring dentist usually designs and fabricates a prosthesis similar to one supported by teeth and, as such, also similarly evaluates and treats the dental implant as a natural tooth. Yet fundamental differences in the surrounding tissues and conditions between these devices are important to be recognized. For example, implants are different than natural teeth in that they do not decay, have no dental pulps to function as early indicators of disease or to cause lesions of endodontic origin, and have no periodontal membrane. The purpose of this chapter is to compare the periodontal indices for a natural tooth and an osteointegrated dental implant.

Literature Review

Several dental health criteria have been adapted for dental implants.[1–12] A majority of reports that include clinical criteria to evaluate an implant include mobility; radiographic assessment of bone loss; and on occasion, gingival and plaque indices. Subjective criteria of discomfort and patient satisfaction also are mentioned.

The clinical criterion most commonly reported is the survival rate, or whether the implant is still physically in the mouth or has been removed.[2] Proponents of this method say it provides the clearest presentation of the data; critics argue implants that should be removed because of pain, disease, or the inability to be restored still may be maintained yet wrongfully reported as successful. It should be noted that reports of traditional prostheses' success supported by natural teeth follow a similar criterion: whether the restoration is still in the mouth. Therefore, survival rates rather than success rates are the most common method to report the "success" of dental implants or dental implant prostheses.

The American Dental Association Council on Dental Materials, Instruments, and Equipment states that consideration for an endosteal implant should be given to the evaluation of (1) durability; (2) bone loss; (3) gingival health; (4) pocket depth; (5) effect on adjacent teeth; (6) function; (7) esthetics; (8) presence of infection, discomfort, paresthesia, or anesthesia; (9) intrusion on the mandibular canal; and (10) the patient's emotional and psychological attitude and satisfaction.[3,4] One may reasonably state that factors controlled primarily by the dentist and the psychological attitude of the patient are not conditions influenced by the implant. As a result, these items should be considered separately and should not be computed in the evaluation of implant success.

Smith and Zarb suggested that patient comfort, sulcus depth, gingival status, damage to adjacent teeth, and violation of the maxillary sinus, mandibular canal, or floor of the nasal cavity are not attributable to the material or design of an implant.[5] However, the sulcus depth and gingival status next to the implant indeed may be related to implant design or surface condition. For example, a smooth, polished collar placed below the bone contributes to crestal bone loss, which affects sulcus depth. The implant surface condition may allow bacteria to readily form on the surface of the implant body after crestal bone loss and may affect the gingival status of the implant. Hence, sulcus depth and gingival status are important indices for the evaluation of dental implants. Patient comfort, damage to adjacent teeth, and violation of anatomical structures are important to note but are not related to the design or material of an implant.

Periodontal indices are often used for evaluation of dental implants. A comparison of natural teeth and implants for each criterion provides insight into their differences in the health–disease continuum. After one understands the basis for evaluation, these criteria may then be used to establish a health–disease implant quality scale related to patient treatment.

This chapter addresses the more common periodontal indices for natural teeth and compares the following periodontal indices for dental implants: (1) longevity, (2) mobility versus rigid fixation, (3) percussion, (4) pain, (5) probing depths, (6) bleeding index, (7) crestal bone loss, (8) radiographic evaluation, (9) keratinized tissue, and (10) periimplant disease.

Longevity

Success criteria for endosteal implants have been proposed previously by several authors, including Schnitman and Shulman,[6] Cranin et al.,[7] McKinney et al.,[8] Albrektsson et al.,[9,11] and Albrektsson and Zarb.[10] The success criteria by Albrektsson et al. was specific for implants with rigid fixation and is widely used today[9] (Box 3-1). However, the Albrektsson et al. success criteria should be used primarily for implant studies or reports, not for individual implants. Assessing less than 0.2 mm vertical annual bone loss is difficult for each individual implant, and if 0.3 mm occurs in 1 year, it does not qualify as implant failure, in and of itself. In addition, the amount of crestal bone lost during the first year is not noted in this success criteria and may affect the sulcus depth and environment for the longevity of the implant.

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Minimum survival rates for a success criteria suggested in the Albrektsson et al.[9] guideline are low compared with present-day reports and do not consider the prosthesis survival related to implant longevity. This report states the minimum implant success rate is 85% for 5 years and 80% for 10 years. However, the proposed criteria do not evaluate the prosthesis. The consideration of a minimum implant survival rate should be in the context of the final prosthesis survival. For example, many early reports indicated that a fixed prosthesis in a completely edentulous arch may be supported by four implants. In a study of 25 patients with 25 prostheses supported by only four implants, there would be 100 implants. A 75% implant success rate could result in 0% prosthesis success if each patient lost only one implant. An 85% implant 5-year survival rate with this treatment plan still would cause almost half the implant restorations to fail. Of course, this survival rate is not acceptable. Implant survival by itself is not an acceptable criterion to evaluate an implant system, and studies should also include the implant restoration.

BOX 3-1 Criteria for Implant Success

- An individual unattached implant is immobile when tested clinically.
- The radiograph does not demonstrate any evidence of periimplant radiolucency.
- Vertical bone loss is less than 0.2 mm annually after the first year of service of the implant.
- Individual implant performance is characterized by an absence of persistent or irreversible signs and symptoms such as pain, infections, neuropathies, paresthesia, or violation of the mandibular canal.
- In the context of the foregoing, success rates of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are minimum criteria for success.

Data from Albrektsson T, Zarb GA, Worthington P, et al: The long-term efficacy of currently used dental implants: a review and proposed criteria of success, *Int J Oral Maxillofac Implants* 1:1, 1986.

Implant "success" is not as relevant for clinical implant evaluation as the quality of health. "Success" is not used for the evaluation of a tooth. Instead, a quality of health is more relevant for the clinical criteria. The clinical criteria for optimum to satisfactory health for implants established by Misch and accepted by the International Congress of Oral Implantologists Pisa Consensus Conference evaluates both implant and prosthesis survival and suggests a minimum of 90% prosthesis survival for 10 years[1,13] (Table 3-1). Of course, these rates require even greater implant survival, and overengineering the support system often is required to obtain this goal. For example, if eight rather than four implants support a full arch fixed prosthesis, possibly one or two implants may be lost, and the same prosthesis still may be used without additional implants and only slight modification of the restoration. For example, if 25 patients were each restored with eight implants to support a full-arch restoration and if each patient lost one implant, the survival rate of the prosthesis still may be 100% and the implant survival rate 87%.

Computed data of dental implant survival or success should include all implants inserted, not just the implants restored or those successfully loaded after 1 year. An implant placed and

TABLE 3-1
Implant Quality

Scale Group	Management	Clinical Conditions
I. Success (optimum health)	Normal maintenance	No pain or tenderness upon function 0 mobility <2 mm radiographic bone loss from initial surgery Probing depth <5 mm No exudate history
II. Survival (satisfactory health)	Reduction of stresses Shorter intervals between hygiene appointments Gingivoplasty Yearly radiographs	No pain 0 mobility 2–4 mm radiographic bone loss Probing depth 5–7 mm No exudate history
III. Survival (compromised health)	Reduction of stresses Drug therapy (antibiotics, chlorhexidine) Surgical reentry and revision Change in prosthesis or implants	No pain upon function 0 mobility Radiographic bone loss >4 mm Probing depth >7 mm May have exudate history
IV. Failure (clinical or absolute failure)	Removal of implant	Pain upon function Mobility Radiographic bone loss > ½ length of implant Uncontrolled exudate No longer in mouth

Suggested Criteria for Implant Success[1]
- Implant quality scale* of 1, 2, or 3 with a survival rate better than 90% at 10 years.
- Prosthesis survival rate better than 90% at 10 years.
- Implants are supporting a prosthesis.

From International Congress of Oral Implantologists, Consensus Conference, Pisa, Italy, 2008.

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left submerged should most often be included in initial or surgical implant failure.

The time of implant failure is also relevant. For the patient and doctors involved in treatment, a 10% implant failure rate before fabrication of the prosthesis is far better than to have 5% implant failure rate after delivery of the restoration.[14] The most common time for an implant failure is within the first 18 months after loading. Hence, most often the final restoration has been delivered and in function.

Mobility

Natural Tooth versus Implant Support Systems

Compared with an implant, the support system of a natural tooth is better designed to reduce the biomechanical forces distributed to the tooth/restoration and the crestal bone region. The periodontal membrane, biomechanical design of the tooth root and material, nerve and blood vessel complex, occlusal material (enamel) and surrounding type of bone blend to decrease the risk of occlusal overload to the natural tooth system.[15]

Tooth Movement

The tooth exhibits normal physiologic movements in vertical, horizontal, and rotational directions. The amount of movement of a natural tooth is related to its surface area and root design. Therefore, the number and length of the roots; their diameter, shape, and position; and the health of the periodontal ligament (PDL) primarily influence a tooth's mobility. A healthy tooth exhibits zero clinical mobility in a vertical direction. Actual initial vertical tooth movement is about 28 microns and is the same for anterior and posterior teeth.[16] The vertical movement of a rigid implant has been measured as 2 to 3 microns under a 10-lb force and is due mostly to the viscoelastic properties of the underlying bone.[17]

Muhlemann found that horizontal tooth movement may be divided into initial mobility and secondary movement.[18] The initial mobility is observed with a light force, occurs immediately, and is a consequence of the PDL. Initial horizontal tooth mobility is greater than initial vertical movement. A very light force (500 g) horizontally moves the tooth. The initial horizontal mobility of a healthy, "nonmobile" posterior tooth is less than that of an anterior tooth and ranges from 56 to 75 microns, which is two to nine times the vertical movement of the tooth. Initial horizontal mobility is even greater in anterior teeth and ranges from 70 to 108 microns in health[16,19] (Figure 3-1).

The secondary tooth movement described by Muhlemann occurs after the initial movement when greater forces are applied. When an additional force is applied to the tooth, a secondary movement is also observed, which is related directly to the amount of force. The secondary tooth movement is related to the viscoelasticity of the bone and measures as much as 40 microns under considerably greater force[18](Figure 3-2).

Implant Movement

Rigid fixation indicates the absence of clinical mobility of an implant tested with vertical or horizontal forces less than 500 g. *Rigid fixation* is a clinical term. *Osseointegration* is a histologic term defined as bone in direct contact with an implant surface at the magnification of a light microscope[20] (Figure 3-3). Over the years, these two terms have been used interchangeably, and implant abutment support is most predictable with rigid

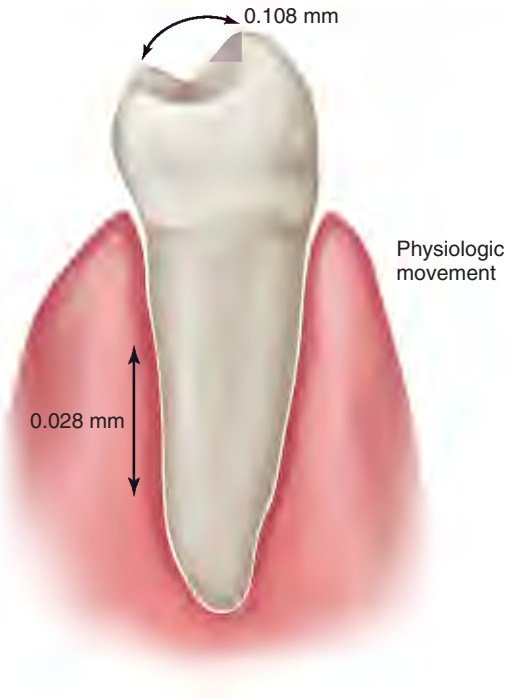


FIGURE 3-1. The physiologic movement of a healing tooth has been measured as 28 microns in the apical direction and up to 108 microns in the horizontal direction.

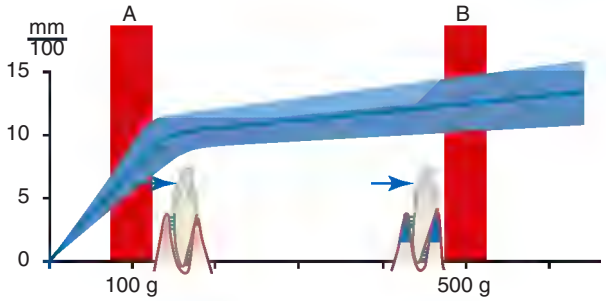


FIGURE 3-2. A secondary horizontal movement of a tooth occurs after the initial tooth movement when a greater force is applied and is related to the deformation of the alveolar bone.

fixation. Lack of implant mobility (IM) does not always coincide with a direct bone–implant interface.[8] However, when observed clinically, rigid fixation usually means that at least a portion of the implant is in direct contact with bone, although the percentage of bone contact cannot be specified.[21] A mobile implant indicates the presence of connective tissue between the implant and bone.

Lack of clinically observable movement does not mean the true absence of any movement. For example, a "nonmobile" posterior natural tooth actually moves horizontally 56 to 73 microns. The human eye does not perceive this movement. The anterior teeth, which often have slight clinically observable movement, actually move approximately 0.1 mm. A healthy implant moves less than 73 microns; thus, it appears as zero clinical mobility (rigid fixation).

Just as a natural tooth, the implant–bone interface exhibits more lateral than apical movement. Sekine et al. evaluated the movement of endosteal implants with rigid fixation and found a range of 12 to 66 microns of movement in the labiolingual

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FIGURE 3-3. *Osseointegration* is a histologic term that describes a direct bone-to-implant contact at the level of magnification of a light microscope.

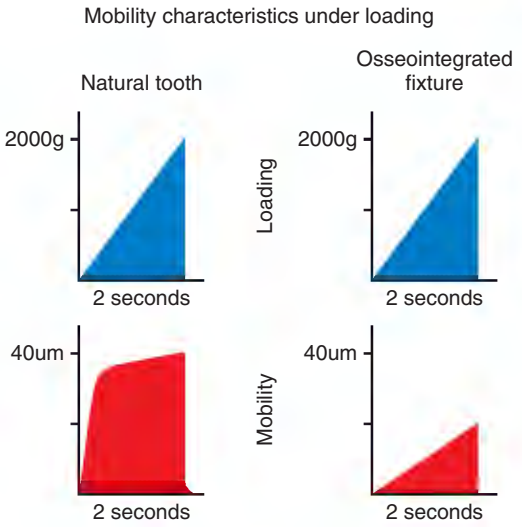


FIGURE 3-4. A gradually increasing load over a 2-second period was applied to a tooth *(left)* and an implant *(right)*. The secondary tooth movement was similar to the implant movement.



FIGURE 3-5. The intraoral technique to evaluate implant mobility is similar as for a natural tooth.

direction.[17] Komiyama reported 40 to 115 microns of implant movement in the mesiodistal direction under a force of 2000 g (≈4.5 psi) and a labiolingual range of 11 to 66 microns.[22] The greater implant movement in the mesiodistal dimension corresponds to the lack of cortical bone between the implants in this direction compared with the thicker lateral cortical plates present in the labiolingual dimension. Rangert et al. suggested that part of this implant movement may also be due to component flexure of the implant abutment and screw.[23] The mobility of implants varies in direct proportion to the load applied and the bone density and reflects the elastic deformation of bone tissue.

Sekine et al. applied a gradually increasing load over a 2-second period to a tooth and an implant. The teeth moved immediately with a light load (primary tooth movement) and less with an additional load (secondary tooth movement). The implant did not move when the tooth had its primary tooth movement. A heavier force caused the implant to gradually move, similar to the secondary tooth movement[17] (Figure 3-4). These mobility characteristics corroborate the findings of Fenton et al., who applied a 500-g load for 4 seconds to maxillary anterior teeth and osseointegrated implants.[24] Whereas the implants were displaced a mean of 10 microns with a rapid elastic return (less than 1 millisecond), the teeth showed a mean displacement of 57 microns with a prolonged viscoelastic return.

Increased tooth mobility may be caused by occlusal trauma or bone loss. Increased tooth mobility alone is not a criterion of periodontal health or pathology. Unlike a tooth, for which mobility is not a primary factor for longevity, mobility is a primary determining factor for implant health.[20] Rigid fixation is also an excellent indicator of the implant health status because it is an easy, objective test. As such, rigid fixation is usually the first clinical criterion evaluated for a dental implant. The techniques to assess rigid fixation are similar to those used for natural tooth mobility. Two rigid instruments apply a labiolingual force of approximately 500 g, and no observed mobility indicates rigid fixation[25] (Figure 3-5).

The amplitude of tooth mobility may be rated from 0 to 4, where 0 is normal mobility from physiologic movement; 1 is detectable increased mobility; 2 is visible mobility up to 0.5 mm; 3 is severe mobility up to 1 mm; and 4 is extreme mobility, including vertical movement.[25] This same gradient may be used for oral implants with slight modification. As Box 3-2 depicts, IM-0 corresponds to the absence of clinical

BOX 3-2 Clinical Implant Mobility Scale[1]

Scale	Description
0	Absence of clinical mobility with 500 g in any direction
1	Slight detectable horizontal movement
2	Moderate visible horizontal mobility up to 0.5 mm
3	Severe horizontal movement greater than 0.5 mm
4	Visible moderate to severe horizontal and any visible vertical movement

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FIGURE 3-6. An implant with any clinical vertical mobility should be removed to avoid future bone loss and complications.



FIGURE 3-7. The Periotest (Gulden-Medizinteknik, Bensheim an der Bergstrasse, Germany) may be used to evaluate implant rigid fixation or prostheses that become partially unretained. A clinical evaluation of zero mobility may correspond to a –8 to +9 Periotest value. These numbers may indicate changes in bone density around the implant or failure of a retention mechanism for the prosthesis.

mobility, IM-1 demonstrates detectable increased movement, IM-2 is visible mobility movement up to 0.5 mm, IM-3 is severe horizontal mobility greater than 0.5 mm, and IM-4 is visible horizontal and vertical movement. The IM scale was used frequently for plate (blade) form implants or disc implants because a clinical goal was for slight mobility when joining the device to natural teeth. However, the goal for root form implants always should be rigid fixation and IM-0 status.

A natural tooth with primary occlusal trauma exhibits an increase in clinical mobility and radiographic PDL space. After the cause of trauma is eliminated, the tooth may return to zero clinical mobility and a normal radiographic appearance. This scenario is not predictable around an implant. The dentist should not restore an implant with any clinical mobility, because the risk of failure is great. However, after the prosthesis is completed and IM-1 develops, the risk is small to evaluate the implant for a few months and decrease almost all stress during this time frame. Implants with slight detectable mobility of approximately 0.1 mm of horizontal movement (IM-1), similar to the mobility of a healthy central incisor, on occasion may return to rigid fixation and zero mobility. However, to reachieve rigid fixation, the implant should be taken completely out of occlusion for several months. Chances improve to return rigid fixation to an implant if no mobility is noted before the implant is placed into function.

An implant with horizontal movement greater than 0.5 mm (IM-3) is at much greater risk than a tooth. A root form implant with greater than 0.5 mm horizontal mobility (IM-3) or any vertical mobility (IM-4) should be removed to avoid continued bone loss and future compromise of the implant site (Figure 3-6).

On occasion, an implant that was rigid may spin in the bone at stage II uncovery, when the implant abutment is threaded into position.[26] The weak bone–implant interface is broken when the shear forces of adding an abutment and screw are placed on the implant body. If this occurs, the implant cover screw should be reinserted and the implant allowed to "reintegrate" with the bone. The chances are greater than 75% that 3 additional months of healing will allow the implant to reestablish a bone–implant interface if it was present before the abutment was added.[27] At the reinsertion of the abutment, a lesser torque is used initially, and a counter torque technique is used (so the rotational force on the abutment screw is not converted to the bone–implant interface, so the interface does not strip again). After an additional time of progressive loading, the abutment screw may be tightened as usual, although a counter torque method on the abutment is still suggested.

The Periotest (Gulden-Medizinteknik, Bensheim an der Bergstrasse, Germany) is a computer-mechanical device, developed by Schulte, that measures the dampening effect or attenuation degree against objects by developing a force of 12 to 18 N against a pistonlike device, which then measures the distance the piston recoils into the chamber after striking an object.[28] A soft surface or mobile object gives higher recordings than a hard or rigid object. The recordings range from negative 8 to positive 50 numbers.

Teeth with zero clinical mobility have typical Periotest ranges from 5 to 9. The degree or absence of clinical movement around an implant corresponds to values ranging from –8 to +9, or a range of 17 units (Figure 3-7). The bone density around the implant may be correlated with Periotest numbers. Whereas softer bone types give higher numbers, harder bone around the implant results in lower numbers. A nondestructive resonance frequency analysis technique to measure implant stability and osteointegration has also been introduced to the profession and provides similar valuable information as to the clinical movement and bone density around implants.[29,30] These devices greatly aid the dentist's tactile senses.

The Periotest device has also been used as a clinical tool to evaluate slight changes in implant rigid fixation or to identify prostheses that become partially unretained.[31–33] Because the restoration does not need to be removed to evaluate the implant, this device may more easily be used to evaluate an implant long term.

Percussion

Percussion often is used on teeth to determine which tooth is sensitive to function or is beginning to abscess. In the past, percussion was used to evaluate the presence of rigid fixation for osteointegrated implants.[20] However, percussion is an

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indicator neither of clinical health nor of rigid fixation for osteointegrated implants. The ringing sound that occurs on percussion only corresponds to the presence of some bone at the interface, because 2 mm of bone and 16 mm of bone–implant interface sound almost identical. Percussion may be used to diagnose pain or tenderness with an implant but is misleading if used to determine the status of rigid fixation.

Pain

Subjective findings of pain, tenderness, and sensitivity are common dental conditions that the dentist treats as part of a general practice. Pain and tenderness are subjective criteria and depend on the patient's interpretation of the degree of discomfort. *Pain* is defined as an unpleasant sensation ranging from mild discomfort to excruciating agony. Tenderness is more an unpleasant awareness of the region. A natural tooth often becomes hyperemic and sensitive to cold as the first indicator of a problem. A tooth with a more serious condition becomes sensitive to heat and painful to percussion, indicating pulpitis. Dental emergencies usually are associated with pain, and the dentist is adept at its diagnosis and treatment planning.

An implant rarely is troubled by the subjective criteria of pain or sensitivity after initial healing. The implant does not become hyperemic and is not temperature sensitive, and the early warning signs and symptoms of a traumatic occlusal problem may not be present. This criterion is less contributory to implant health determination.

After the implant has achieved primary healing, absence of pain under vertical or horizontal forces is a primary subjective criterion. Usually (but not always), pain does not occur unless the implant is mobile and surrounded by inflamed tissue or has rigid fixation but impinges on a nerve. The most common condition that causes discomfort from an implant is when a loose implant abutment is entrapping some of the soft tissue in the abutment–implant connection. After the soft tissue in the region is eliminated and the abutment is secured, the discomfort subsides. When the abutment–implant connection is secure and pain is present, consideration is given to an implant body fracture.

On rare occasions, an implant may cause discomfort during function, although a clinical examination is unable to identify a cause. The persistent presence of pain during percussion or function on properly inserted implants and components often requires removal of the implant even in the absence of mobility. Because pain is a subjective criterion, the dentist asks the patient to relate the pain from the implant site on a scale of 1 to 10, with 1 being a slight aggravation and 10 being the most intense pain the patient can perceive. When the patient reports a pain level greater than 5, the dentist should strongly consider removal of the implant.

Whereas pain from rigidly fixated implants is rare and is observed as an early problem, pain from a mobile implant may occur early or late in treatment. In either case, the condition rarely improves. Pain on loading of rigid implants has been observed more often on immediately loaded implants compared with those healing unloaded for an extended period.

Implant sensitivity or mild tenderness rather than pain in a rigid implant is also most unusual and signals a more significant complication for an implant than for a tooth. Tenderness during function or percussion usually implies healing in the proximity of a nerve or, on rare occasions, bone stress beyond physiologic limits.

If the implant tenderness immediately after surgery and loading (immediate loading) occurs when the implant is in the proximity of the mandibular canal, the implant may be unthreaded 1 mm and reevaluated for a decrease in symptoms after 3 or more weeks. If the tenderness of a rigid fixated implant is after stage I healing and is not due to surgical encroachment on an anatomical landmark, attention is first brought to the soft tissue and prosthetic components. If this is not the cause, treatment then consists of the elimination of as much stress on the implant or prosthesis as is possible for 3 or more weeks. The dentist especially should address occlusion and parafunctional habits in the presence of implant sensitivity. Most often the prosthesis should be modified to reduce a cantilever of occlusal contacts. On occasion, additional implants may be placed and the restoration remade to dissipate the forces. The tenderness may be decreased with these procedures but rarely is eliminated. Instead, the dentist notifies the patient of the poor prognosis and asks whether the tenderness is significant enough to warrant the removal of the implant. It should be emphasized this condition is rare and has been observed only a few times by the author in more than 30 years.

On occasion, an implant body may fracture from fatigue. Fatigue is related to the amount of force, the number of cycles, the strength of the material, the diameter of the component, and the number of implants splinted together. This condition is similar to a fractured root. In any case, radiographic evidence of the fracture may be difficult to ascertain. Percussion and forces up to 500 g (1.2 psi) with a bite stick are used clinically to evaluate a tooth or implant for pain or discomfort. Percussion and heavy biting on a wood stick associated with pain are clinical indices. In these cases, the implant is most often removed.

Probing Depths

Probing depths around teeth are an excellent proven means to assess the past and present health of natural teeth. The increasing sulcus depth around natural teeth is related to disease and bone loss.[25] However, probing depth indices used to evaluate dental implants are more controversial because relating implant sulcus depth to health is not always directly related.

For a natural tooth, the surrounding soft tissue has an average biological width of 2.04 mm between the depth of the sulcus and the crest of the alveolar bone.[34] It should be noted the biological "width" is actually a height dimension with a greater range in the posterior region compared with the anterior and may be greater than 4 mm in height.[35] In teeth, it is composed of a connective tissue attachment (1.07 mm average) above the bone and a junctional epithelial attachment (JEA) (0.97 mm average) at the sulcus base, with the most consistent value among individuals being the connective tissue attachment (Figure 3-8).

The sulcular regions around an implant and around a tooth are similar in many respects. The rete peg formation within the attached gingiva and the histologic lining of the gingiva within the sulcus are similar in implants and teeth.[36] A free gingival margin forms around a tooth or implant with nonkeratinized sulcular epithelium, and the epithelial cells at its base are also similar to teeth and implants, with junctional epithelial cells for both (Figure 3-9). However, a fundamental difference characterizes the base of the gingival complex around teeth. Whereas a tooth has two primary regions that make up the biological width, an implant only has one.

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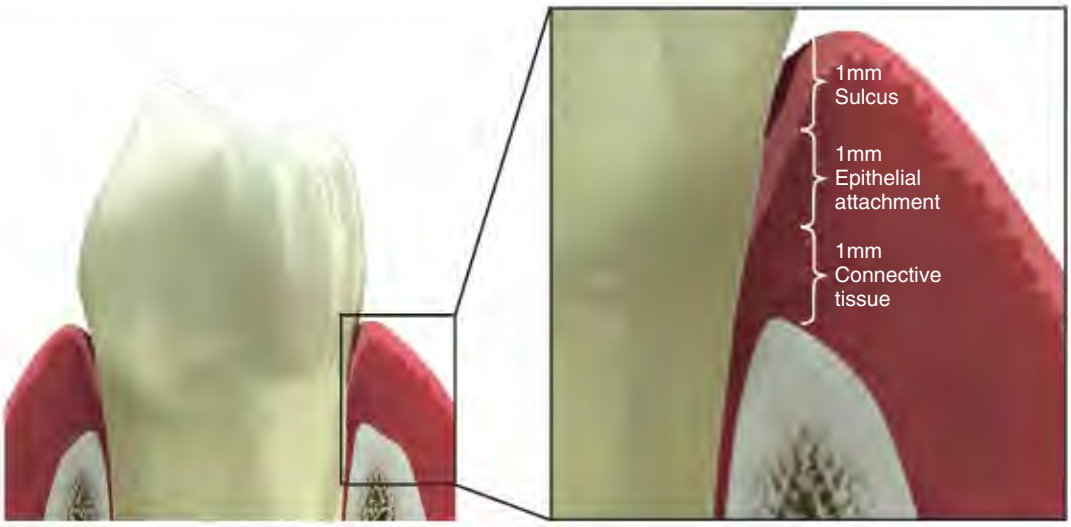


FIGURE 3-8. The biologic width for a natural tooth is approximately 1 mm of connective tissue above the bone and 1 mm of epithelial attachment between the sulcus and the connective tissue.

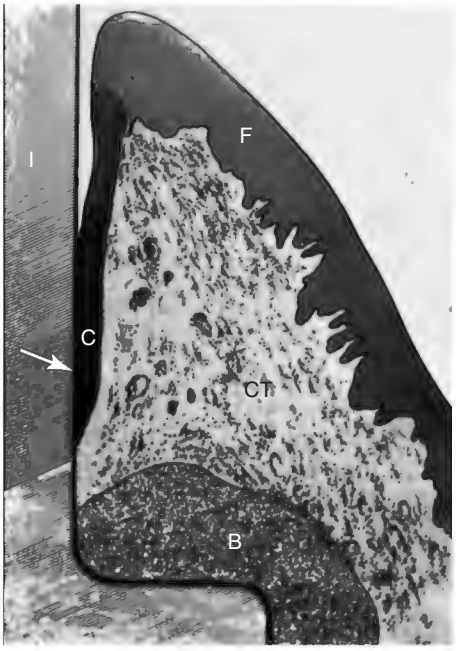


FIGURE 3-9. The soft tissue around an implant (I) has a sulcular region very similar to a tooth. A free gingival margin (F) with nonkeratinized sulcular epithelium and cells at the base (C) have junctional epithelial attachment above the bone (B). *CT,* Connective tissue.

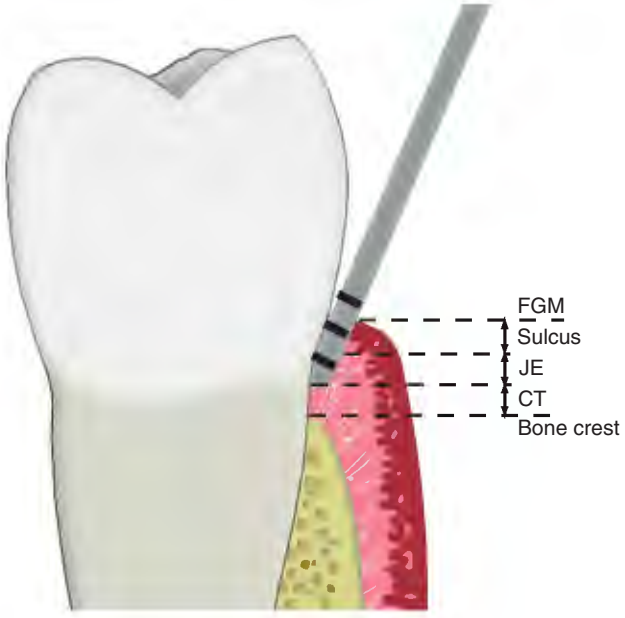


FIGURE 3-10. A probe placed into the sulcus of a tooth goes through the sulcus and the epithelial attachment. It is stopped by the connective tissue attachment. The biological width of a natural tooth has a connective tissue zone that inserts into the cementum of the tooth. A periodontal probe will penetrate the sulcus and the junctional epithelial (JE) attachment. *CT,* Connective tissue; *FGM,* free gingival margin.

When probing next to a tooth, the probe not only measures the sulcus depth but also penetrates and measures the JEA.[37] The junctional epithelial "attachment" of a tooth is not a true attachment. A periodontal probe easily separates the hemidesmosomal close approximation of the epithelial cells. High-volume air from a syringe may blow it off, plaque destroys it, and the placement of impression string in the sulcus displaces it. In other words, the mucopolysaccharide close approximation of the hemidesmosome found in the JEA is not an attachment (Figure 3-10).

The connective tissue attachment zone of the "biological width" around a tooth prevents the probe from penetrating deeper into the sulcus and allows gingival fibers of the connective tissue attachment zone to establish direct connection with the cementum of the natural tooth. It acts as a physical barrier to the bacteria in the sulcus to the underlining periodontal tissues. Eleven different gingival fiber groups comprise the connective tissue attachment zone observed around a natural tooth and tissue: dentogingival (coronal, horizontal, and apical), alveologingival, intercapillary, transgingival, circular, semicircular, dentoperiosteal, transseptal, periosteogingival, intercircular, and intergingival.[25] At least six of these gingival fiber groups insert into the cementum of the natural tooth: the dentogingival (coronal, horizontal, and apical), dentoperiosteal, transseptal,

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circular, semicircular, and transgingival fibers. In addition, some crestal fibers from the periodontal fiber bundles also insert into the cementum above the alveolar bone. These Sharpey fibers form a true attachment to the tooth. They prevent a periodontal probe from invading the PDL space and delay the ingress of plaque.

James and Schultz were first to begin a systematic study to investigate the biological seal phenomenon of the soft tissue around dental implants.[36] Hemidesmosomes from the JEA region help form a basal lamina–like structure on the implant, which can act as a biological seal.[38] However, collagenous components of the linear body cannot physiologically adhere to or become embedded into the implant body.[39] The hemidesmosomal seal has a circumferential band of gingival tissue to provide mechanical protection against tearing.[40] However, the mucopolysaccharide layer is less adherent to an implant surface than a natural tooth root. The hemidesmosome of the natural tooth has a lamina lucida and a lamina densa. The hemidesmosome next to an implant has a lamina lucida lamina densa, and sublamina lucida (which is less adherent).[41]

The biological width for implants has been reported by Cochran et al. to be 3.3 mm, but unlike the biological width dimension for teeth, they also included the sulcus depth.[42] In a typical implant gingival region, only two of the gingival fiber groups found around a tooth (circular and periosteogingival fibers) and no periodontal fibers are present.[43] These fibers do not insert into the implant body below the abutment margin as they do into the cementum of natural teeth.[37] Instead, the collagen fibers around an implant run parallel to the implant surface, not perpendicular, as with natural teeth.[44] Hence, the implant only has a junctional epithelial "attachment" system.

The gingival and periosteal fiber groups are responsible for the connective tissue attachment component of the biological width around teeth, and these are not present around the transosteal region of an implant. The "biological width" around the abutment–implant connection should not be similarly compared with the connective tissue attachment of a tooth. The biological seal around dental implants can prevent the migration of bacteria and endotoxins into the underlying bone. It is unable, however, to constitute an attachment component of the biological width similar to the one found with natural teeth (Figure 3-11).

A dental probe introduced into an implant sulcus may proceed through the junctional epithelial close approximation of tissue and the probe may proceed to the crestal bone (Figure 3-12). The connective tissue zone for an implant has only two fiber groups, and neither of them inserts into the implant. As a result, with an implant, the probe goes beyond the sulcus, through the JEA, and through the type III collagen connective tissues and reaches closer to the bone[37] (Table 3-2). Because the probe penetrates deeper next to an implant compared with a tooth, one should take care not to contaminate the implant sulcus with bacteria from a diseased periodontal site.

The benefit of probing the implant sulcus has been challenged in the literature because sound scientific criteria for the rationale are lacking. The location of the probe tip subgingivally for a tooth depends on the pressure used, the presence of inflammation, and the angle at which the probe is introduced in the sulcus depth between the junctional epithelium and the root surface. The correct pressure recommended for probing is 20 g, yet conventional probing often exerts a force more than five times this level and greatly varies. Pressure-sensitive probes have been made available to address these issues but are rarely used in a clinical practice.[45] The potential for damage to the fragile hemidesmosome attachment to the implant or marring of the implant surface exists during probing. In addition, reports in the literature suggest that the reproducibility of attachment level measurements may be questionable independently from the instrument used to perform the measurements.[46,47] Many of these variables are similar for a dental implant. Unlike natural teeth, fixed implant prostheses with subgingival margins of crowns often have wide emergence profiles, making probe positioning difficult around most implant bodies.

The implant sulcus depth may be a reflection of the original soft tissue thickness of the area before implant placement. The



FIGURE 3-11. The sulcus and epithelial attachment above the implant body does not have a true connection to the implant.

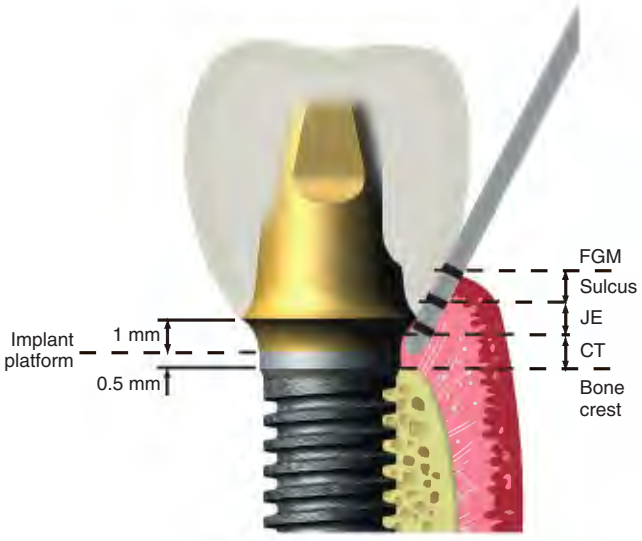


FIGURE 3-12. An implant has no connective tissue fibers in the connective tissue zone that insert into the implant. The periimplant probe penetrates the sulcus, junctional epithelial attachment (JE), and most of the connective tissue zone. *CT*, Connective tissue; *FGM*, free gingival margin.

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TABLE 3-2
Comparison of Tooth and Implant Support Structures

Structure	Tooth	Implant
Connection to bone	Cementum, bone, periodontium	Osseointegration, bone functional ankylosis
Junctional epithelium	Hemidesmosomes and basal lamina (lamina lucida and lamina densa zones)	Hemidesmosomes and basal lamina (lamina lucida, lamina densa, and sublamina lucida zones)
Connective tissue	12 groups: six insert perpendicular to tooth surfaces ↓collagen, ↑ fibroblasts	Only two groups: parallel and circular fibers; no attachment to the implant surface ↑ collagen, ↓fibroblasts
Biological width	2.04–2.91 mm	3.08 mm (includes sulcus)
Vascularity	Greater; supraperiosteal, and periodontal ligament	Less periosteal
Probing depth	3 mm in health	2.5–5.0 mm (depending on previous soft tissue depth)
Bleeding on probing	More reliable	Less reliable

posterior maxillary tissue can be thicker than 4 mm after tooth extraction and subsequent bone volume loss before implant placement. As a result, the tissue above the bone before implant insertion may be 4 mm thick or more. As a result of greater tissue thickness before surgery and a greater probing depth compared with teeth, the probing depth next to a healthy implant may be greater than that of a healthy natural tooth.

When the tissues are thick, gingivoplasty to reduce the flap thickness and pocket depth can be performed at the initial surgery. The advantage of the reduction in tissue thickness at this time is the tissue heals and matures as the bone–implant interface develops. However, thinning the flap at the initial surgery may cause greater loading of the implant body during healing from an overlying soft tissue–borne temporary prosthesis. After initial bone healing, the stage II uncovery surgery also may correct tissue thickness.

Lekholm et al. found that the presence of deep pockets was not accompanied by accelerated marginal bone loss.[48] Stable, rigid, fixed implants were reported with pocket depths ranging from 2 to 6 mm. Healthy, partially edentulous implant patients consistently exhibit greater probing depths around implants than around teeth. An increasing probing depth next to an implant is a more significant sign than a probing depth unrelated to a time interval because it usually signifies bone loss except in cases of gingival hyperplasia or hypertrophy. Probing using fixed reference points on the abutment or crown margin allows evaluation of crestal bone loss versus tissue hypertrophy.

Despite the limitations, charting the attachment level in implant permucosal areas does aid the dentist in monitoring these regions. As the sulcus depth increases, the oxygen tension decreases. The bacteria in an implant sulcus are similar to those of a natural tooth.[49,50] A toothbrush and daily hygiene procedures cannot clean a sulcus greater than 2 mm.[51] Sulcus depths greater than 5 to 6 mm have a greater incidence of anaerobic bacteria[50,52] (Box 3-3). As a consequence, this sulcus depth often requires gingivectomy or bone revision surgery. Therefore, as a general rule, to enable the patient to perform effective daily hygiene, the ideal implant sulcus should be maintained at less than 5 mm.

The monitoring of early crestal bone loss is most important during the first critical year of stress accommodation of the bone. Minor bone changes are clinically easier to observe with a periodontal probe than with radiographs. Early bone loss may occur on the facial aspect of the implant; radiographs only demonstrate clearly the mesial and distal regions (Figure 3-13).

BOX 3-3 Subgingival Microflora Associated with Human Dental Implants[52]

	Pocket Depth (mm)	
MICROFLORA	**<5**	**>6**
Spirochetes (%)	2	32
Motile rods (%)	16	18
Coccoids (%)	64	30



FIGURE 3-13. The bone loss on these implants is primarily on the facial. Radiographs did not detect bone loss. Probing found loss of bone of the facial.

Changes in crestal bone levels warrant close monitoring and early intervention. Patient education to reduce parafunctional stress on the implant system, the use of parafunctional appliances, and other stress-reducing methods are required when early crestal bone loss beyond the first thread is detected.

Despite the uncertain meaning of pocket depth increase, probing is an appropriate method to assess potential deleterious changes in the periimplant environment and should be performed every 3 to 4 months for 1 year after prosthesis delivery. After this time, if crestal bone levels are stable, probing is still relevant. Probing also reveals tissue consistency, bleeding, and exudate. Therefore, probing is important not only to measure increasing sulcus depths but also to allow the dentist to evaluate several periimplant parameters at the same time and at the same sites.

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FIGURE 3-14. Controversies related to probing include the material of the probe and the value in probing next to an implant.

Controversy exists as to the material from which the probe should be fabricated. In theory, different metal types (e.g., stainless steel, titanium) should not come into contact because of a risk of contamination of the two metals and the resulting galvanic corrosion that may develop and cause crestal bone loss. As a result of this fear, the suggestion has been made that only titanium surgical instruments be used to contact the implant and that only titanium or plastic instruments be used to probe or scale the implant (Figure 3-14).

Touching the surface of the abutment subgingivally with a stainless steel instrument is not of clinical concern. However, scratching the surface may contribute to plaque migration following the direction of the scratch. Plaque follows the direction of scratches on a titanium plate even though right angles and a maze pattern may be scratched onto the surface. Therefore, when probing almost to the bone level around the implant, one should take care not to scratch the surface because plaque that forms at the surface may follow the scratch subgingivally to the bone level. This is particularly important during scaling procedures and during the removal of cement below a crown margin. One should use semicircular strokes, parallel to the sulcus or crown margin, to scale the implant above the bone. If a scratch on the implant body occurs, plaque will not have a direct "highway" below the tissue.

Bleeding Index

Gingival bleeding when probing around teeth correlates with sulcular inflammation and the plaque index. Easily ulcerated sulcular epithelium represents inflammation from plaque and is the primary cause of bleeding when probing. A bleeding index is an indicator of sulcus health. Bleeding also can be provoked by undue pressure on the probe.

Controversy surrounds the issue of using bleeding and gingival health as an implant health indicator.[35] Unlike a natural tooth, implant success in the first few years is related more often to biomechanical equilibrium than to gingival health. Compared with a natural tooth, the soft tissue inflammation from bacteria may be more restricted to above the crestal bone because of the lack of a periodontal membrane or fibrous tissue between the implant and the bone interface. As a result, the bleeding index may not be as important a factor when evaluating the early implant quality of health.

The correlation between gingival health and implant success appears in part to be related to the cervical surface condition of the implant. Adell et al. found no evidence that gingivitis was a precursor of progressive bone loss.[53] Lekholm et al. also found that gingivitis and deep sulcular pockets were not accompanied by accelerated bone loss.[48] Both of these reports evaluated a machined-surface titanium screw design (e.g., Nobel Biocare).

In contrast to the previous reports with machined-surface implants, Kirsch and Mentag found a correlation between the gingival sulcus depth and implant failure.[54] The implant design studied in this report had an intramobile element with a larger implant body abutment crevice and a roughened, titanium plasma spray body (IMZ, Germany). A similar correlation between implant failure and gingival health status was observed when a porous titanium alloy microball surface was exposed above the bone (Endopore, Canada).[55,56]

In addition to the surface condition of the implant, other studies show a correlation to gingival health and implant teeth. Jepsen et al. identified elevated levels of proteolytic enzymes in an implant sulcus with inflammation and bleeding on probing as predictors of implant disease.[57] Lekholm et al. and Quirynen et al. found that plaque and gingivitis around implants were correlated.[48,58] Steflik et al. found that the gingival bleeding index correlated highly with the plaque index and the crevicular fluid index.[21]

The dentist already is encouraged to probe the sulcular region to evaluate crestal bone loss around the implant. Periodontal probing is less demanding than the determination of a gingival sulcular fluid volume index. One may observe the bleeding index while probing for sulcus depth and therefore may record it easily to help evaluate gingival health (Figure 3-15).

Regardless of whether gingival health is relative to success, all dentists agree that the ideal soft tissue condition around an implant is an absence of inflammation. Radiographic bone loss and increased pocket depth have been correlated with sulcular bleeding.[21] Therefore, the gingival status around an implant should be recorded and used to monitor the patient's daily oral hygiene. However, surrounding soft tissues around implants have fewer blood vessels than teeth; therefore, inflammation is typically less around implants than around teeth[69,70] (Figure 3-16).

The most common bleeding gingival index used for implants is the Loe and Silness gingival index.[25] When used on teeth, this index scores gingival inflammation from 0 to 3 on the facial, lingual, and mesial surfaces of all teeth. The symptom of bleeding comprises a score of at least 2 (Box 3-4).

The gingival index scores may also be used on implants to record the gingival inflammation on the facial, lingual, and mesial surfaces. The facial and lingual are already being probed to evaluate bone loss that cannot be seen on a radiograph. Because the bleeding index evaluates inflammation, the Loe and Silness index is adequate for implants, and because fewer implants typically are used to restore a region compared with the presence of natural teeth, one also may evaluate the distal surface when bleeding is present because the implants are more than 2 mm apart and access often is unobstructed.

When the sulcus depth is less than 5 mm and the bleeding index increases, use of chlorhexidine often is indicated along with other professional and home care methods. Sulcus depths in excess of 5 to 6 mm have a greater incidence of bleeding and usually require gingivectomy or revision surgery to correct an anaerobic environment.

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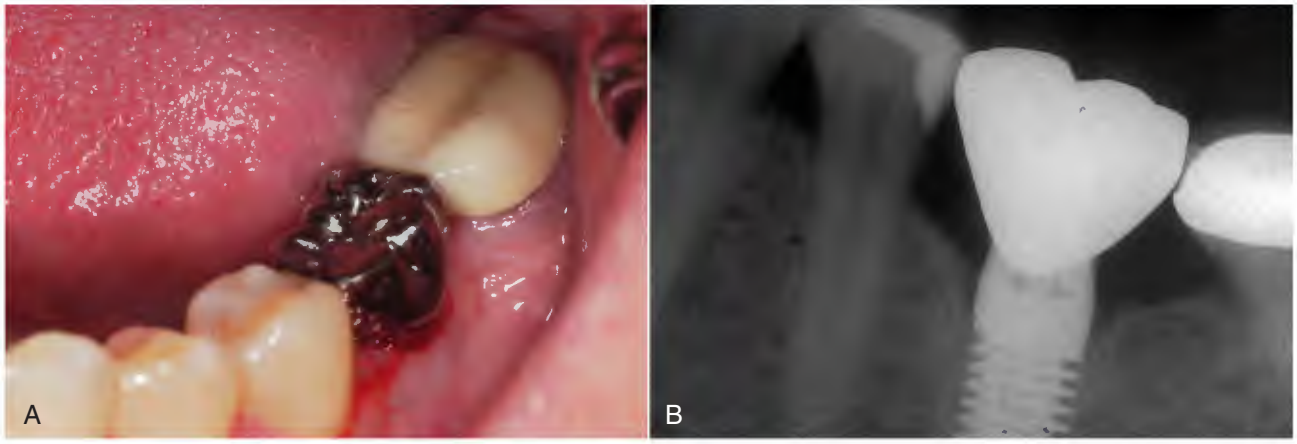


FIGURE 3-15. **A,** The bleeding upon probing around this implant crown indicates sulcular inflammation and is related to dental plaque. **B,** The periapical radiograph indicates the implant was countersunk below the bone and has crestal bone loss.



FIGURE 3-16. **A,** Bleeding upon probing on this implant indicates sulcular inflammation. **B,** The facial probing depth is 12 mm; this bone loss amount was not evident on a radiograph because it is on the facial.

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BOX 3-4 Gingival Index (Loe and Silness)

Normal	
0	Mild inflammation, slight color change and edema, no bleeding
1	Moderate inflammation, redness, edema, bleeds on probing
2	Severe inflammation, marked redness and edema ulceration, spontaneous bleeding

During the first year of clinical examinations for the periimplant tissues, the dentist should record color, form, and consistency along with bleeding on probing and should probe depths for all sites. After 1 year of stable probing depths, the examination may be restricted to facial and lingual checks at maintenance appointments and may be correlated with radiographic observation for the mesial and distal surfaces. Removal of the prosthesis for more accurate probing and evaluation is not indicated unless warranted by changing conditions. Repeated removal of a screw-retained fixed prosthesis causes wear of the screw attachment system and causes more frequent partially unretained restorations over the long term.

Crestal Bone Loss

The marginal bone around the implant crestal region is usually a significant indicator of implant health. Unlike natural teeth, the causes of crestal bone loss around the implant are multifactorial and may occur at different time periods: surgical bone loss, initial "biologic width" bone loss, early loading bone loss, intermediate-term bone loss, and long-term bone loss. Each time period may have a different cause for the bone loss. Most often the surgical trauma causes little bone loss, but on occasion, bone loss may reach several millimeters. The dentist may assess the presence of surgical bone loss when a two-stage surgery is used to obtain initial rigid fixation.

The level of the crestal bone is measured from the crestal position of the implant at the stage II uncovery surgery. When the abutment is attached to the implant body, approximately 0.5 to 1 mm of connective tissue forms apical to this

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connection.[58] This bone loss may be caused by an "implant biologic width." Initial bone loss during the surgical healing phase may vary for submerged and unsubmerged healing protocols.[61–65]An implant originally placed 2 mm above the bone and another countersunk 2 mm below the bone also have a different initial bone loss history after the abutment is attached to the implant.[61] Whenever possible, the implant should be inserted at or above the bone crest to avoid an increase in the sulcus depth around the implant related to the crestal bone loss after abutment placement.

After the implant is connected to a permucosal element, the marginal bone may be lost during the first month from (1) the position of the abutment–implant connection or (2) the crest module design of the implant. The abutment–implant connection will cause 0.5 to 1.0 mm of bone loss when it is at or below the bone. In addition, when smooth metal is below the abutment–implant connection and extends onto the neck of the implant, additional bone loss will occur in direct relation to the smooth metal region. The bone levels will most often reside at the first thread or at a roughened surface after the first month a permucosal element or abutment extends through the soft tissue[42] (Figure 3-17).

Periodontal Complex versus Direct Bone Interface

The presence of a periodontal membrane around natural teeth significantly reduces the amount of stress transmitted to the bone, especially at the crestal region.[66] The displacement of the periodontal membrane dissipates the energy to the fibrous tissue interface (PDL) surrounding natural teeth and acts as a viscoelastic shock absorber, serving to decrease the magnitude of stress to the bone at the crest and to extend the time during which the load is dissipated (thereby decreasing the impulse of the force). The force transmission is so efficient and within ideal strain conditions for bone that a thin layer of cortical-like bone (cribriform plate) forms around the tooth. When the tooth is lost, the cortical plate lining disappears, demonstrating this is not an anatomic structure but is a result of an ideal strain interface to the bone.

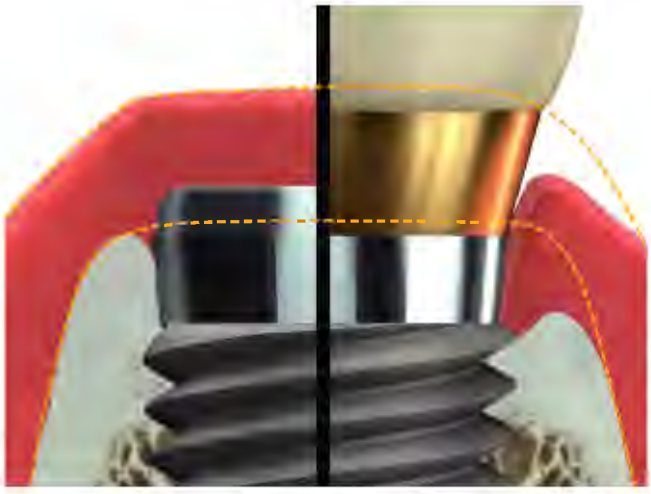


FIGURE 3-17. When an implant is placed with the abutment connection at the crest of the ridge (left side), after the permucosal abutment is connected, the bone is usually lost to the first thread, especially when the crest module is machined or smooth (right side).

Compared with a tooth, the direct bone interface with an implant is not as resilient. No cortical lining is present around the implant, which indicates the forces are not dissipated ideally around the interface. Instead, the energy imparted by an occlusal force is not dissipated away from the crestal region but rather transmits a higher intensity force to the crestal contiguous bone interface.[67]

The mobility of a natural tooth can increase with occlusal trauma. This movement dissipates stresses and strains otherwise imposed on the adjacent bone interface or the prosthetic components. After the occlusal trauma is eliminated, the tooth can return to its original condition with respect to the magnitude of movement.[66] Mobility of an implant also can develop under occlusal trauma. However, after the offending element is eliminated, an implant does not return to its original rigid condition. Instead, its health is compromised, and failure of the entire implant system is usually imminent.

A lateral force on a natural tooth is dissipated rapidly away from the crest of bone toward the apex of the tooth. The healthy, natural tooth moves almost immediately 56 to 108 microns (primary tooth movement) and pivots two thirds down toward the tapered apex with a lateral load.[18] This action minimizes crestal loads to the bone. An implant does not exhibit a primary immediate movement with a lateral load. Instead, a more delayed movement of 10 to 50 microns occurs, which is related to the viscoelastic bone movement.[17,22] In addition, this action does not pivot (as a tooth) toward the apex but instead concentrates greater forces at the crest of surrounding bone. Therefore, if an initial lateral or angled load (e.g., premature contact) of equal magnitude and direction is placed on an implant crown and a natural tooth, the implant system (crown, cement or screw retention, abutment screw, marginal bone, implant–bone interface) sustains a higher proportion of the load that is not dissipated to the surrounding structures.

The dentist uses mobility ratings to evaluate the quality of a natural abutment. A tooth with a Miller index mobility of 0 is considered "stronger" than a tooth with mobility of 2. Implants exhibit no clinical mobility compared with teeth. Phrases such as "solid as a rock" were used originally to describe their rigid fixation. As a result, the dentist may consider the implant a stronger abutment than a tooth, especially when the literature has implied that distal cantilevers off four anterior implants can be used to restore an entire arch.[20] However, when considering stress factors, mobility is an advantage. The natural tooth, with its PDL, constitutes a near perfect optimization system to handle biomechanical stress. In fact, the stress is handled so well, bacteria-related disease is the weak link. An implant system handles stress poorly (capturing the stress at the crest of the ridge) and is unable to increase mobility without failure, so that biomechanical stress is the weakest link in the system.

The natural teeth may have an occlusal adjustment by using fremitus—the act of lightly placing the fingers against the buccal of the teeth as they are lightly tapped together. The implant crowns do not have fremitus as they occlude together, which makes it more difficult to adjust the occlusal contact intensity.

A radiograph of a natural tooth that has occlusal trauma will have a widened periodontal space and a thicker lamina dura (cribriform plate). A radiograph of an implant crown with occlusal trauma has no changes in the bone around the implant. However, crestal bone loss may be a consequence of the excessive load because the forces are concentrated on the marginal bone. The complete bone–implant interface may also break

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FIGURE 3-18. The bone loss beyond the first thread after occlusal loading is most often from occlusal trauma.

down, and the implant may become mobile and surrounded by fibrous tissue.

Periodontal probing is used to assess attachment levels to the tooth and is a prime indicator of health. Radiographic bone loss around a tooth does not indicate the presence of a disease state but is a reflection of past or present periodontal disease. Occlusal trauma may cause an increase in tooth mobility but does not cause marginal bone loss in the absence of periodontal disease.

The initial bone loss beyond the abutment connection and smooth neck region of the implant after function is often a result of excessive stress at the crestal implant–bone interface[67–69] (Figure 3-18). The dentist should evaluate and reduce stress factors, such as occlusal forces, cantilever length, and especially parafunction, on observation of initial bone loss after loading.

Crestal bone loss after prosthesis delivery beyond the first thread or rough surface condition of an implant is a primary indicator of the need for initial preventive therapy. Early loss of crestal bone beyond 1 mm from the microgap of the abutment after prosthesis delivery usually results from excess biomechanical stress at the permucosal site or implant crest module design.[67–69]

The majority of implants do not lose bone each year. Several studies report marginal bone loss after the first year of function in the range of 0 to 0.2 mm. Adell et al. determined that successful implants after the first year of loading had an average 0.1 mm of bone loss for each following year.[20] Cox and Zarb observed a similar amount of mean bone loss of 0.1 to 0.13 mm per year after the first year of prosthesis function.[65] Kline et al. reported an average of less than 0.1 mm each year after the first year.[70] However, if one implant in a study of 10 loses 1 mm of bone, the average bone loss for the study is 0.1 mm. Hence, the 0.1-mm bone loss average means most implants do not lose bone on an annual basis.

Slight changes in interproximal bone loss can be determined by radiographs. The threaded implant pitch (distance between the threads) is a known distance for each system (e.g., 0.6 mm for a classic Brånemark design) and can be used as a radiographic marker. The dentist should suspect occlusal overload, including parafunctional habits when implants have lost bone after the prosthesis delivery.

Intermediate-term bone loss around an implant is usually a compound condition created by bacteria and increased stress (a result of parafunction or increasing crown height from crestal bone loss and anaerobic bacteria forming when the sulcus is greater than 5 to 6 mm)[52] (Box 3-5).

BOX 3-5 Implant Crestal Bone Loss

Time	Cause
Surgery	Trauma to bone
Uncovery	"Implant biologic width" related to abutment location and implant crest module design
Early	Occlusal trauma
Intermediate	Bacteria or occlusal trauma
Long-term	Bacteria

Under ideal conditions, a tooth or implant should lose minimum bone. However, it is not possible to quantify how much bone loss indicates success or failure. In general, if more than half the implant height has lost crestal bony contact, the implant is at significant risk and may be considered a failure, regardless of the original amount of implant–bone contact. In addition to radiographic bone loss, the probing depth of the soft tissue should be considered related to the bone loss. If an implant has lost 5 mm of bone and has a probing depth of 10 mm, the situation is much worse than an implant with 6 mm of bone loss and a 3-mm probing depth.

Radiographic Evaluation

The radiographic assessment of natural teeth assists in determining the presence of decay, lesions of endodontic origin, and periodontal bone loss. Radiographs may be used to evaluate the result of periodontal diseases on the supporting bone but cannot indicate the presence or absence of the disease process. Assessments of bone loss for natural teeth may include (1) the presence or absence of intact lamina dura; (2) the width of the PDL space; (3) the bone crest morphology (even or angular); and (4) the distance from the cementoenamel junction (CEJ) and the coronal level of the PDL (normal or abnormal width). Normal radiographic bone levels next to natural teeth are typically between 1 to 3 mm from the CEJ.

Implants do not decay and do not develop endodontic-related conditions. However, the crestal bone region is often the most diagnostic for the ranges of optimum, satisfactory, and compromised health conditions. Radiographic interpretation is one of the easiest clinical tools to use to assess implant crestal bone loss but has many limitations. A radiograph only illustrates clearly the mesial and distal crestal levels of bone. However, early bone loss often occurs on the facial aspect of the implant.

An absence of radiolucency around an implant does not mean bone is present at the interface, especially in the anterior mandible. As much as 40% decrease in density is necessary to produce a traditional radiographic difference in this region because of the dense cortical bone.[71] When the bone is wide, a V-shaped crestal defect around an implant may be surrounded by cortical bone and, as a result, the radiograph is less diagnostic.

Parallel periapical radiographs are more difficult to obtain for implants than for teeth. The implant is often apical to the apex of the preexisting natural tooth. As a result, the apex of the implant often is located beyond muscle attachments or in regions almost impossible to capture with a parallel radiographic method. A foreshortened image to accommodate the

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apical portion of the implant defeats the purpose of radiographic interpretation of the crestal bone. Crestal bone loss is often best evaluated with vertical bitewing films or periapical radiographs that do not include the apical portion of the implant (Figure 3-19).

The clear depiction of the threads on the radiograph indicates use of a proper angulation. If the threads are clear on one side but fuzzy on the other, the angulation was incorrect by approximately 10%[72] (Figure 3-20). If both sides of a threaded implant are unclear, the radiograph is not diagnostic for crestal bone loss assessment. Ideally, the abutment–implant connection should appear as a clear line between the two components. When the top of the implant is placed at the crest of the regional bone, the amount of crestal bone loss is most easy to evaluate.



FIGURE 3-19. Vertical bitewings are often more diagnostic to determine radiographic bone loss compared with radiographs, which attempt to capture the apex of the implant.



FIGURE 3-20. On this periapical radiograph, the threads are clear on one side only. The central ray was not directed completely perpendicular to the implant body but was within 10 degrees. This film is not ideal but is clinically acceptable in most situations.

A periimplant radiolucency indicates the presence of surrounding soft tissue and is a sign of implant failure. The cause may be from infection (bacterial), iatrogenic (heat-induced bone loss), nonrigid fixation (iatrogenic or patient induced), or local bone-healing disorders.

On rare occasions, an apical radiolucency has been observed on a nonmobile implant. This is most likely a perforation of one of the lateral cortical plates of bone but also may be from contamination of the drill, overheating, or infection.[73,74]

If the apical radiolucent region expands or is accompanied by a fistula, reentry surgery and correction are warranted. If the implant is mobile, it must be removed. If the implant has rigid fixation and the crestal half is in good order, the apical cause of the radiolucency may be removed and aggressively curetted, which may include sectioning and removal of the apical portion of the implant (Figure 3-21).

The implant quality of health evaluation protocol depends on clinical and radiographic observations. A baseline radiograph is obtained at the initial delivery of the prosthesis. By this time the "biological width" and influence of the implant crest module design have already contributed to its influence on crestal bone loss. Because crestal bone changes often occur during the first year of loading, preventive maintenance appointments are scheduled every 3 to 4 months, and a periapical/vertical bitewing radiograph at 6 to 8 months may be compared with the baseline if probing depths increase. Vertical bitewing radiographs may be taken at 1 year and compared with the previous two images. If no changes are apparent, subsequent radiographic examinations may be scheduled for every 3 years unless other clinical signs warrant more frequent examinations.

If crestal changes are evident by probing or radiographs, stress reduction and hygiene are modified accordingly. Radiographs are taken and reviewed every 6 to 8 months until the bone is stable for two consecutive periods. If bone loss greater than 2 mm is observed from the bone levels noted at the prosthesis delivery, the dentist should strongly suspect parafunction on too few implants. Night guards and stress reduction on the affected implants are indicated.

Keratinized Tissue Concerns

The absence or presence of a zone of keratinized gingiva around teeth and oral implants remains a controversial issue.[75–85] No direct evidence confirms or denies the need for nonmobile keratinized tissue next to natural teeth. The tooth with the least amount of keratinized tissue is often the mandibular first premolar.[25] Yet this tooth is rarely the first tooth lost from periodontal disease. If all other periodontal indices are normal, the amount or absence of keratinized gingiva has little to do with the expected longevity of the tooth. In longitudinal studies, Wennstrom[76] and Kennedy et al.[77] demonstrated that the lack of adequate keratinized and attached tissue does not compromise the long-term health of soft and hard tissue as long as patients maintain good oral hygiene (Figure 3-22).

On the other side of the issue, some authors consider keratinized attached gingiva important. Lang and Loe advocate a minimum 2 mm of keratinized gingiva and 1 mm of attached gingiva to maintain gingival health.[75] Stetler and Bissada addressed mucogingival considerations in restorative dentistry

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FIGURE 3-21. **A,** A radiograph of a rigid fixated implant and crown replacing the mandibular first premolar with an apical radiolucency. **B,** An implant apicoectomy and removal of the infection resulted in a stable condition.

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FIGURE 3-22. Attached keratinized tissue in the mandible is often less in the first premolar region. Likewise, a first premolar implant site often has little keratinized tissue. Yet no current study indicates that the first premolar tooth or implant is the least predictable location for health or survival. This suggests that although ideal for long-term maintenance and health, the presence of keratinized tissue may not be mandatory.

in 1987.[79] They concluded that if subgingival restorations were to be placed in areas of minimally keratinized gingiva and less than optimal plaque control, augmentation to widen the zone of keratinized tissue may be warranted. However, they also noted that in unrestored teeth, the difference in the inflammatory status of sites with or without a wide zone of keratinized tissue was not significant.

Although keratinized tissue around a tooth may not be mandatory for long-term health, a number of benefits are present with keratinized mucosa. The color, contour, and texture of the soft tissue drape should be similar around implants and teeth when in the esthetic zone. The interdental papillae should ideally fill the interproximal spaces. A high smile line often exposes the free gingival margin and interdental papillae zones. The keratinized tissue is more resistant to abrasion. As a result, hygiene aids are more comfortable to use, and mastication is less likely to cause discomfort. The degree of gingival recession appears related to the absence of keratinized gingiva. Root sensitivity and esthetic concerns may be associated with gingival recession. From a restorative dental aspect, keratinized mucosa is more manageable during the retraction and impression-making process. Subgingival margin placement is improved, as is long-term stability in the presence of keratinized tissue. Many of these benefits directly apply to the soft tissue around an implant.

Natural teeth typically have two primary types of tissue: attached, keratinized gingiva and unattached, unkeratinized mucosa. The type of tissue around a dental implant is more varied than natural teeth. After bone loss in the maxilla, excess

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tissue is often found, and the tissue is usually keratinized, unattached gingiva. An implant placed in the region may also have keratinized, unattached tissue. The tissues around the implant may also be similar to most natural teeth, surrounded by keratinized, attached gingiva (Figure 3-23). The tissues may be unkeratinized, unattached mucosa, more often in the mandible after bone height loss, or after a bone graft and flap advancement to approximate the gingiva (Figure 3-24). The unkeratinized tissue may also be attached when acellular tissue (Alloderm) is positioned under the periosteum and bounds the overlying tissues to the bone.

The need for keratinized tissue around dental implants seems more controversial than that around teeth.[43,82,86–88] In theory, structural differences in implants compared with teeth make them more susceptible to the development of inflammation and bone loss when exposed to plaque accumulation or microbial invasion (e.g., less vascular supply, less fibroblasts, lack of connective tissue attachment to cementation).[39,59] Some reports indicate the lack of keratinized tissue may contribute to implant failure. Kirsch and Ackermann reported that the most important criterion for implant health in the posterior mandible was related to the absence or presence of keratinized gingiva.[86] In this report, mobile, nonkeratinized mucosa exhibited greater probing depths, which was histologically confirmed.



FIGURE 3-23. The soft tissues around these implants are keratinized, attached gingiva, similar to natural teeth.



FIGURE 3-24. The soft tissue on the facial of the implant crown for the maxillary right central incisor is unkeratinized, unattached mucosa.

A study by Warrer et al. in monkeys found that an absence of keratinized mucosa increases the susceptibility of periimplant regions to plaque-induced destruction.[85]

The presence of keratinized tissue next to an oral implant presents some unique benefits compared to natural teeth. Keratinized gingiva has more hemidesmosomes; thus, the JEA zone may be of benefit when in keratinized tissue. Whereas the orientation of collagen fibers in the connective tissue zone of an implant may appear perpendicular to the implant surface, these fibers in mobile, nonkeratinized tissue run parallel to the surface of the implant. Schroeder et al., James and Schultz, McKinney et al., and Listgarten et al. have suggested that mobile mucosa may disrupt the implant-epithelial attachment zone and contribute to an increased risk of inflammation from plaque[8,36,38,43] (Figure 3-25).

In addition to the general advantages of keratinized tissue stated for teeth, keratinized tissue around implants may also be beneficial in several other ways. In a two-stage protocol, the implant is less likely to become exposed during the healing process. The formation of an interdental/implant papillae is completely unpredictable with mobile unkeratinized tissues. When the unkeratinized tissue is mobile, several reports state that this is unsatisfactory. Ono et al. have proposed a classification of attached gingiva and surgical alternatives to improve soft tissue types in edentulous sites for implant placement.[40] Meffert et al. prefer to obtain keratinized tissue before implant placement, especially in the posterior regions.[88]

Interestingly, the studies that have advocated the need for keratinized mucosa around dental implants have primarily investigated implants with rough surfaces. Failure of rough-surface implants (e.g., hydroxyapatite coated and plasma-sprayed cylinder-shaped implants) have been related to a lack of keratinized mucosa.[89] On the other hand, the studies that have questioned the need of keratinized mucosa around dental implants have examined implants with smooth surfaces. A meta-analysis of the literature was performed on the subject by Esposito et al. and reported 20% less periimplantitis in smooth-surface implants compared with rough-surface implants.[90]

Another benefit of keratinized tissue is the clinical ease of treatment to reduce pocket depths if crestal bone loss occurs. Probing depths 6 mm or more are more often associated with anaerobic bacteria. If the implant is out of the esthetic zone, a gingivectomy to reduce pocket depth is very predictable. An apically positioned flap with unkeratinized mucosa is less predictable and is more difficult to perform.



FIGURE 3-25. Mobile mucosa around a dental implant results in more complications than nonmobile tissues.

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However, it should be noted that several reports demonstrate the long-term implant survival in the absence of keratinized tissue.[20,53,81] Although reports are more cautious with mobile mucosa next to an implant, nonmobile tissue rather than keratinized tissue appears to be the primary criterion relative to tissue type.

A study by Chung et al. evaluated the significance of keratinized mucosa in the maintenance of dental implants with different surface conditions.[91] All 69 patients and 339 implants in the study had implant restorations for at least 3 years and as long as 24 years with an average of 8.1 years. Bleeding index, modified plaque index, gingival index, probing depth, width of attached keratinized mucosa, and amount of attached mucosa were recorded. In addition, average annual bone loss was calculated using past and present radiographs. Gingival inflammation and plaque accumulation were significantly higher in patients with less than 2 mm of keratinized mucosa or 1 mm of attached mucosa. The surface condition of the implant was not statistically significant in this study, although the smooth implants with less than 2 mm of keratinized mucosa were less stable than other groups relative to the soft tissue profile.

This study also found the average annual bone loss was not influenced by the amount of keratinized or attached mucosa or the type of implant surface configuration (smooth vs. rough). The greatest amount of bone loss was observed with rough implants in keratinized mucosa of less than 1 mm, but the difference was not statically relevant. The presence of keratinized mucosa in this study was most significantly advantageous in the soft tissue health of posterior implants, as indicated by the gingival index. Posterior implants, even in the presence of keratinized tissue, had a 3.5-fold higher annual bone loss than anterior implants in this study (0.14 vs. 0.04 mm).[89] Therefore, implant location appears more important than the presence or absence of keratinized mucosa.

The question relative to the need for keratinized tissue around implants should be modified to "Which would you prefer?" No one in the literature has stated that the unkeratinized tissue is more preferred than keratinized tissue; therefore, the controversy is abated. Some authors prefer keratinized mucosa more intensely than others. If one side of the controversy demonstrates benefits while the other side states that keratinized tissue is not mandatory, both sides may be correct.

In specific clinical instances attached, keratinized gingiva is more often desirable. For example, a fixed prosthesis (FP-1) in the esthetic zone requires keratinized mucosa to develop the soft tissue drape around the implant crowns. A second prime example is a mandibular overdenture, which benefits from a vestibule and zone of nonmobile tissue around the implant abutments.

Periimplant Disease

Gingivitis is a bacteria-induced inflammation involving the region of the marginal gingiva above the crest of bone and next to a natural tooth. It is always associated with plaque and may be classified as (1) acute necrotizing, (2) ulcerative, (3) hormonal, (4) drug induced, or (5) spontaneously occurring.[25] These categories also can relate to the gingival tissues around an implant because the mode of attachment of the gingiva to a tooth and implant has been reported to be partially similar.[38]

The bacteria in gingivitis around a tooth may affect the epithelial attachment without loss of connective tissue attachment. Because the connective tissue attachment of a tooth extends an average of 1.07 mm above the crestal bone, at least 1 mm of protective barrier above the bone is left. In contrast, no connective tissue attachment zone exists around an implant because no connective fibers extend into the implant surface. Therefore, no connective tissue barrier exists to protect the crestal bone around an implant.[92]

Periodontitis around teeth is characterized by apical proliferation and ulceration of the junctional epithelium, progressive loss of the connective tissue attachment, and loss of alveolar bone.[25] Bacteria is primarily responsible for periodontitis. The disease has been classified as adult, rapidly progressive, localized juvenile, and prepubertal periodontitis.

After prosthesis delivery, early crestal bone loss around an implant usually is not caused by bacteria. Most often the bone loss results from stress factors too great for the immature, incompletely mineralized bone–implant interface or an extension of the biological width onto a smooth metal crest module.[68] Therefore, an implant may exhibit early crestal bone loss with a different mechanism or cause compared with natural teeth. However, on occasion, bacteria may be the primary factor. Anaerobic bacteria have been observed growing in the microgap between the implant and the abutment or in the sulcus of implants, especially when sulcus depths are greater than 5 mm[52] (Box 3-6).

The term *periimplantitis* describes a bacteria-related complication around dental implants. According to Mombelli et al., the microbiota are site specific and similar to chronic adult periodontitis.[49] The clinical signs include radiographic or probing vertical bone loss, periimplant pockets, bleeding upon probing (with or without exudate), mucosal swelling and redness, and an absence of pain (Box 3-7) The crestal bone loss may be induced by stress, bacteria, or a combination of both. Stress-induced bone loss occurs without bacteria as the primary causative agent. However, after the bone loss from stress or bacteria deepens the sulcular crevice and decreases the oxygen tension,

BOX 3-6 Stable Integrated Implants: Bacteria Related to Pocket Depth Increases

Shallow
Gram-positive facultative cocci, rods
Gram-negative anaerobic cocci, rods
Motile rods
Spirochetes
Black-pigmented *Bacteroides*
Fusobacterium

Deep
Vibrios organisms

BOX 3-7 Clinical Signs of Periimplantitis

Vertical bone loss (radiographic, probing, or both)
Periimplant pockets
Bleeding upon probing
± Exudate
Mucosal swelling
Erythema
No pain

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anaerobic bacteria may become the primary promoters of the continued bone loss. An exudate or abscess indicates exacerbation of the periimplant disease and possible accelerated bone loss (Figure 3-26).

Short-term antibiotic treatment and aggressive topical application of chlorhexidine or local antibiotics with thorough, extensive professional and patient care of the soft tissue are indicated. An exudate persisting for more than 1 to 2 weeks usually warrants surgical revision of the periimplant area to eliminate causative elements.

After the exudate is eliminated, the bacterial smear layer remaining on the implant surface must be eliminated before bone can grow in close contact with the implant. The reduced bone height, after the exudate episode, makes the implant more prone to secondary occlusal trauma. Therefore, the dentist must reevaluate stress factors for the new bony condition and often must reduce them to improve long-term performance.



FIGURE 3-26. **A,** Periimplant probing measures pocket depths and may indicate the presence of exudate. Symptoms of exudate should be addressed with aggressive therapy. **B,** Surgical reentry into the implant site from **A** demonstrates advanced bone loss around the facial aspect of the implant.

Summary

An implant is often treated as a tooth when evaluated or restored by the dentist. Yet fundamental differences are present in these two support systems. Periodontal indices may be used as a method to compare the similarities and differences. Most often, implant indices must be modified when compared with natural teeth.

In 2008, the International Congress of Oral Implantologists sponsored a Consensus Conference in Pisa, Italy for implant success, survival, and failure.[93] These guidelines used the Misch implant quality scale and this chapter as a baseline for discussion. Hence, according to these guidelines, the material in this chapter may be widely used to discuss the differences and controversies in the support systems of teeth and implants.

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CHAPTER 4

Biomaterials for Dental Implants

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Compatibility of Surgical Biomaterials and the Role of Synthetic Materials

The biocompatibility profiles of synthetic substances (biomaterials) used for the replacement or augmentation of biological tissues have always been a critical concern within the health care disciplines. Special circumstances are associated with dental implant prosthetic reconstruction of the oral-maxillofacial areas because the devices extend from the mouth, across the protective epithelial zones, and onto or into the underlying bone. The functional aspects of use also include the transfer of force from the occlusal surfaces of the teeth through the crown and bridge and neck-connector region of the implant into the implant for interfacial transfer to the supporting soft and hard tissues. This situation represents a very complex series of chemical and mechanical environmental conditions.

This most critical aspect of biocompatibility is, of course, dependent on the basic bulk and surface properties of the biomaterial. All aspects of basic manufacturing, finishing, packaging and delivering, sterilizing, and placing (including surgical placement) must be adequately controlled to ensure clean and nontraumatizing conditions. The importance of these considerations has been reemphasized through the concept and practice of osseointegration of endosteal root form implant systems.

The disciplines of biomaterials and biomechanics are complementary to the understanding of device-based function. The physical, mechanical, chemical, and electrical properties of the basic material components must always be fully evaluated for any biomaterial application because these properties provide key inputs into the interrelated biomechanical and biological analyses of function. It is important to separate the roles of macroscopic implant shape from the microscopic transfer of stress and strain along biomaterial–tissue interfaces. The macroscopic distribution of mechanical stress and strain is predominantly controlled by the shape and form of the implant device. One important material property related to design (shape and form) optimization is the elastic strain (one component of the elastic modulus) of the material.

The localized microscopic strain distribution is controlled more by the basic properties of the biomaterial (e.g., surface chemistry, microtopography, modulus of elasticity) and by whether the biomaterial surface is attached to the adjacent tissues. Engineering analyses of implant systems include optimization considerations related both to the design and to the biomaterial used for construction. Therefore, the desire to positively influence tissue responses and to minimize biodegradation often places restrictions on which materials can be safely used within the oral and tissue environments. Designs are often evolved for specific biomaterials because of the imposed environmental or restorative conditions.

Bulk Properties

History of Materials and Designs

Over the past several decades, definitions of material biocompatibilities have evolved and reflect an ever-changing opinion related to philosophies of surgical implant treatment. In general, the definition of biocompatibility has been given as an appropriate response to a material (biomaterial) within a device (design) for a specific clinical application.[1] Metallic and nonmetallic implantable materials have been studied in the field of orthopedics since the turn of the twentieth century.[2–7]

In the 1960s, emphasis was placed on making the biomaterials more inert and chemically stable within biological environments. The high-purity ceramics of aluminum oxide (Al_2O_3), carbon, and carbon–silicon compounds and extra-low-interstitial (ELI) grade alloys are classic examples of these trends. In the 1970s, biocompatibility was defined in terms of minimal harm to the host or to the biomaterial. The importance of a stable interaction then moved into central focus for both the research and the clinical communities. In the 1980s, the focus transferred to bioactive substrates intended to positively influence tissue responses. In the past two decades, emphasis was on chemically and mechanically anisotropic substrates combined with growth (mitogenic) and inductive (morphogenic) substances. Today many biomaterials are being constituted, fabricated, and surface modified to directly influence short- and long-term tissue responses. Bioactive coatings on most classes of biomaterials have continued to evolve from human clinical trials to acceptable modalities of surface preparation, and research focus has shifted to combinations of active synthetic and biological implants.

Of interest, dental implants have significantly influenced these trends. In the 1960s, dental devices were recognized as being in a research and development phase, and critical longitudinal reviews of clinical applications were strongly recommended.[8] During this time, longevity studies of various devices demonstrated that the longest duration of clinical applications were for orthopedic prostheses. In the 1980s, controlled clinical trials showed that dental implants provided functional longevities that exceeded most other types of functional tissue replacement modalities.[9,10] Clearly, these clinical studies have strongly influenced both the research and development and the clinical application processes. At the present time, the exponential growth of implant use and related scientific reports support the views expressed by early visionaries several decades ago.

The evolution of any implant modality is a multipart story in which significant roles have been played by biomaterials; biomechanical analyses of designs, tissues, and function; wound healing along interfaces; surgical methods to minimize mechanical, chemical, and thermal trauma; prosthodontic and

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periodontal restorative and maintenance treatment modalities; and protocols for controlled multidisciplinary clinical trials. The interdependence of all phases of basic and applied research should be recognized. All interrelate and must evolve to provide a level of better understanding of the basic physical and biological phenomena associated with the implant systems before the longer clinical outcomes will be fully described.

Evaluations of endosteal and subperiosteal dental implants raise interesting questions with respect to the interrelationships between material and design selection. Opportunities exist to select a material from a number of systems, such as metals, ceramics, carbons, polymers, or composites. In addition, only the available anatomical dimensions and the requirement to attach some form of intraoral restorative device limit implant shape and form (design). Because of the wide range of biomaterial properties demonstrated by the classes of materials available, it is not advisable to fabricate any new implant design without a thorough biomechanical analysis. Another approach now often used is to determine a specific design based on clinical considerations and then to select the biomaterial of choice from computer-based analyses. The safety of these combinations can then be demonstrated through laboratory and animal investigations. Controlled clinical trials after prospective protocols, of course, provide the final evaluation for both safety and effectiveness. Long-term success is thus determined clinically in investigator follow-up studies and is clearly an area that should be emphasized for many available dental implant systems.

Research and Development

Basic studies within the physical and biological sciences have been supportive of the development of surgical implant systems. One example is the continued progress from materials that have been available for industrial applications to the new classes of composites that have evolved for biomedical applications. This same situation exists within a broad area (e.g., surface science and technology, mechanics and biomechanics of three-dimensional structures, pathways and processes of wound healing along biomaterial interfaces, and the description of the first biofilms that evolve on contact with blood or tissue fluids).[11–14] The progressive move from materials to quantitatively characterized biomaterials has been extremely important to the biomedical applications of surgical implants. Dental implant investigations now play a leadership role within selected areas of this overall process, and all phases of medicine and dentistry should benefit.

Physical, Mechanical, and Chemical Requirements for Implant Materials

Physical and Mechanical Properties

Forces exerted on the implant material consist of tensile, compressive, and shear components. As for most materials, compressive strengths of implant materials are usually greater than their shear and tensile counterparts. A hypothesis that dental implants are less affected by alternating stresses than implants of the cardiovascular and locomotor systems because of the significantly lower number of loading cycles must be qualified because of the special concern that dental implants are considerably smaller in physical dimension. All fatigue failures obey mechanical laws correlating the dimensions of the material to the mechanical properties of said material.[11,15] In addition, when present, parafunction (nocturnal or diurnal) can be greatly detrimental to longevity because of the mechanical properties, such as maximum yield strength, fatigue strength, creep deformability, ductility, and fracture. Limitations of the relevance of these properties are mainly caused by the variable shape and surface features of implant designs. A recurring problem exists between the mechanical strength and deformability of the material and the recipient bone. A different approach to match more closely the implanted material and hard tissue properties led to the experimentation of polymeric, carbonitic, and metallic materials of low modulus of elasticity.[16,17]

Because bone can modify its structure in response to forces exerted on it, implant materials and designs must be designed to account for the increased performance of the musculature and bone in jaws restored with implants. The upper stress limit decreases with an increasing number of loading cycles sometimes reaching the fatigue limit after 10^6 to 10^7 loading cycles.[11,15,18] In other words, the higher the applied load, the higher the mechanical stress—and therefore the greater the possibility for exceeding the fatigue endurance limit of the material.

In general, the fatigue limit of metallic implant materials reaches approximately 50% of their ultimate tensile strength.[11,18] However, this relationship is only applicable to metallic systems, and polymeric systems have no lower limit in terms of endurance fatigue strength. Ceramic materials are weak under shear forces because of the combination of fracture strength and no ductility, which can lead to brittle fracture. Metals can be heated for varying periods to influence properties, modified by the addition of alloying elements or altered by mechanical processing such as drawing, swagging, or forging followed by age or dispersion hardening until the strength and ductility of the processed material are optimized for the intended application.

The modifying elements in metallic systems may be metals or nonmetals. A general rule is that constitution or mechanical process hardening procedures result in an increased strength but also invariably correspond to a loss of ductility. This is especially relevant for dental implants. Most all consensus standards for metals (American Society for Testing and Material [ASTM], International Standardization Organization [ISO], American Dental Association [ADA]) require a minimum of 8% ductility to minimize brittle fractures. Mixed microstructural phase hardening of austenitic materials with nitrogen (e.g., stainless steels) and the increasing purity of the alloys seem most indicated to achieve maximum strength and maintain this high level of possible plastic deformation.[1,15,19–23]

Corrosion and Biodegradation

Corrosion is a special concern for metallic materials in dental implantology because implants protrude into the oral cavity, where electrolyte and oxygen compositions differ from those of tissue fluids. In addition, the pH can vary significantly in areas below plaque and within the oral cavity. This increases the range of pH that implants are exposed to in the oral cavity compared with specific sites in tissue.[24–29] Plenk and Zitter[15] state that galvanic corrosion (GC) could be greater for dental implants than for orthopedic implants. Galvanic processes depend on the passivity of oxide layers, which are characterized by a minimal dissolution rate and high regenerative power for metals such as titanium. The passive layer is only a few nanometers thick and usually composed of oxides or hydroxides of the metallic elements that have greatest affinity for oxygen. In reactive group metals such as titanium, niobium, zirconium, tantalum, and

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related alloys, the base materials determine the properties of the passive layer. The stability zones of the oxides of passivable elements cover the redox potentials and pH values typical of the oral environment. However, titanium, tantalum, and niobium oxides cover a markedly larger zone of environmental stability compared with chromium oxides.

The risk of mechanical degradation, such as scratching or fretting of implanted materials, combined with corrosion and release into bone and remote organs has been previously considered. For example, investigators such as Laing,[30] Willert et al.,[31] and Lemons,[32,33] have extensively studied the corrosion of metallic implants. Steinemann[34] and Fontana and Greene[35] have presented many of the basic relationships specific to implant corrosion. Mears[26] addressed concerns about GC and studied the local tissue response to stainless steel and cobalt–chromium–molybdenum (Co-Cr-Mo) and showed the release of metal ions in the tissues. Williams[36] suggested that three types of corrosion were most relevant to dental implants: (1) stress corrosion cracking (SCC), (2) GC, and (3) fretting corrosion (FC).

Stress Corrosion Cracking

The combination of high magnitudes of applied mechanical stress plus simultaneous exposure to a corrosive environment can result in the failure of metallic materials by cracking, where neither condition alone would cause the failure. Williams[36] presented this phenomenon of SCC in multicomponent orthopedic implants. Others hypothesized that it may be responsible for some implant failures in view of high concentrations of forces in the area of the abutment–implant body interface.[37–39] Most traditional implant body designs under three-dimensional finite element stress analysis show a concentration of stresses at the crest of the bone support and cervical third of the implant. This tends to support potential SCC at the implant interface area (i.e., a transition zone for altered chemical and mechanical environmental conditions). This has also been described in terms of corrosion fatigue (i.e., cyclic load cycle failures accelerated by locally aggressive medium). In addition, nonpassive prosthetic superstructures may incorporate permanent stress, which strongly influences this phenomenon under loaded prostheses[37,40,41] (Figure 4-1, *A* and *B*).

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FIGURE 4-1. **A,** Stainless steel (316L) fracture fixation screw showing crevice corrosion after 1 year in vivo (≈μ 5). **B,** Microscopic characteristics of cobalt alloy root form surface showing environmental degradation (≈μ 100). **C,** As-polished microstructure of cobalt alloy subperiosteal showing porosity associated with galvanically assisted corrosion (≈μ 100).

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Galvanic corrosion occurs when two dissimilar metallic materials are in contact and are within an electrolyte resulting in current flowing between the two. The metallic materials with the dissimilar potentials can have their corrosion currents altered, thereby resulting in a greater corrosion rate (Figure 4-1, *C*). FC occurs when a micromotion and rubbing contact occurs within a corrosive environment (e.g., the perforation of the passive layers and shear-directed loading along adjacent contacting surfaces). The loss of any protective film can result in the acceleration of metallic ion loss. FC has been shown to occur along implant body–abutment–superstructure interfaces.

Normally, the passive oxide layers on metallic substrates dissolve at such slower rates that the resultant loss of mass is of no mechanical consequence to the implant. A more critical problem is the irreversible local perforation of the passive layer that chloride ions often cause, which may result in localized pitting corrosion. Such perforations can often be observed for iron–chromium–nickel–molybdenum (Fe-Cr-Ni-Mo) steels that contain an insufficient amount of the alloying elements stabilizing the passive layer (i.e., Cr and Mo) or local regions of implants that are subjected to abnormal environments. Even ceramic oxide materials are not fully degradation resistant. Corrosion-like behavior of ceramic materials can then be compared with the chemical dissolution of the oxides into ions or complex ions of respective metallic oxide substrates. An example of this is the solubility of aluminum oxide as alumina or titanium oxide as titania. This statement is generally valid; however, most metallic oxides and nonmetallic substrates have amorphous hydroxide–inclusive structures, but bulk ceramics are mostly crystalline. The corrosion resistance of synthetic polymers, on the other hand, depends not only on their composition and structural form but also on the degree of polymerization. Unlike metallic and ceramic materials, synthetic polymers are not only dissolved but also penetrated by water and substances from biological environments. The resulting degree of alteration depends on the material property conditions for the manufactured component.

Toxicity and Considerations

Toxicity is related to primary biodegradation products (simple and complex cations and anions), particularly those of higher atomic weight metals. Factors to be considered include (1) the amount dissolved by biodegradation per time unit, (2) the amount of material removed by metabolic activity in the same time unit, and (3) the quantities of solid particles and ions deposited in the tissue and any associated transfers to the systemic system. For example, the quantity of elements released from metals during corrosion time (e.g., grams per day) can be calculated by using the following formula[15]:

$$\text{TE (g/day)} = \text{TEA (\%)} \times \text{CBR (g/cm}^2 \times \text{day)} \times \text{IS (cm}^2\text{)}/100$$

where *TE* = toxic element, *TEA* = toxic elements in alloy, *CBR* = corrosion biodegradation, and *IS* = implant surface.

It is of little importance for the formula whether or not the metallic substrate is exposed because the passive layer is dissolved. The critical issue is that the surface represents the "finished" form of the implant. The formula is also valid for ceramic materials and for substances transferred from synthetic polymers. Therefore, it appears that the toxicity is related to the content of the materials' toxic elements and that they may have a modifying effect on corrosion rate.[15]

The transformation of harmful primary products is dependent on their level of solubility and transfer. It is known that whereas chromium and titanium ions react locally at low concentrations, cobalt, molybdenum, or nickel can remain dissolved at higher relative concentrations and thus may be transported and circulated in body fluids. Several studies have documented the relative toxicity of titanium and its alloys and are addressed within the section on titanium.

Lemons[32] reported on the formation of electrochemical couples as a result of oral implant and restorative procedures and stressed the importance of selecting compatible metals to be placed in direct contact with one another in the oral cavity to avoid the formation of adverse electrochemical couples. The electrochemical behavior of implanted materials has been instrumental in assessing their biocompatibility.[42] Zitter and Plenk[43] have shown that anodic oxidation and cathodic reduction take place in different spaces but must always balance each other through charge transfer. This has been shown to impair both cell growth and transmission of stimuli from one cell to another. Therefore, an anodic corrosion site can be influenced by ion transfer but also by other possibly detrimental oxidation phenomena. Charge transfer appears to be a significant factor specific to the biocompatibility of metallic biomaterials. Passive layers along the surfaces of titanium, niobium, zirconium, and tantalum increase resistance to charge transfer processes by isolating the substrate from the electrolyte in addition to providing a higher resistance to ion transfers. On the other hand, metals based on iron, nickel, or cobalt are not as resistant to transfers through the oxidelike passive surface zones.

Metals and Alloys

To date, most of the dental implant systems available within the United States are constructed from metals or alloys. These materials are reviewed in this chapter by separating the metals and alloys according to their elemental compositions because a growing proportion have modified surface characteristics that are addressed in the second section of this chapter.

Several organizations have provided guidelines for the standardization of implant materials.[44] ASTM Committee F4 (ASTM F4) and ISO (ISOTC 106, ISOTR 10541) have provided the basis for such standards.[19,20] To date, a multinational survey by ISO indicated that titanium and its alloy are mainly used. The most widely used nonmetallic implants are oxidic, carbonitic, or graphitic oxidelike materials.[45]

The major groups of implantable materials for dentistry are titanium and alloys, cobalt chromium alloys, austenitic Fe-Cr-Ni-Mo steels, tantalum, niobium and zirconium alloys, precious metals, ceramics, and polymeric materials.

Titanium and Titanium–6 Aluminum–4 Vanadium (Ti-6Al-4V)

This reactive group of metals and alloys (with primary elements from reactive group metallic substances) form tenacious oxides in air or oxygenated solutions. Titanium oxidizes (passivates) on contact with room temperature air and normal tissue fluids. This reactivity is favorable for dental implant devices. In the absence of interfacial motion or adverse environmental conditions, this passivated (oxidized) surface condition minimizes biocorrosion phenomena. In situations in which the implant would be placed within a closely fitting receptor site in bone, areas scratched or abraded during placement would repassivate in vivo. This characteristic is one important property consideration related to the use of titanium for dental implants.[37,46–48] Some reports show that the oxide layer tends to increase in

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thickness under corrosion testing[48] and that breakdown of this layer is unlikely in aerated solutions.[49]

Bothe et al.[50] studied the reaction of rabbit bone to 54 different implanted metals and alloys and showed that titanium allowed bone growth directly adjacent to the oxide surfaces. Leventhal[51] further studied the application of titanium for implantation. Beder et al.,[52] Gross et al.,[53] Clarke et al.,[54] and Brettle[55] were able to expand indications of these materials. In all cases, titanium was selected as the material of choice because of its inert and biocompatible nature paired with excellent resistance to corrosion.[1,56–60]

Specific studies in the literature addressed the corrosion of titanium implants and are reported in the surface characteristics section. Unfortunately, most are for in vitro and unloaded conditions, and few identify precisely the type of titanium and titanium surface studied.

The general engineering properties of the metals and alloys used for dental implants are summarized in Table 4-1. Titanium shows a relatively low modulus of elasticity and tensile strength compared with most other alloys. The strength values for the wrought soft and ductile metallurgic condition (normal root forms and plate form implants) are approximately 1.5 times greater than the strength of compact bone. In most designs in which the bulk dimensions and shapes are simple, the strength of this magnitude is adequate. Because fatigue strengths are normally 50% weaker or less than the corresponding tensile strengths, implant design criteria are decidedly important. The creation of sharp corners or thin sections must be avoided for regions loaded under tension or shear conditions. The modulus of elasticity of titanium is five times greater than that of compact bone, and this property places emphasis on the importance of design in the proper distribution of mechanical stress transfer. In this regard, surface areas that are loaded in compression have been maximized for some of the newer implant designs. Four grades of unalloyed titanium and titanium alloy are the most popular. Their ultimate strength and endurance limit vary as a function of their composition.

The alloy of titanium most often used is titanium–aluminum–vanadium. The wrought alloy condition is approximately six times stronger than compact bone and thereby affords more opportunities for designs with thinner sections (e.g., plateaus, thin interconnecting regions, implant-to-abutment connection screw housing, irregular scaffolds, porosities). The modulus of elasticity of the alloy is slightly greater than that of titanium, being about 5.6 times that of compact bone. The alloy and the primary element (i.e., titanium) both have titanium oxide (passivated) surfaces. Information has been developed on the oxide thickness, purity, and stability as related to implant biocompatibilities.[9,14,19] In general, titanium and alloys of titanium have demonstrated interfaces described as *osseointegrated* for implants in humans. In addition, surface conditions in which the oxide thickness has varied from hundreds of angstroms of amorphous oxide surface films to 100% titania (titanium dioxide [TiO_2] rutile form ceramic) have demonstrated osseointegration.

The possible influences of aluminum and vanadium biodegradation products on local and systemic tissue responses have been reviewed from the perspectives of basic science and clinical applications.[61] Extensive literature has been published on the corrosion rate of titanium within local tissue fluids[62–64] and the periimplant accumulation of "black particles."[65] A few adverse effects have been reported.[66] Increased titanium concentrations were found in both periimplant tissues and parenchymal organs,[67,68] mainly the lung and much lesser concentrations in the liver, kidney, and spleen.[25,66–70] However, alloy compositions were not well defined or controlled. Corrosion and mechanical wear have been suggested as possible causes.[48,67,68] Authors who still caution about the applicability of these results to the presently available titanium alloys have developed other alloys using iron, molybdenum, and other elements as primary alloying agents.[17] More recently, several new titanium alloys of higher strength have been introduced.[33,71]

Although many basic science questions remain, clinical applications of these alloys in dental and orthopedic surgical systems have been very positive, especially in light of improved strength, and the titanium alloys have not demonstrated significant numbers of identifiable negative sequelae.[19]

Electrochemical studies support the selection of conditions in which elemental concentrations would be relatively low in magnitude.[11] Electrochemically, titanium and titanium alloy are slightly different in regard to electromotive and galvanic potentials compared with other electrically conductive dental

TABLE 4-1
Engineering Properties of Metals and Alloys Used for Surgical Implants*

Material	Nominal Surface Analysis (w/o)	Modulus of Elasticity, GN/m^2 (psi μ 10^6)	Ultimate Tensile Strength, MN/m^2 (ksi)	Elongation to Fracture (%)	
Titanium oxide	99+Ti	97 (14)	240–550 (25–70)	15	Ti
Titanium oxide aluminum–vanadium	90Ti-6Al-4V	117 (17)	869–896	>12	Ti
Cobalt–oxide chromium–molybdenum (casting)	66Co-27Cr-7Mo	235 (34)	655 (95)	>8	Cr
Stainless oxide steel (316L)	70Fe-18Cr-12Ni	193 (28)	480–1000	>30	Cr
Zirconium oxide		97 (14)	552 (80)	20	Zr
Tantalum oxide		—	690 (100)	11	Ta
Gold	99^+Au	97 (14)	207–310 (30–45)	>30	Au
Platinum	99^+Pt	166 (24)	131 (19)	40	Pt

*Minimum values from the American Society for Testing and Materials Committee F4 documents are provided. Selected products provide a range of properties.
GN/m^2, Giganewtons per meter squared; *ksi*, thousand pounds per inch squared; *MN/m^2*, meganewtons per meter squared; *psi*, pounds per inch squared; *w/o*, weight percent.

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TABLE 4-2
Electrochemical Reactivity

A	Gold alloys
B	Palladium alloys
C	Titanium alloys
D	Cobalt alloys
E	Nickel alloys

materials. Results of these electrochemical potentials and how they relate to in vivo responses have been published previously.[9,42,63] In general, titanium- and cobalt-based systems are electrochemically similar; however, comparative elements imitating the conditions in an aeration cell revealed that the current flow in titanium and titanium alloys is several orders of magnitude lower than that in Fe-Cr-Ni-Mo steels or Co-Cr alloys.[15]

Recent reports have challenged traditional thinking in some ways regarding the use of cobalt-based alloys as superstructures for implant prosthetics. As the price of noble metals has increased, clinicians are exploring alternatives for prosthetic constructs. This is particularly true in the case of implant dentistry, in which metal substructures can be of considerable size, with a comparable cost. Dissimilar metals, when attached electrochemically, may experience ion flow, and the deleterious clinical consequences of this are noted.[72,73] Because of the unique and tenacious oxide layer formed by titanium, ion flow is limited. If titanium is coupled with a gold superstructure, for example, the titanium oxide formed on the surface of the titanium prevents clinically significant ion exchange, leading to clinically acceptable intraoral couples. In couples in which the titanium is the more noble metal, the less noble metal continues to corrode, especially in crevices. In other words, the more noble metal will corrode the less noble metal (Table 4-2). The amount of corrosion and current flow depends on the particular host environment; the assessment is further complicated by varied in vitro techniques used.[74] At least one in vitro study supports the use of a cobalt-based alloy coupled with titanium.[75] The use of cobalt-based superstructures is further supported by a wide variety of clinical experiences and commercially available superstructures made from cobalt–chromium alloys. As one example, many large commercial laboratories mill implant superstructures out of cobalt-based alloys. Other clinicians have published case reports using cobalt-based implant superstructures.[76,77]

At least one manufacturer (NobleBond; Argen) has responded to the concerns above by producing a cobalt-based alloy with large amounts of ruthenium. Ruthenium (Ru) is a noble metal in the platinum family, with excellent corrosion resistance, but is considerably cheaper than gold and platinum. This alloy contains 40% cobalt, 25% ruthenium, and 24% chromium. Although the clinical performance of this alloy remains to be seen, advances such as these may eventually permit clinicians to use alternative alloys such as palladium- and ruthenium-based metals for clinical restoration of implants (Figure 4-2). The use of palladium-based alloys is also supported by clinical use and in vitro analysis.[78]

To eliminate the presence of dissimilar metals, some clinicians have chosen to fabricate implant superstructures using milling techniques. With this technology, an implant bar superstructure, for example, can be milled from a single billet of titanium (Figure 4-3). Advances in optical imaging (for impressions, either in the laboratory or intraorally), as well as milling

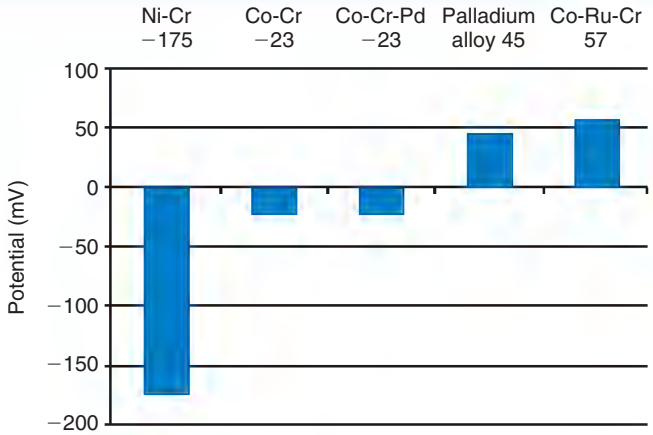


FIGURE 4-2. Corrosion of alloys coupled to titanium. Base metals coupled to titanium show inferior corrosion properties compared with noble metals palladium alloy and Co-Ru alloy. (Source: Argen Corporation.)



FIGURE 4-3. Milled implant superstructures. A variety of precision-milled devices are readily available with contemporary laboratory support. When devices are milled from titanium, the electrochemical potential is zero, and current flow is eliminated. Abutments may also be fabricated using CAD/CAM techniques, either from metallic or ceramic materials, or combinations.

technology, have made this approach possible. Because the superstructure is milled from the same material as the implants themselves, dissimilar metals are not present, and current does not flow. Alternatively, the superstructure can be milled from all ceramic (Zirconzahn; Figure 4-4). This approach can use machined metal connectors that are luted into the structure (Figure 4-5), or the implant–abutment interface may be milled into the prosthesis as well.

Mechanically, titanium is much more ductile (bendable) than titanium alloy. This feature has been a very favorable aspect related to the use of titanium for endosteal plate form devices. The need for adjustment or bending to provide parallel abutments for prosthetic treatments has caused manufacturers to optimize microstructures and residual strain conditions. Coining, stamping, or forging followed by controlled annealing heat treatments are routinely used during metallurgic processing. However, if an implant abutment is bent at the time of implantation, then the metal is strained locally at the neck region (bent), and the local strain is both cumulative and dependent on the total amount of deformation introduced during the procedure. This is one reason, other than prior loading fatigue cycling, why reuse of implants is not

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FIGURE 4-4. Monolithic zirconia ceramic framework, fixed implant prosthesis. The occlusal surfaces and framework are milled from a single block of ceramic. After applying metal oxide liquids and firing to color teeth, a thin pink veneering porcelain may be added to create gingival contours and tones.



FIGURE 4-5. All-ceramic milled prosthesis with metal connectors. After sintering and coloration, machined metal connectors may be used to interface with the implant platform.

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recommended. In addition, mechanical processes can sometimes significantly alter or contaminate implant surfaces. Any residues of surface changes must be removed before implantation to ensure mechanically and chemically clean conditions.

The emerging techniques to cast titanium and titanium alloys remain limited for dental implant application because of high melting points of the elements and propensity for absorption of oxygen, nitrogen, and hydrogen, which may cause metallic embrittlement. A high vacuum or ultrapure protective gas atmosphere allows the production of castings in titanium and its alloys at different purity levels,[79,80] although microstructures and porosity are relatively unfavorable related to fatigue and fracture strengths.[9,32] Typical strengths of cast commercially pure (CP) titanium grade 2 and Ti-6Al-4V after heat treatment and annealing can be in the range of those of wrought titanium alloys used for dental implants.[81]

Cobalt-Chromium-Molybdenum–Based Alloy

The cobalt-based alloys are most often used in an as-cast or cast-and-annealed metallurgic condition. This permits the fabrication of implants as custom designs such as subperiosteal frames. The elemental composition of this alloy includes cobalt, chromium, and molybdenum as the major elements. Cobalt provides the continuous phase for basic properties; secondary phases based on cobalt, chromium, molybdenum, nickel, and carbon provide strength (four times that of compact bone) and surface abrasion resistance (see Table 4-1); chromium provides corrosion resistance through the oxide surface; and molybdenum provides strength and bulk corrosion resistance. All of these elements are critical, as is their concentration, which emphasizes the importance of controlled casting and fabrication technologies. Also included in this alloy are minor concentrations of nickel, manganese, and carbon. Nickel has been identified in biocorrosion products, and carbon must be precisely controlled to maintain mechanical properties such as ductility. Surgical alloys of cobalt are not the same as those used for partial dentures, and substitutions should be avoided.

In general, the as-cast cobalt alloys are the least ductile of the alloy systems used for dental surgical implants, and bending of finished implants should be avoided. Because many of these alloy devices have been fabricated by dental laboratories, all aspects of quality control and analysis for surgical implants must be followed during alloy selection, casting, and finishing. Critical considerations include the chemical analysis, mechanical properties, and surface finish as specified by the ASTM F4 on surgical implants and the ADA.[19,21] When properly fabricated, implants from this alloy group have shown to exhibit excellent biocompatibility profiles.

Iron-Chromium-Nickel–Based Alloys

The surgical stainless steel alloys (e.g., 316 low carbon [316L]) have a long history of use for orthopedic and dental implant devices. This alloy, as with titanium systems, is used most often in a wrought and heat-treated metallurgic condition, which results in a high-strength and high-ductility alloy. The ramus blade, ramus frame, stabilizer pins (old), and some mucosal insert systems have been made from the iron-based alloy.

The ASTM F4 specification for surface passivation was first written and applied to the stainless steel alloys.[19] In part, this was done to maximize corrosion–biocorrosion resistance. Of the implant alloys, this alloy is most subject to crevice and pitting biocorrosion, and care must be taken to use and retain the passivated (oxide) surface condition. Because this alloy contains nickel as a major element, use in patients allergic or hypersensitive to nickel should be avoided. In addition, if a stainless steel implant is modified before surgery, then recommended procedures call for repassivation to obtain an oxidized (passivated) surface condition to minimize in vivo biodegradation.

The iron-based alloys have galvanic potentials and corrosion characteristics that could result in concerns about galvanic coupling and biocorrosion if interconnected with titanium, cobalt, zirconium, or carbon implant biomaterials.[82–84] In some clinical conditions, more than one alloy may be present within the same dental arch of a patient. For example, if a bridge of a noble or a base-metal alloy touches the abutment heads of a stainless steel and titanium implant simultaneously, then an electrical circuit would be formed through the tissues. If used independently, where the alloys are not in contact or not electrically interconnected, then the galvanic couple would not exist, and each device could function independently. As with the other metal and alloy systems discussed, the iron-based alloys have a long history of clinical applications. Long-term device retrievals have demonstrated that, when used properly, the alloy can function without significant in vivo breakdown. Clearly, the

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mechanical properties and cost characteristics of this alloy offer advantages with respect to clinical applications.

Other Metals and Alloys

Many other metals and alloys have been used for dental implant device fabrication. Early spirals and cages included tantalum, platinum, iridium, gold, palladium, and alloys of these metals. More recently, devices made from zirconium, hafnium, and tungsten have been evaluated.[15,85,86] Some significant advantages of these reactive group metals and their alloys have been reported, although large numbers of such devices have not been fabricated in the United States.

Gold, platinum, and palladium are metals of relatively low strength, which places limits on implant design. In addition, cost-per-unit weight and the weight-per-unit volume (density) of the device along the upper arch have been suggested as possible limitations for gold and platinum. These metals, especially gold because of nobility and availability, continue to be used as surgical implant materials. For example, the Bosker endosteal staple design represents use of this alloy system.[87]

Ceramics and Carbon

Ceramics are inorganic, nonmetallic, nonpolymeric materials manufactured by compacting and sintering at elevated temperatures. They can be divided into metallic oxides and other compounds. Oxide ceramics were introduced for surgical implant devices because of their inertness to biodegradation, high strength, physical characteristics such as color and minimal thermal and electrical conductivity, and a wide range of material-specific elastic properties.[88,89] In many cases, however, the low ductility or inherent brittleness has resulted in limitations. Ceramics have been used in bulk forms and more recently as coatings on metals and alloys.

Aluminum, Titanium, and Zirconium Oxides

High-strength ceramics from aluminum, titanium, and zirconium oxides have been used for root form, endosteal plate form, and pin type of dental implants.[90] The overall characteristics of these ceramics are summarized in Table 4-3. The compressive, tensile, and bending strengths exceed the strength of compact bone by three to five times. These properties, combined with high moduli of elasticity, and especially with fatigue and fracture strengths, have resulted in specialized design requirements for these classes of biomaterials.[19,91] For example, the fabrication of a subperiosteal device from a high ceramic should not be done because of the custom nature of these devices, the lower fracture resistance, and the relative cost for manufacturing. The aluminum, titanium, and zirconium oxide ceramics have a clear, white, cream, or light-gray color, which is beneficial for applications such as anterior root form devices. Minimal thermal and electrical conductivity, minimal biodegradation, and minimal reactions with bone, soft tissue, and the oral environment are also recognized as beneficial compared with other types of synthetic biomaterials. In early studies of dental and orthopedic devices in laboratory animals and humans, ceramics have exhibited direct interfaces with bone, similar to an osseointegrated condition with titanium. In addition, characterization of gingival attachment zones along sapphire root form devices in laboratory animal models has demonstrated regions of localized bonding.[9,92–96]

Although the ceramics are chemically inert, care must be taken in the handling and placement of these biomaterials. Exposure to steam sterilization results in a measurable decrease in strength for some ceramics; scratches or notches may introduce fracture initiation sites; chemical solutions may leave residues; and the hard and sometimes rough surfaces may readily abrade other materials, thereby leaving a residue on contact. Dry-heat sterilization within a clean and dry atmosphere is recommended for most ceramics.

One series of root form and plate form devices used during the 1970s resulted in intraoral fractures after several years of function.[97] The fractures were initiated by fatigue cycling where biomechanical stresses were along regions of localized bending and tensile loading. Although initial testing showed adequate mechanical strengths for these polycrystalline alumina materials,[98] the long-term clinical results clearly demonstrated a functional design-related and material-related limitation. This illustrates the need for controlled clinical investigation to relate basic properties to in vivo performance. The established chemical biocompatibilities, improved strength and toughness capabilities of sapphire and zirconia, and the basic property characteristics of high ceramics continue to make them excellent candidates for dental implants.

Bioactive and Biodegradable Ceramics Based on Calcium Phosphates

Bone Augmentation and Replacement

The calcium phosphate ($CaPO_4$) materials (i.e., calcium phosphate ceramics [CPCs]) used in dental reconstructive surgery include a wide range of implant types and thereby a wide range of clinical applications. Early investigations emphasized solid and porous particulates with nominal compositions that were relatively similar to the mineral phase of bone ($Ca_5[PO_4]_3OH$). Microstructural and chemical properties of these particulates were controlled to provide forms that would remain intact for

TABLE 4-3
Engineering Properties of Some Inert Ceramics Used as Biomaterials*

Material	Modulus of Elasticity, GN/m^2 (psi μ 10^6)	Ultimate Bending Strength, MPa (ksi)	Surface
Aluminum oxide (43–80)	Polycrystalline Al_2O_3	372 (54)	300–550
	Single crystal (sapphire) Al_2O_3	392 (56)	640 (93)
Zirconium oxide zirconia (PSZ) (72–94)	ZrO_2	195–210 (28–30)	500–650
Titanium oxide (titania)	280 (41)	69–103 (10–15)	TiO_2

*These high ceramics have 0% permanent elongation at fracture.
GN/m^2, Giganewtons per meter squared; *ksi*, thousand pounds per inch squared; *MPa*, megapascals; *psi*, pounds per inch squared.

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structural purposes after implantation. The laboratory and clinical results for these particulates were most promising and led to expansions for implant applications, including larger implant shapes (e.g., rods, cones, blocks, H-bars) for structural support under relatively high-magnitude loading conditions.[99,100] In addition, the particulate size range for bone replacements was expanded to both smaller and larger sizes for combined applications with organic compounds. Mixtures of particulates with collagen, and subsequently with drugs and active organic compounds such as bone morphogenetic protein, increased the range of possible applications. Over the past 20 years, these types of products and their uses have continued to expand significantly.[100–103]

Endosteal and Subperiosteal Implants

The first series of structural forms for dental implants included rods and cones for filling tooth root extraction sites (ridge retainers)[104] and, in some cases, load-bearing endosteal implants.[105] Limitations in mechanical property characteristics soon resulted in internal reinforcement of the CPC implants through mechanical (central metallic rods) or physicochemical (coating over another substrate) techniques.[106,107]

The numbers of coatings of metallic surfaces using flame or plasma spraying (or other techniques) increased rapidly for the CPCs.[100] The coatings have been applied to a wide range of endosteal and subperiosteal dental implant designs, with an overall intent of improving implant surface biocompatibility profiles and implant longevities (and are addressed later in this chapter).[108–110]

Advantages and Disadvantages

Box 4-1 summarizes the advantages and disadvantages of CPCs. The recognized advantages associated with the CPC biomaterials are as follows[111]:

1. Chemical compositions of high purity and of substances that are similar to constituents of normal biological tissue (calcium, phosphorus, oxygen, and hydrogen)
2. Excellent biocompatibility profiles within a variety of tissues, when used as intended
3. Opportunities to provide attachments between selected CPC and hard and soft tissues
4. Minimal thermal and electrical conductivity plus capabilities to provide a physical and chemical barrier to ion transport (e.g., metallic ions)
5. Moduli of elasticity more similar to bone than many other implant materials used for load-bearing implants
6. Color similar to bone, dentin, and enamel
7. An evolving and extensive base of information related to science, technology, and application

Some of the possible disadvantages associated with these types of biomaterials are as follows:

1. Variations in chemical and structural characteristics for some currently available implant products
2. Relatively low mechanical tensile and shear strengths under condition of fatigue loading
3. Relatively low attachment strengths for some coating-to-substrate interfaces
4. Variable solubilities depending on the product and the clinical application (the structural and mechanical stabilities of coatings under in vivo load-bearing conditions, especially tension and shear, may be variable as a function of the quality of the coating.)
5. Alterations of substrate chemical and structural properties related to some available coating technologies
6. Expansion of applications that sometimes exceed the evolving scientific information on properties

Critical to applications are the basic properties of these substances. Table 4-4 provides a summary of some properties of bioactive and biodegradable ceramics. In general, these classes of bioceramics have lower strengths, hardnesses, and moduli of elasticity than the more chemically inert forms previously

BOX 4-1 Advantages and Disadvantages of Calcium Phosphate Ceramics

Advantages	Disadvantages
Chemistry mimics normal biological tissue (C, P, O, H)	Variable chemical and structural characteristics (technology and chemistry related)
Excellent biocompatibility	Low mechanical tensile and shear strengths under fatigue loading
Attachment between calcium phosphate ceramics and hard and soft tissues	Low attachment between coating and substrate
Minimal thermal and electrical conductivity	Variable solubility
Moduli of elasticity closer to bone than many other implantable materials	Variable mechanical stability of coatings under load-bearing conditions
Color similar to hard tissues	Overuse
Extensive research	

TABLE 4-4
Properties of Bioactive and Biodegradable Ceramics*

Material	Modulus of Elasticity, GPa (psi μ 10^6)	Ultimate Bending Strength, MPa (ksi)	Surface
Hydroxyapatite	40–120 (6–17)	40–300 (6–43)	$Ca_{10}(PO_4)_6(OH)_2$
Tricalcium phosphate	30–120 (4–17)	15–120 (2–17)	$Ca_3(PO_4)_2$
Bioglass or Ceravital	40–140 (6–20)	20–350 (3–51)	$CaPO_4$
AW ceramic	124 (18)	213 (31)	$CaPO_4$ + F
Carbon	25–40 (4–6)	150–250 (22–36)	C
Carbon–silicon (LTI)	25–40 (4–6)	200–700 (29–101)	CSi

*These ceramics and carbons have 0% permanent elongation at fracture.
GPa, Gigapascals; *psi*, pounds per inch squared; *ksi*, thousand pounds per inch squared; *LTI*, low-temperature isotropic; *MPa*, megapascals.

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discussed. Fatigue strengths, especially for porous materials, have imposed limitations with regard to some dental implant designs. In certain instances, these characteristics have been used to provide improved implant conditions (e.g., biodegradation of particulates).

Calcium aluminates, sodium–lithium invert glasses with $CaPO_4$ additions (Bioglass or Ceravital), and glass ceramics (AW glass-ceramic) also provide a wide range of properties and have found extended applications.[103,107]

Bioactive Ceramic Properties

Physical properties are specific to the surface area or form of the product (block, particle), porosity (dense, macroporous, microporous), and crystallinity (crystalline or amorphous). Chemical properties are related to the calcium–phosphate ratio, composition, elemental impurities (e.g., carbonate), ionic substitution in atomic structure, and the pH of the surrounding region. These properties plus the biomechanical environment all play a role in the rate of resorption and the clinical application limits of the materials.

The atomic relationships of the basic elements, stoichiometric ratios, and the normal chemical names for several characterized CPCs are provided in Table 4-5. The general family of apatites has the following formula:

$$M_{10}^{2+}(XO_4^{3})_6Z_2^{1}$$

Very often, apatite atomic ratios are nonstoichiometric; that is, 1 mol of apatite may contain fewer than 10 mol of metallic ions (M^{2+}) and fewer than 2 mol of anions Z^{-1}.[112] The number of XO retains a number of 6. Multiple metals and anions can be substituted within this formulation. Most important, the relative physical, mechanical, and chemical properties of each final $CaPO_4$ material, including each of the apatites, are different from one another.[96,102] In addition, the microstructure of any final product (solid structural form or coating) is equally important to the basic properties of the substance alone. The crystalline monolithic hydroxyapatite (HA) (fired ceramic $Ca_{10}[PO_4]_6[OH]_2$) of high density and purity (50 maximum ppm impurities) has provided one standard for comparison related to implant applications. The ratio of calcium to phosphorus of $Ca_{10}(PO_4)_6(OH)_2$ is 1.67, and the ceramic can be fully crystalline. Considerable differences exist between the synthetic HA ceramics (HAs) that are produced by elevated temperature processing and biological apatites (HAs).[112] Biological apatites contain trace amounts of $(CO_3)^2$, sodium, magnesium, fluorine, and chlorine ions. These exist in varying ratios and distributions and, of course, are only one phase of calcified tissues.

The crystalline tricalcium phosphate ($bCa_3[PO_4]_2$) (b-TCP) ceramic has also provided a high-purity (<50 ppm maximum impurities) biomaterial for comparison with other products. National standard specifications related to the basic properties and characteristics of both HA and TCP have been published.[19] These two compositions have been used most extensively as particulates for bone augmentation and replacement, carriers for organic products, and coatings for endosteal and subperiosteal implants.

One of the more important aspects of the CPCs relates to the possible reactions with water. For example, hydration can convert other compositions to HA; also, phase transitions among the various structural forms can exist with any exposure to water. This has caused some confusion in the literature in that some CPCs have been steam autoclaved for sterilization purposes before surgical implantation. Steam or water autoclaving can significantly change the basic structure and properties of CPCs (or any bioactive surface) and thereby provide an unknown biomaterial condition at the time of implantation. This is to be avoided through the use of presterilized or clean, dry heat or gamma-sterilized conditions.

Forms, Microstructures, and Mechanical Properties

Particulate HA, provided in a nonporous (<5% porosity) form as angular or spherically shaped particles, is an example of a crystalline, high-purity HA biomaterial[113] (Figure 4-6, *A*). These particles can have relatively high compressive strengths (up to 500 MPa), with tensile strengths in the range of 50 to 70 MPa. Usually, dense polycrystalline ceramics consisting of small crystallites exhibit the highest mechanical strength apart from monocrystalline ceramics free of defects (e.g., single-crystal sapphire implants). Ceramics are brittle materials and exhibit high compressive strengths compared with tensile strengths. However, less resistance to tensile and shear stresses limit their application as dental implants because of mechanical constraints of implant form and volume. Nonresorbable, "bioinert" ceramics exhibiting satisfactory load-bearing capability are limited to dense monocrystalline and polycrystalline aluminum, zirconium, and titanium oxide ceramics. These same mechanical characteristics exist for the solid portions of several porous HA particulates and blocks. The macroporous (>50 mm)

TABLE 4-5
Names, Formulae, and Atomic Ratios for Some Calcium Phosphate Materials

Mineral or General Name	Formula	Ca:P Ratio	Applications
Monetite (DVP) substitute particulate	$CaHPO_4$	1	Nonceramic bone
Brushite (DCPD) biomaterials	$CaHPO_4\ 2H_2O$	1	Phase of some $CaPO_4$
Octacalcium phosphate (OCP)	$Ca_8(HPO_4)_2(PO_4)\ 5H_2O$	11.33	Phase of some $CaPO_4$ biomaterials
Whitlockite (WH) biomaterials	$Ca_{10}(HPO_4)(PO_4)_6$	1.43	Phase of some $CaPO_4$ biomaterials
Beta-tricalcium phosphate (b-TCP)	$Ca_3(PO_4)_2$	1.48	Biodegradable $CaPO_4$ ceramic for bone substitute and coatings; also a phase of some $CaPO_4$ biomaterials
Defective hydroxyapatite (DOHA) biomaterials	$Ca_9(HPO_4)(PO_4)_5(OH)$	1.5	Component of some $CaPO_4$ biomaterials
Hydroxyapatite (HA)	$Ca_{10}(PO_4)_6(OH)_2$	1.67	Major mineral phase of bone; when fired as a ceramic, named *HA*

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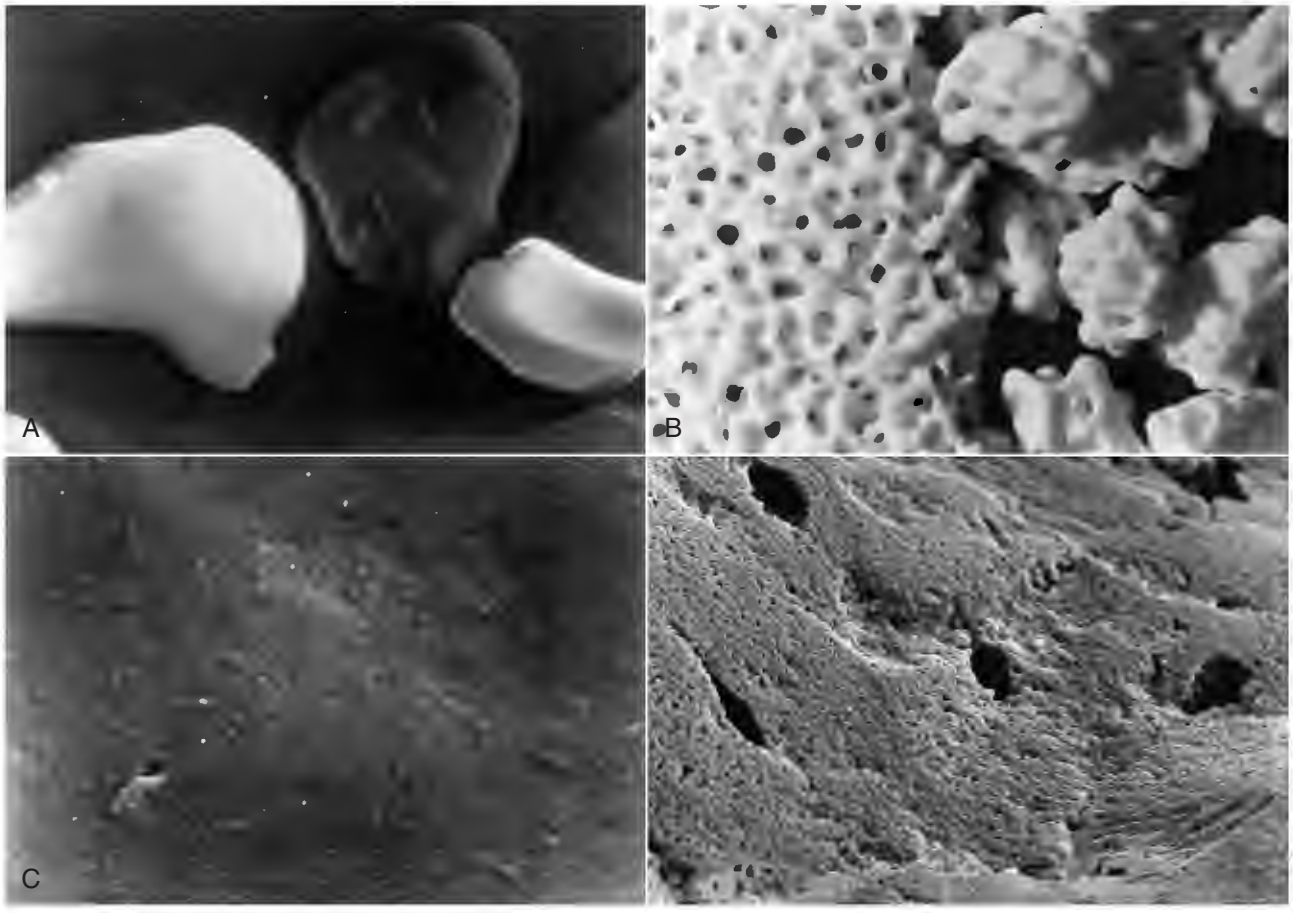


FIGURE 4-6. **A,** Particulate dense hydroxyapatite presents as a crystalline nonporous material with angular or spherical particles. Macroporous (**B**) and microporous (**C**) particulates offer the advantage of increased surface area per unit volume, which facilitates solution and cell-mediated resorption. (Courtesy DENTSPLY Implants, Waltham, MA.)

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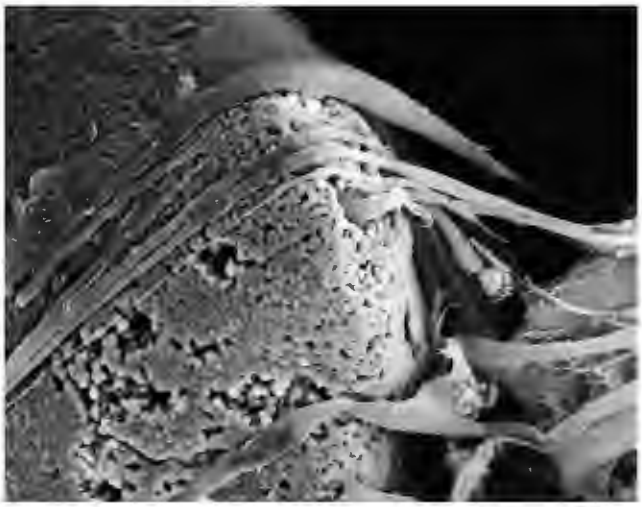


FIGURE 4-7. Scanning electron microscopy of cells, which actively endocytosed fragments of granules (μ 1500). (Courtesy DENTSPLY Implants, Waltham, MA.)

or microporous (<50 mm) particulates have an increased surface area per unit volume. This provides more surface area for solution- and cell-mediated resorption under static conditions and a significant reduction in compressive and tensile strengths (Figure 4-6, *B* and *C*; Figure 4-7). The porous materials also provide additional regions for tissue ingrowth and integration (mechanical stabilization) and thereby a minimization of interfacial motion and dynamic (wear-associated) interfacial breakdown. The strength characteristics after tissue ingrowth would then become a combination of the ceramic and the investing tissues.[114]

A number of the CPCs are phase mixtures of HA and TCP, but some compounds are composites or mechanical mixtures with other materials[100] (see Table 4-5). These classes of bioactive ceramics, including glasses, glass-ceramics, mixtures of ceramics, combinations of metals and ceramics, and polymers and ceramics, exhibit a wide range of properties. In general, these biomaterials have shown acceptable biocompatibility profiles from laboratory and clinical investigations. Bulk-form implant designs made from CPCs, which were contraindicated for some implant designs because of poor mechanical performance, have found a wide range of indications as coatings of stronger implant materials.

The coatings of CPCs onto metallic (cobalt- and titanium-based) biomaterials have become a routine application for dental implants. For the most part these coatings are applied by plasma spraying, have average thickness between 50 and 70 mm, are mixtures of crystalline and amorphous phases, and have variable microstructures (phases and porosities) compared with the solid portions of the particulate forms of HA and

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TCP biomaterials.[100,115] At this time, coating characteristics are relatively consistent, and the quality control and stricter quality assurance programs from the manufacturers have greatly improved the consistency of coated implant systems. (A more detailed discussion of surface treatment options is presented in the next section.)

Concerns continue to exist about the fatigue strengths of the $CaPO_4$ coatings and coating–substrate interfaces under tensile and shear loading conditions. There have been some reports of coating loss as a result of mechanical fracture, although the numbers reported remain small.[96] This has caused some clinicians and manufacturers to introduce designs in which the coatings are applied to shapes (geometric designs) that minimize implant interface shear or tensile loading conditions (e.g., porosities, screws, spirals, plateaus, vents). From theoretical considerations, the coating of mechanically protected areas seems most desirable.

Density, Conductivity, and Solubility

Bioactive ceramics are especially interesting for implant dentistry because the inorganic portion of the recipient bone is more likely to grow next to a more chemically similar material. The bioactive (bioreactive) categorization includes $CaPO_4$ materials such as TCP, HA, calcium carbonate (corals), and calcium sulfate–type compounds and ceramics. A chemical–biochemical contact between the host bone and grafted material may be developed, as well as a possible stimulus of bone activity.[102] Their limitations have been associated with the material forms that have lower strengths (i.e., similar to or less than bone).[102]

The very technique-sensitive fabrication steps related to phase transition and thermal expansion during cooling might cause the final product of $CaPO_4$-type coatings to be more or less resorbable. In addition, the original categories of resorbable versus nonresorbable for these materials must be carefully weighed as a function of their particle size, porosity, chemical structure, and environmental exposure conditions.

Dissolution characteristics of bioactive ceramics have been determined for both particulates and coatings.[116,117] In general, solubility is greater for TCP than for HA. Each increase relative to increasing surface area per unit volume (porosity), and the CPC solubility profiles depend on the environment (e.g., pH, mechanical motion).

If one considers a uniform material chemistry, then the larger the particle size is, the longer the material will remain at an augmentation site. Thus, 75-mm particles will be resorbed more rapidly than 3000-mm particles. In addition, the porosity of the product affects the resorption rate. Tofe et al.[118] reported on the porosity of dense, macroporous and microporous $CaPO_4$. Some of the dense HA lacks any macroporosity or microporosity within the particles. The longest resorption rate occurred with the dense nonporous HA type because osteoclasts may only attack the surface and cannot penetrate the nonporous material. Macroporous $CaPO_4$ (e.g., coralline HA) demonstrated 100- or 500-mm pores, which comprised 15% or more of the total material volume. Minimal porosity was found in the HA bulk material that surrounded the large pores. Microporous apatites often have their origin from bovine or human bone. The porosity observed in these materials is approximately 5 mm or less and comprises less than 28% of the total volume. The pores or holes are regions where blood components and organic materials can reside when placed within bone, and they represent the regions where living material existed before the processing of the implant material. The greater the porosity is, the more rapid

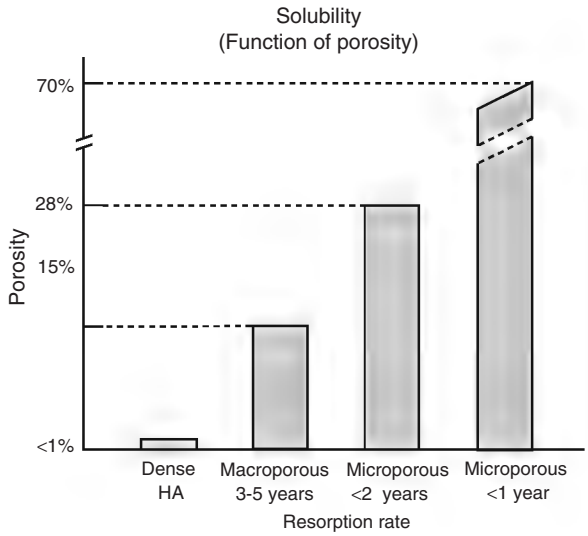


FIGURE 4-8. Diagram of solubility of hydroxyapatite (HA) in function of percent porosity.

is the resorption of the graft material. For example, clinical observation shows dense crystalline forms of HA may last longer than 15 years in the bone, the macroporous 5 years, and the microporous HA as short as 6 months (Figure 4-8).

The crystallinity of HA also affects the resorption rate of the material. The highly crystalline structure is more resistant to alteration and resorption. An amorphous product has a chemical structure that is less organized with regard to atomic structure. The hard or soft tissues of the body are more able to degrade the components and resorb the amorphous forms of grafting materials. Thus crystalline forms of HA are found to be very stable over the long term under normal conditions, but the amorphous structures are more likely to exhibit resorption and susceptibility to enzyme- or cell-mediated breakdown.[119] Therefore, in general, the less crystalline the material, the faster its resorption rate.[99,100,102,119,120]

The purity of the HA bone substitutes may also affect the resorption rate. The resorption of the bone substitute may be cell or solution mediated. Cell-mediated resorption requires processes associated with living cells to resorb the material, similar to the modeling and remodeling process of living bone, which demonstrates the coupled resorption and formation process. A solution-mediated resorption permits the dissolution of the material by a chemical process. Impurities or other compounds in bioactive ceramics, such as calcium carbonate, permit more rapid solution-medicated resorption, which then increases the porosity of the bone substitute. Although the coralline HA does not demonstrate micropores along the larger holes, the HA may have carbonates incorporated within the material, which hastens the resorption process.

The pH in the region in which the bone substitutes are placed also affects the rate of resorption. As the pH decreases (e.g., because of chronic inflammation or infection), the components of living bone, primarily $CaPO_4$, resorb by a solution-mediated process (i.e., they become unstable chemically).

The $CaPO_4$ coatings are nonconductors of heat and electricity. This can provide a relative benefit for coated dental implants, where mixtures of conductive materials may be included in the overall prosthetic reconstruction. In combination with color (off white), these properties are considered to be advantageous.

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In most applications within bone, solubilities are higher during the first few weeks, then decrease with continued in vivo exposure and the apposition of mineralized structures.[116,117] However, some investigators have shown situations in which osteoclastic resorption has removed localized zones of $CaPO_4$ coatings.[121] This raises interesting questions about long-term in vivo stabilities. At this time, clinical results have been favorable, and expanded applications have continued.

Carbon and Carbon Silicon Compounds

Carbon compounds are often classified as *ceramics* because of their chemical inertness and absence of ductility; however, they are conductors of heat and electricity. Extensive applications for cardiovascular devices, excellent biocompatibility profiles, and moduli of elasticity close to that of bone have resulted in clinical trials of these compounds in dental and orthopedic prostheses. One two-stage root replacement system (Vitredent) was quite popular in the early 1970s.[10] However, a combination of design, material, and application limitations resulted in a significant number of clinical failures and the subsequent withdrawal of this device from clinical use.

Ceramic and carbonitic substances continue to be used as coatings on metallic and ceramic materials. Advantages of coatings, as mentioned in an earlier section, include tissue attachment; components that are normal to physiologic environments; regions that serve as barriers to elemental transfer, heat, or electrical current flow; control of color; and opportunities for the attachment of active biomolecules or synthetic compounds. Possible limitations relate to mechanical strength properties along the substrate–coating interface; biodegradation that could adversely influence tissue stabilities; time-dependent changes in physical characteristics; minimal resistance to scratching or scraping procedures associated with oral hygiene; and susceptibility to standard handling, sterilizing, or placing methodologies. Greater uses of surface-coated dental implants have been developed by the research and development communities.

Polymers and Composites

The use of synthetic polymers and composites continues to expand for biomaterial applications. Fiber-reinforced polymers offer advantages in that they can be designed to match tissue properties, can be anisotropic with respect to mechanical characteristics, can be coated for attachment to tissues, and can be fabricated at relatively low cost. Expanded future applications for dental implant systems, beyond inserts for damping force transfers such as those used in the IMZ (Interpore, Inc.) and Flexiroot (Interdent Corp.) systems, are anticipated as interest continues in combination synthetic and biological composites.

Structural Biomedical Polymers

The more inert polymeric biomaterials include polytetrafluoroethylene (PTFE), polyethylene terephthalate (PET), polymethylmethacrylate (PMMA), ultra-high-molecular-weight polyethylene (UHMW-PE), polypropylene (PP), polysulfone (PSF), and polydimethylsiloxane (PDS, or silicone rubber [SR]). These are summarized in Table 4-6. In general, the polymers have lower strengths and elastic moduli and higher elongations to fracture compared with other classes of biomaterials. They are thermal and electrical insulators, and when constituted as a high-molecular-weight system without plasticizers, they are relatively resistant to biodegradation. Compared with bone, most polymers have lower elastic moduli with magnitudes closer to soft tissues.

TABLE 4-6
Engineering Properties of Polymers (Some Medical Grades)*

Material	Modulus of Elasticity, GPa (psi μ 10^5)	Ultimate Tensile Strength, MPa (ksi)	Elongation to Fracture (%)
PTFE	0.5–3 (0.07–4.3)	17–28 (2.5–4)	200–600
PET	3 (4.3)	55 (8)	50–300
PMMA	3 (4.3)	69 (10)	2–15
PE	8 (1.2)	48 (7)	400–500
PP	9 (1.3)	35 (5)	500–700
PSF	3.5 (5)	69 (10)	20–100
SR	0.1 (0.014)	5 (1.1)	300–900
POM	3 (4.3)	70 (10.1)	10–75

*Polymer properties exhibit a wide range depending on processing and structure. These values have been taken from general tables.
GPa, Gigapascals; *ksi,* thousand pounds per inch squared; *MPa,* megapascals; *PE,* polyethylene; *PET,* polyethylene terephthalate; *PMMA,* polymethylmethacrylate; *POM,* polyoxymethylene (IME insert); *PP,* polypropylene; *PSF,* polysulfone; *psi,* pounds per inch squared; *PTFE,* polytetrafluoroethylene; *SR,* silicone rubber.

Polymers have been fabricated in porous and solid forms for tissue attachment, replacement, and augmentation and as coatings for force transfer to soft tissue and hard tissue regions. Cold-flow characteristics and creep and fatigue strengths are relatively low for some classes of polymers (e.g., SR and PMMA) and have resulted in some limitations. In contrast, some are extremely tough and fatigue cycle resistant (e.g., PP, UHMW-PE, PTFE) and afford opportunities for mechanical force transfer within selected implant designs. Most uses have been for internal force distribution connectors for osseointegrated implants, where the connector is intended to better simulate biomechanical conditions for normal tooth functions. The indications for PTFE have grown exponentially in the past decade because of the development of membranes for guided tissue regeneration techniques. However, PTFE has a low resistance to contact abrasion and wear phenomena.

Composites

Combinations of polymers and other categories of synthetic biomaterials continue to be introduced. Several of the more inert polymers have been combined with particulate or fibers of carbon, Al_2O_3, HA, and glass-ceramics. Some are porous, but others are constituted as solid-composite structural forms.[122,123]

In some cases, biodegradable polymers, such as polyvinyl alcohol (PVA), polylactides or glycolides, cyanoacrylates, or other hydratable forms, have been combined with biodegradable $CaPO_4$ particulate or fibers.[124] These are intended as structural scaffolds, plates, screws, or other such applications. Biodegradation of the entire system, after tissues have adequately reformed and remodeled, has allowed the development of significantly advantageous procedures such as bone augmentation and periimplant defect repairs.

In general, polymers and composites of polymers are especially sensitive to sterilization and handling techniques. If intended for implant use, then most cannot be sterilized by

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steam or ethylene oxide. Most polymeric biomaterials have electrostatic surface properties and tend to gather dust or other particulate if exposed to semiclean air environments. Because many can be shaped by cutting or autopolymerizing in vivo (PMMA), extreme care must be taken to maintain quality surface conditions of the implant. Porous polymers can be deformed by elastic deformation, which can close open regions intended for tissue ingrowth. In addition, cleaning of contaminated porous polymers is not possible without a laboratory environment. In this regard, talc or starch on surgical gloves, contact with a towel or gauze pad, and the touching of any contaminated area must be prevented for all biomaterials.

Long-term experience, excellent biocompatibility profiles, ability to control properties through composite structures, and properties that can be altered to suit the clinical application make polymers and composites excellent candidates for biomaterial applications, as the constant expansion of the applications of this class of biomaterials can verify.

Inserts and Intramobile Elements

Relatively low moduli of elasticity (compared with metals and ceramics), high elongations to fracture, and inherent toughnesses have resulted in use of selected polymers for connectors or interpositional spacers for dental implants. One popular polymer insert system is included in Table 4-6 for general reference purposes. The most significant limitation has been the polymeric materials resistance to cyclical-load creep and fatigue phenomena. Retrieved transfer systems, in some clinical retrievals, have shown significant plastic deformation and fracture.[125] Although the desire to achieve such a stress-damping effect seems well founded, the inadequate long-term performance of the materials and high time and cost associated with maintenance of these devices have limited their field of application, and they are used less today than during the last decade.

Future Areas of Application

Synthetic substances for tissue replacement have evolved from selected industrial-grade materials such as metals, ceramics, polymers, and composites. This situation offers opportunities for improved control of basic properties. The simultaneous evolution of the biomechanical sciences also provides optimization of design and material concepts for surgical implants. Knowledge of tissue properties and computer-assisted modeling and analyses also support the present developments. The introduction of anisotropy with respect to mechanical properties; chemical gradients from device surface to center, with bonding along the tissue interfaces; and control of all aspects of manufacturing, packaging, delivering, placing, and restoring enhance the opportunities for optimal application and, it is hoped, device treatment longevities. Health care delivery would benefit from better availability and decreased per-unit costs.

Combinations to provide compositions with bioactive surfaces, the addition of active biomolecules of tissue-inductive substances, and a stable transgingival attachment mechanism could improve device systems. An integrated chemical and physical barrier at the soft tissue transition region would, at least theoretically, enhance clinical longevities. Devices that function through bone or soft tissue interfaces along the force transfer regions could be systems of choice, depending on the clinical situation.[9]

Unquestionably, the trend for conservative treatment of oral diseases will continue. Thus, it can be anticipated that dental implants will frequently be a first treatment option. Therefore, increased use of root form systems is to be expected. Clearly, the true efficacy of the various systems will be determined by controlled clinical studies with 10- to 20-year follow-up periods, which include statistically significant quantitative analyses.

Surface Characteristics

Many aspects of biocompatibility profiles established for dental surgical implants have been shown to depend on interrelated biomaterial, tissue, and host factors. For discussion purposes, the biomaterial characteristics can be separated into categories associated with either (1) surface or (2) bulk properties. In general, the biomaterial surface chemistry (purity and critical surface tension for wetting), topography (roughness), and type of tissue integration (osseous, fibrous, or mixed) can be correlated with shorter and longer-term in vivo host responses. In addition, the host environment has been shown to directly influence the biomaterial-to-tissue interfacial zone specific to the local biochemical and biomechanical circumstances of healing and longer term clinical aspects of load-bearing function. The interfacial interaction between recipient tissues and implanted material are limited to the surface layer of the implant and a few nanometers into the living tissues. The details of the integration (hard or soft tissue) and force transfer that results in static (stability) or dynamic (instability or motion) conditions have also been shown to significantly alter the clinical longevities of intraoral device constructs.

Many of the conference proceedings cited have focused on biomaterial-to-tissue interfacial interactions, which strongly supports the value of scrutinizing the surface characteristics of dental implants. This was one consistent recommendation from the 1978 and 1988 consensus conferences on the benefit and risk aspects of dental implant–based clinical treatments.[9,10,126]

The synthetic biomaterials used for the construction of dental implants and the associated abutments that contact subepithelial zones of oral tissues can be classified into *metallic, ceramic,* and *surface-modified* (coated, reacted, or ion-implanted) groups. It has long been recognized that synthetic biomaterials should be mechanically and chemically clean at the time of surgical placement. Surface properties are chemical in nature and have been described in terms of atomic structural characteristics with extensions to the subatomic scale. These characteristics are critical to the surface composition, corrosion resistance, cleanliness, surface energy, flexure, and tendency to interact (e.g., the ability to denature proteins).

Surface characteristics are the theme of this section with emphasis on metallic, ceramic, and surface-modified dental implant biomaterials.

Surface Characterization and Tissue Interaction

Metal and Alloy Surfaces

Standard grades of alpha (unalloyed) titanium and alpha-beta and beta-base alloys of titanium exist with an oxide surface at normal temperatures, with ambient air or normal physiologic environments that act as oxidizing media. A formation of a thin oxide exists via dissociation of and reactions with oxygen or other mechanisms such as oxygen or metal ion diffusion from and to the metallic surface, especially for titanium. Independent from the fabrication process, the oxide is primarily TiO_2, with small quantities of Ti_2O_3 and TiO, with some minor variable stoichiometry.[127–131] This thin layer of amorphous oxide will rapidly reform if removed mechanically. Surface properties are

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the result of this oxide layer and differ fundamentally from the metallic substrate.[63,128] Therefore, the oxidation parameters such as temperature, type and concentration of the oxidizing elements, and eventual contaminants all influence the physical and chemical properties of the final implant product. The type of oxide on surgical implants is primarily amorphous in atomic structure (brookite) if formed in normal-temperature air or tissue fluid environments and is usually very adherent and thin in thickness dimensions (<20 nm). In contrast, if unalloyed titanium (alpha) substrates (titanium grades 1 to 4) are processed at elevated temperatures (above approximately 350° C [660° F]) or anodized in organic acids at higher voltages (above 200 mV), then the oxide forms a crystalline atomic structure (rutile or anatase) and can be 10 to 100 times thicker. The grain structure of the metal and the oxidation conditions also condition the microstructure and morphology of the surface oxides. Porosity, density, and general homogeneity of the substrate are all related to this process. Low-temperature thermal oxides are relatively homogeneous and dense[132]; with increasing temperatures, they become more heterogeneous and more likely to exhibit porosity as scale formations, and some have glasslike surface oxide conditions (semicrystalline).[130,132]

Depending on the mechanical aspects of polishing and the chemical and electrochemical aspects of cleaning and passivating, these amorphous or crystalline oxides can exhibit microscopically smooth or rough topographies at the micrometer level. However, surface macroscopic roughness is normally introduced into the substrate beneath the oxide zone by mechanical (grinding), particulate blasting (resorbable blast media or other), or chemical (acid etching) procedures. The surface topography and roughness obtained by such techniques are characteristic of each fabrication process.[11,133] The oxide dimension (thickness) along these rougher surfaces remains relatively constant and within nanometer dimensional thicknesses under normal temperature and environmental exposure conditions.

The titanium alloys used for dental implant components include microstructural phases of alpha and beta or room temperature stabilized beta (only). Whereas the alpha-phase surface regions of the alloy are similar to unalloyed titanium in atomic arrangement (close-packed hexagonal), the beta phases demonstrate a different atomic structure (body-centered cubic) and elemental chemistry. However, the beta-phase oxide formation kinetics, chemistry, dimensions, and environmental stabilities are relatively similar to the alpha-phase regions. Electrochemical investigations have shown that the alpha- and beta-phase oxides provide substrate coverage and a high degree of chemical and biochemical inertness (resistance to corrosion and ion transfer) for titanium and alloys of titanium. Both titanium and Ti-6Al-4V have been reported to contain small amounts of titanium nitride along their surface oxide.[129,134,135] Ions, carbon, and substances other than alloying elements may be picked up in the oxide through the preparation process, similar to that found at the surface of CP titanium.[131,136–139] Nevertheless, in the cases of titanium and titanium alloy, the oxide layer grows homogeneously, and a well-controlled inert coating of very stable insoluble oxide normally contacts the living tissues.

Considerable research has been conducted on the roles of alloying elements in titanium alloys and how these elemental compositions may influence oxide properties and host tissue compatibility. This is dependent on the amount of the ions available to the tissues and relative rates of ion transfers, which could result in host tissue toxicity. In general, adequately processed and finished titanium alloys have shown integration with bone and soft tissue environments for a wide range of dental and medical implant devices.

Surface analysis studies have shown that the titanium alloy exhibits a similar oxide layer and as such is able to interact with surrounding bone in ways that are similar to unalloyed titanium.[140] Predictable results can be achieved with titanium alloy implant with a similar degree of bone integration.[141] In addition, electrochemical measurements of corrosion and ion release rates strongly support the chemical–biochemical stability properties of titanium alloys.

Some reports have expressed concerns because titanium alloy surface oxides contain significant amounts of alloying elements and exhibit different morphology and crystallization.[34,142–145] Aluminum in particular has been reported in both the outermost and the innermost layers. At the innermost layer, it was found especially over mixed (alpha) and (beta) phases grains of the alloy.[134] The different surface oxides are then argued to be responsible for a "lesser" quality of osseointegration in particular because of the potential of corrosion products containing aluminum and vanadium.[146–148] The orthopedic and dental literature specific to in vivo animal and human studies have also documented long-term success with titanium alloys that demonstrated close physical adaption of the bone to the surface of the alloy.[149–156]

Tissue Interactions

Oxide modification during in vivo exposure has been shown to result in increased titanium oxide layer thickness of up to 200 nm.[157–159] Whereas the highest oxide growth area corresponded to a bone marrow site, the lowest growth was associated with titanium in contact with cortical regions of bone. Increased levels of calcium and phosphorus were found in the oxide surface layers and seemed to indicate an active exchange of ions at the interface. Hydrogen peroxide environmental conditions have been shown to interact with Ti and form a complex gel.[160–162] "Titanium gel conditions" are credited with attractive in vitro properties such as low apparent toxicity, inflammation, bone modeling, and bactericidal characteristics. The authors restricted their studies to CP titanium exclusively and not titanium alloys.

Other elements interacting with the surface layer of several implanted materials are calcium and phosphorus,[163,164] exhibiting a $CaPO_4$ structure somewhat similar to apatite on the titanium surface. However, the low percentage of these elements along the material surface indicates this was the result of transfer and adsorption of these elements from tissue fluids, not an osseointegration process per se.

The surface biointeraction processes may be slow or activated by local reactions and may cause ion release and oxide alteration of the substrate. Local and systemic increases of the ion concentration have been reported.[165,166] In vitro studies showed that both titanium or titanium alloy were released in measurable quantities of the substrate elements at the surface.[23,167] Especially high rates of ion release were observed in ethylenediamine tetraacetic acid (EDTA) and sodium citrate solutions and varied as a function of the corroding medium.[167] Ion release corresponds to an oxide layer thickness growth with inclusions of calcium, phosphorus, and sulfur in particular. This is especially a concern for larger orthopedic or porous implants, in which such ion release may be a part of the origin of implant failure and allergic reactions and has even been proposed to be a local or systemic reason for the formation of tumors. In

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addition, free-titanium ions have been shown to inhibit the growth of HA crystals (i.e., the mineralization of calcified tissues at the interface).[168–170]

Integration with Titanium and Alloys

Although titanium is known to exhibit better corrosion resistance, independent of the surface preparation, in vivo and in vitro studies have shown that titanium may interact with the recipient living tissues over several years. This interaction results in the release of small quantities of corrosion products even though a thermodynamically stable oxide film exists.

Several studies have concentrated on the behavior of titanium and titanium alloys in simulated biological environments. Williams cautioned that although titanium can demonstrate excellent properties of its tenacious oxide film, it is usually not sufficiently stable to prevent wear and galling in bearing systems under load. Some situations have resulted in metal-to-metal contact and local welding.[36] Solar et al.[171] stated that under static conditions, titanium and titanium alloy should withstand exposure to physiologic chlorine solutions at body temperature indefinitely but would be susceptible to oxide changes caused by mechanical micromotion. Bundy et al.[172] exposed implant alloys simultaneously to tensile stress and corrosive environments (stress-applied conditions). In vivo, stainless steel and titanium alloy demonstrated cracklike features when loaded to yield stress and then reimplanted under laboratory conditions for 8 weeks. Cracklike features also were seen in stainless steel and titanium alloy loaded to or beyond the yield stress and subsequently electrochemically polarized for 38 weeks in the in vitro part of the study. None of the samples actually failed by completely cracking, but the authors presumed that it would have occurred with a longer exposure time as previously suggested.[36,173] Geis-Gerstorfer and Weber[39] used linear polarization methods to show that titanium showed minimal breakdown in simulated tissue fluids, but Ni-Ti showed rapid breakdown of passivity with increased chlorine product–related concentrations in unbuffered solutions. Therefore, body fluids could be responsible for the dissolution of some metallic passive oxide films.[174]

Lemons[75] studied single-stage solid implants modified by bending or cutting and showed that damage could increase corrosion. Rostoker and Pretzel[175] studied couple corrosion in vitro for alloys and found that dissimilar metals in a combined prosthesis did not create a regional breakdown of the titanium passive layer. A second in vivo study evaluated couple and crevice corrosion of prosthetic alloys in vertebral muscles of dogs for 30 weeks (non–load-bearing, nonosseointegrated).[176] It was concluded that metals of superior corrosion resistance, such as titanium alloy, and wrought cobalt alloys can be combined with titanium alloy in one prosthesis to provide superior mechanical performance without creating additional corrosion. However, repeated oxide breakdown such as sustained abrasion was likely to damage the corrosion resistance of an alloy for any type of coupling. Results from Thompson et al.[177] did not predict accelerated corrosion for titanium alloy coupled to carbon for galvanic couples under static conditions.

Marshak et al.[178] and Marshak[179] studied the potential for existence of SCC, GC, and FC in an in vitro study of titanium alloy and gold alloy abutment implants and abutment complexes simultaneously submitted to a laterally oriented 10-kg loading and a simulated tissue fluid solution at 37° C. SCC was studied in the most likely area, that is, the screw-to-abutment connection, which was under constant and simultaneous tension and compression stresses. These studies showed possibilities for interactions at contact regions between the cast gold and titanium alloy and components under selected environmental conditions.

Cohen and Burdairon[180] showed that odontologic fluoride gels, which create an acidic environment, could lead to the degradation of the titanium oxide layer and possibly inhibit the osseointegration process. Deposits consistent with the presence of GC byproducts were detected on various surfaces of the experimental metal.[181,182] Liles et al.[183] investigated the GC between titanium and seven crown and bridge alloys in 1% sodium chloride (NaCl) solution. The nonprecious Ni-Co complex was likely to trigger GC. Clinically, this means that in the short term, the presence of the surface impurities such as iron found on some implant parts, as well as other contaminants related to the machining process, could result in loss of bone and integration in crestal areas exposed to corrosion products. The long-term presence of corrosion reaction products and ongoing corrosion could also lead to fracture of the affected alloy–abutment interface, the abutment, or possibly the implant body itself. This combination of stress and corrosion, possibly together with factors associated with bacteria, could be one of the reasons why implants fail at the local or individual levels rather than in a generalized fashion.[184] Protocols for manufacturing and cleaning prosthetic titanium parts (specifically abutments contacting the implant body) appear less stringent than those for implant bodies. This should not be the case, and the same standards should be applied to both implant body and prosthetic components. In addition, the short-term and longer-term clinical implications of the potential GC effect could be ideally nullified by the use of electrochemically compatible alloys for the superstructure.

Cobalt and Iron Alloys

The alloys of cobalt (Vitallium) and iron (surgical stainless steel—316L) exhibit oxides of chromium (primarily Cr_2O_3 with some suboxides) under normal implant surface-finishing conditions after acid or electrochemical passivation. These chromium oxides, as with titanium and alloys, result in a significant reduction in chemical activity and environmental ion transfers. Under normal conditions of acid passivation, these chromium oxides are relatively thin (nanometer dimensions) and have an amorphous atomic structure. The oxide atomic spatial arrangement can be converted to a crystalline order by elevated temperature or electrochemical exposures.

The chromium oxides on cobalt and iron alloys are microscopically smooth, and again, roughness is usually introduced by substrate processing (grinding, blasting, or etching). Because these oxides, similar to titanium oxides, are very thin (nanometer dimensions), the reflected light color of the alloys depends on the metallic substrate under the oxide.[33] However, as mentioned, the titanium, cobalt, and iron metallic systems depend on the surface reaction zones with oxygen (oxides) for chemical and biochemical inertness.

The cobalt and iron alloy bulk microstructures are normally mixtures of the primary alloy phases with regions of metallic carbides distributed throughout the material.[33,56,83,84] Along the surfaces, whereas the chromium oxide covers the matrix phase (metallic regions), the carbides stand as secondary components (usually as mounds above the surface) at the microscopic level. In contrast to homogenization-annealed alloys, the as-cast cobalt alloys exhibit multiphasic characteristics within their microstructures, with relatively extensive regions of the alloy

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surfaces occupied by complex metallic carbides. Thus tissue-to-oxide and tissue-to–metallic carbide zones could be used to describe tissue integration of cobalt alloy. This is uniquely different compared with titanium implant biomaterials, in which tissue-to-oxide regions predominate at the interface.[83,84]

The iron-based alloy chromium oxide and substrate are more susceptible to environmental breakdown compared with cobalt- and titanium-based biomaterials. This has been discussed in the literature related to crevice and pitting corrosion biodegradation phenomena for stainless steel implant systems.[59,83,84] In general, if stainless steel implant surfaces are mechanically altered during implantation or if the construct introduces an interface that is subjected to biomechanical fretting, then the iron alloy will biodegrade in vivo, and the fatigue strength of surgical stainless steel can be significantly decreased in a corrosive environment.[185] In some cases, this has resulted in implant loss. However, in the absence of surface damage, the chromium oxides on stainless steel biomaterials have shown excellent resistances to breakdown, and multiple examples of tissue and host biocompatibility have been shown for implants removed after long-term (beyond 30 years in vivo) implantations.

Dental implants and implant abutments have also been fabricated from gold alloy with many abutments fabricated from palladium or Co-Cr-Ni-Mo alloys.[37] The minimally alloyed gold and palladium systems are noble electrochemically and do not depend on surface oxides for chemical and biochemical inertness. This would be the case for the high-noble alloys (major compositions of gold, platinum, palladium, iridium, and ruthenium). However, some palladium alloys and other lower noble element content alloys gain chemical and biochemical inertness from complex metallic surface oxides.[37] As mentioned, the multicomponent (wrought) cobalt-based alloys, as with other base-metal systems, depend on chromium oxide surface conditions for inertness.

In general, the noble-metal alloys do not demonstrate the same characteristics of tissue interaction when compared with the base-metal (Ti and Co alloy) systems. The ultrastructural aspects of tissue integration have not been extensively investigated for noble-alloy systems, although some have presented results describing osseointegration of gold alloys. The noble alloys, when used in a polished condition, are resistant to debris accumulation on a relative basis compared with other alloys. This has been listed as an advantage for their use in intraoral abutment systems. In addition, mechanical finishing of the more noble alloys can result in a high degree of polish and a minimal concern about damaging or removing surface oxides.

Ceramics

Aluminum oxide ceramics have been extensively investigated related to surface properties and how these properties relate to bone and soft tissue integration.[99,100,111–122] Aluminum oxide ceramics are fully oxide materials (bulk and surface), thereby affording advantages related to tissue interface–related investigation. In addition, studies have included the polycrystalline (alumina) and single-crystalline (sapphire) forms of the oxide structure. These forms have introduced very different surface roughness values for the same material substrate plus bulk properties in which ion transfer and electrochemical phenomena are minimal influences. Bone and soft tissue integration have been demonstrated for this oxide material over the long term in humans and laboratory animals. Direct relationships have been established between the interfacial events of tissue integration for metallic surface oxides of titanium and chromium and the Al_2O_3 systems. As mentioned previously, surface quality can be directly correlated with tissue integration and clinical longevity. Because the Al_2O_3 ceramics are crystalline and extend throughout the surface and bulk zones, biomechanical instabilities do not alter the chemical aspects of biomaterial properties. (No electrochemical charge is introduced if the surface is removed.) Ceramic coatings (e.g., Al_2O_3) have been shown to enhance the corrosion resistance and biocompatibility of metal implants, particularly surgical stainless steel and Ni-Cr and Co-Cr alloys.[186] However, the Ni-Cr and steel alloys can be subject to crevice corrosion. Studies in orthopedics caution that the Al_2O_3 coating may cause a demineralization phenomenon caused by a high local concentration of substrate ions in the presence of metabolic bone disease.[187] This remains to be established within the use of Al_2O_3 implants for clinical applications.

Hydroxyapatite

In addition to the bulk Al_2O_3 biomaterials, $CaPO_4$–based ceramic or ceramic-like coatings have been added to titanium and cobalt alloy substrates to enhance tissue integration and biocompatibility. These coatings, for the most part, are applied by plasma spraying small-size particles of crystalline HA ceramic powders. The process of coating and the coating dimensions and property characteristics are addressed further in the next section.

The surface topography is characteristic of the preparation process. Variations in the roughness and porosity of the surface (<100 mm) can be categorized in function of the surfacing process. Machined implants exhibit an irregular surface with grooves, ridges, and pits including a nanometer-thickness scale.[188,189] Proponents of such a surface argue that it is the most conducive to cell attachment[127–129] (Figure 4-9).

Surface roughening by particulate blasting can be achieved by different media. Sandblasting provides irregular rough surfacing with less than 10-mm scales and a potential for impurity inclusions. Researchers used a titanium alloy Ti-6Al-4V to improve the mechanical properties and elected to electropolish the surface to reduce surface roughness to be only in the 0.1-mm scale by controlled removal of the surface layer by dissolution.[188,190,191] Titanium implants may be etched with a solution of nitric and hydrofluoric acids to chemically alter the surface and eliminate some types of contaminant products (Figure 4-10). The acids very rapidly attack metals other than titanium,



FIGURE 4-9. Machined surfaces exhibit an irregular surface with grooves, ridges, and pits, including a nanometer-thickness scale (Brånemark fixture, Nobel Biocare).

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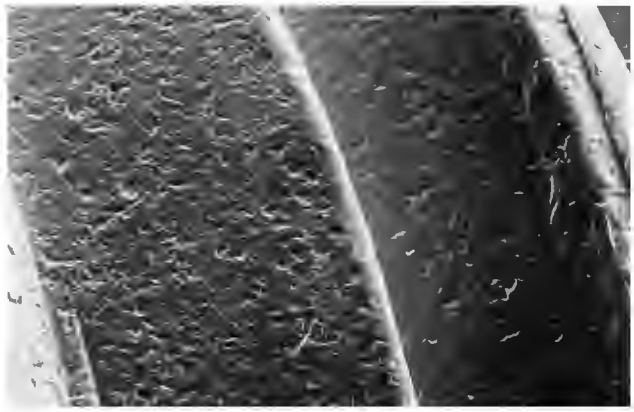


FIGURE 4-10. Titanium implants may be etched with a solution of nitric and hydrofluoric acids (Screw-Vent implant, Zimmer.)

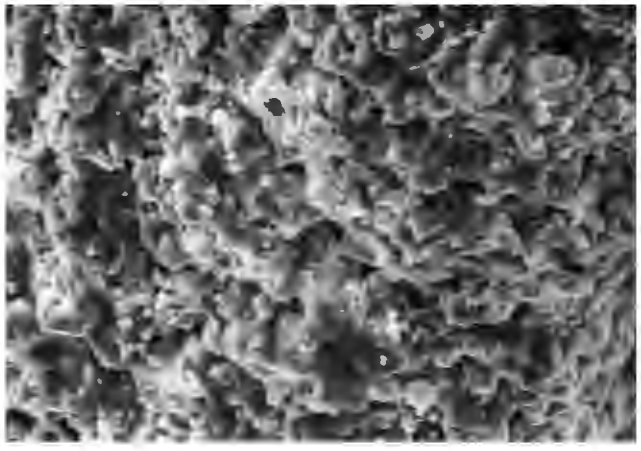


FIGURE 4-11. Resorbable blast media provide a comparable roughness to alumina grit blast finish, which can be rougher than machined or etched surfaces (D2 Maestro implant, BioHorizons.)

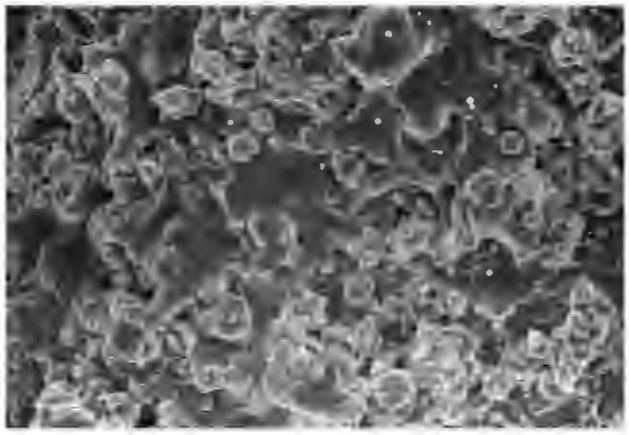


FIGURE 4-12. Titanium plasma-sprayed surfaces result in increased total surface area, which may introduce a dual physical and chemical anchor system and increase load-bearing capability. Scanning electron microscopy of BioHorizons D3 implant; μ 500.

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and these processes are electrochemical in nature. Proponents of this technique argue that implants treated by sandblasting and acid etch provide superior radiographic bone densities along implant interfaces compared with titanium plasma–sprayed surfaces.[192] Recently, concerns have been expressed regarding embedded media from glass beading (satin finish) and grit blasting (alumina Al_2O_3) and a possible risk of associated osteolysis caused by foreign debris.[193,194] Ricci et al.[194] reported on failed retrieved implants that exhibited extensive surface inclusions consisting of silicon or Al_2O_3-related products, which were also present in the surrounding tissues. Because alumina is resistant to acid dissolution, particulate may remain embedded in the surface of the implant even after ultrasonic cleaning, acid passivation, and sterilization.

In response to these concerns, a new process of surface finishing was introduced that uses a restorable media for the surface etching process. The particulate used in this process lends its name to the technique, restorable blast media (RBM). This technique provides a comparable roughness to an alumina grit blast finish, which can be a rougher surface than the machined, glass-beaded, or acid-etched surfaces (Figure 4-11).[195] However, the surface differs from prior sandblasting techniques because any particulate that remains embedded in the surface of the implant may be removed with chemical dissolution. Examples of blast particulate include hydroxyapatite, beta-tricalcium phosphates, and similar calcium phosphate ceramics. These particulates are more biocompatible than alumina and easier to remove from the roughened surface. Surface roughness varies depending on the size of the blast particle used. Data suggest that RBM surfaces increase bone–implant contact (osseointegration) compared with other surfaces.[196,197] Mueller et al. compared implants blasted with alumina or bioceramics in a rabbit model; their data suggest increased bone integration for implants blasted with the restorable media.[198] In an experiment using matched controls in an animal model, Piattelli observed significantly greater bone-to-implant contact with RBM surfaces compared with machined controls, with osseointegration rates of 62% and 55%, respectively.[197] These benefits may be related to improved biological response to rougher surfaces.[199,200]

Porous and Featured Coatings

The implant surface may also be covered with a porous coating. These may be obtained with titanium or HA particulate–related fabrication processes. Examples of coatings and processes for producing surface-modified implants are summarized in the following sections.

Titanium Plasma Sprayed

Porous or rough titanium surfaces have been fabricated by plasma spraying a powder form of molten droplets at high temperatures. At temperatures in the order of 15,000° C, an argon plasma is associated with a nozzle to provide very high-velocity 600 m/sec partially molten particles of titanium powder (0.05- to 0.1-mm diameter) projected onto a metal or alloy substrate.[63,201] The plasma-sprayed layer after solidification (fusion) is often provided with a 0.04- to 0.05-mm thickness. When examined microscopically, the coatings show round or irregular pores that can be connected to each other (Figure 4-12). Hahn and Palich[202] first developed these types of surfaces and reported bone ingrowth in titanium hybrid powder plasma spray–coated implants inserted in animals. Karagianes et al.[203] assessed the suitability of porous titanium and titanium alloy to achieve bone–implant bonding characteristics in miniature swine and likened it to a three-dimensional surface. Kirsch[125] conducted histologic studies for plasma flame-sprayed particulate titanium coating root form specimen (IMZ) implanted and

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integrated to the bone in dogs, with complete integration reported at 6 weeks. In animal experiments and histologic studies, Schroeder et al.[204] concluded that the rough and porous surfaces showed a three-dimensional interconnected configuration likely to achieve bone–implant attachment for stable anchorage. Other animal studies concluded that a porous titanium surface from various fabrication methods may increase the total surface area (up to several times), produce attachment by osteoformation, enhance attachment by increasing ionic interactions, introduce a dual physical and chemical anchor system, and increase the load-bearing capability 25% to 30%.[107,125,205–210] In vitro studies of fibroblast attachment conducted by Lowenberg et al.[211] showed superior attachment to surface-ground titanium alloy disks compared with porous titanium but with a better cell orientation on porous forms of titanium.

In 1981, Clemow et al.[212] showed that the rate and percentage of bone ingrowth into the surface was inversely proportional to the square root of the pore size for sizes greater than 100 mm and that the shear properties of the interface were proportional to the extent of bone ingrowth. The optimum pore size for bone ingrowth was determined in a study of cobalt-base alloy porous implants inserted in canine femurs. The optimum pore size was deduced from the maximum fixation strength measurements. These surface porosities ranged from 150 to 400 mm and coincidentally correspond to surface feature dimensions obtained by some plasma-spraying processes.[213–216] In addition, porous surfaces can result in an increase in tensile strength through ingrowth of bony tissues into three-dimensional features. High shear forces determined by the torque-testing methods and improved force transfer into the periimplant area have also been reported.[217,218]

In 1985 at the Brussels Osseointegration Conference, the basic science committee did not present results that showed any major differences among smooth, rough, or porous surfaces regarding their ability to achieve osseointegration. However, proponents of porous surface preparations reported that there have been results showing faster initial healing compared with noncoated porous titanium implants and that porosity allows bone formation within the porosities even in the presence of some micromovement during the healing phase.[219,220] Such surfaces were also reported to allow the successful placement of shorter-length implants compared with noncoated implants. The basic theory was based on increased area for bone contact. Reports in the literature caution about cracking and scaling of coatings because of stresses produced by elevated temperature processing[221,222] and risk of accumulation of abraded material in the interfacial zone during implanting of titanium plasma–sprayed implants. It may be indicated to restrict the limit of coatings in lesser bone densities that cause less frictional torque transfer during implant placement process. In addition, the present technology allows metallurgic bonding of coatings and a high resistance against mechanical separation of the coating, with many coating test values exceeding the published standard requirements.[223]

Hydroxyapatite Coating

Hydroxyapatite coating by plasma spraying was brought to the dental profession by deGroot.[99] Kay et al. used scanning electron microscopy (SEM) and spectrographic analyses to show that the plasma-sprayed HA coating could be crystalline and could offer chemical and mechanical properties compatible with dental implant applications.[224] Block et al.[225] and Thomas et al.[226] showed an accelerated bone formation and maturation around HA-coated implants in dogs compared with noncoated implants. HA coating can also lower the corrosion rate of the same substrate alloys.[227] Researchers measured the HA coating thickness after retrieval from specimens inserted in animals for 32 weeks and showed a consistent thickness of 50 mm, which is in the range advocated for manufacturing.[19,96,228,229] The bone adjacent to the implant has been reported to be better organized than with other implant materials and with a higher degree of mineralization.[230] In addition, numerous histologic studies have documented the greater surface area of bone apposition to the implant compared with uncoated implants,[225,231,232] which may enhance the biomechanics and initial load-bearing capacity of the system. HA coating has been credited with enabling HA-coated titanium or titanium alloy implants to obtain improved bone–implant attachment compared with machined surfaces.

Studies also demonstrated that the HA–bone attachment is superior to the HA–implant interface.[226,228,233] However, proponents of such surfaces report excellent reliability of HA-coated implants.[234,235] The most significant result is the increase in bone penetrations, which enhances fixation in areas of limited initial bone contact.[37,40,41,236] However, controversies still exist, and some authors caution that HA coatings do not necessarily represent an advantage for the long-term prognosis of the system.

Implants of solid sintered HA have been shown to be susceptible to fatigue failure.[105,229,233] This situation can be altered by the use of a CPC coating along metallic substrates. Although several methods may be used to apply CPC coatings, the majority of commercially available implant systems are coated by a plasma spray technique. A powdered crystalline HA is introduced and melted by the hot, high-velocity region of a plasma gun and propelled onto the metal implant as a partially melted ceramic (Figure 4-13).[115,201] One of the concerns regarding CPC coatings is the strength of the bond between the CPC and the metallic substrate. Investigative ion beam–sputtering coating techniques for CPC or CPC-like nonresorbable coatings to varied substrates appear to produce dense, more tenacious, and thinner coatings (a few micrometers), which would minimize the problem of poor shear strength and fatigue at the coating–substrate interface.[115] Recent reports have introduced a new type

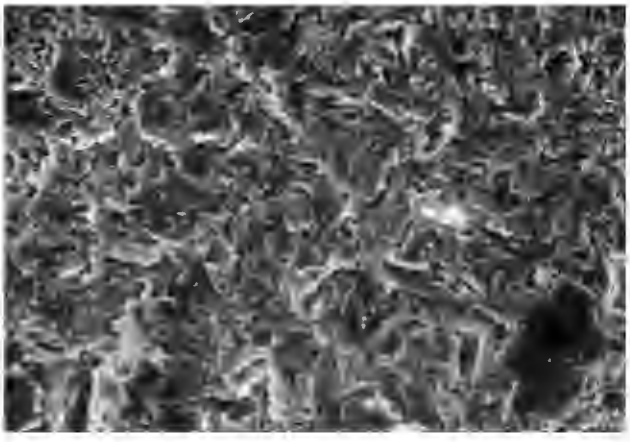


FIGURE 4-13. Hydroxyapatite (HA) coatings on implant surface provide several clinical properties because of the osteoconductive properties of HA. Scanning electron microscopy of BioHorizons D4 implant; μ 500.

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of treatment for coatings, which appear primarily amorphous in nature, and further in vivo studies are needed to determine tissue response.[237,238] Other investigations include developing new biocompatible coatings based on TCP or titanium nitride.[239]

It has been shown that the plasma-spraying technique can alter the nature of the crystalline ceramic powder and can result in the deposition of a variable percentage of a resorbable amorphous phase.[240] A dense coating with a high crystallinity has been listed as desirable to minimize in vivo resorption. In addition, the deposited CPC may be partially resorbed through remodeling of the osseous interface.[28,241,242] It is therefore wise to provide a biomechanically sound substructure design[240,241] that is able to function under load-bearing conditions to compensate for the potential loss of the CPC coating over years. In addition, the CPC coatings may resorb in infected or chronic inflammation areas. Animal studies also show reductions in coating thickness after in vivo function.[243] One advantage of CPC coatings is that they can act as a protective shield to reduce potential slow ion release from the Ti-6Al-4V substrate.[244] In addition, the interdiffusion between titanium and calcium (and phosphorus and other elements) may enhance the coating substrate bond by adding a chemical component to the mechanical bond.[242,245–248]

When these coatings were introduced more than two decades ago, many researchers expressed concerns about the biomechanical and gingival sulcus area biochemical stabilities. It was recommended that national and international standards for these coatings be developed, in part to provide detailed description of coating properties using consistent and uniform (standardized) test methods. Initial national standards were developed for *Beta Tricalcium Phosphate for Surgical Implantation by the ASTM Committee F4* (ASTM F4-1088). A standard specification for *Composition of Ceramic Hydroxyapatite for Surgical Implants* (ASTM F4-1185) was developed, and additional standards have been more recently approved, including *Glass and Glass-Ceramic Biomaterials for Implantation* (ASTM F4-1538), *Standard Test Method for Tension Testing of Calcium Phosphate Coatings* (ASTM F4-1501 F1147-05), *Standard Test Method for Calcium Phosphate Coatings for Implantable Materials* (ASTM F4-1609), *Test Method for Bending and Shear Fatigue Testing of Calcium Phosphate Coatings on Solid Metallic Substrates* (ASTM F4-1659 1160), and a *Standard Test Method for Shear Testing of Calcium Phosphate Coatings* (ASTM F4-1658 1044).[19] Additional standards being developed at the task group level with ASTM F4 include *Calcium Phosphate Coating Crystalline Characteristics, Mechanical Requirements for Calcium Phosphate Coatings,* and *Environmental Stability of Calcium Phosphate Coatings F1926.* An additional standard on anorganic bone (ASTM F4-1581) has also been established within the ceramics subcommittee of ASTM F4.[19]

These national and related international standards (ISO) should provide basic property information for $CaPO_4$ materials and coatings. This information should prove most useful as longer-term investigations on biocompatibility are conducted for dental implant systems. In addition, national and international standards have been established for the surgical implant alloys, bulk ceramics, and surface finishing of metallic biomaterials.

The concerns related to $CaPO_4$ coatings have focused on (1) the biomechanical stability of the coatings and coating-substrate interface under in vivo conditions of cyclic loading and (2) the biochemical stability of these coatings and interfaces within the gingival sulcus (especially in the presence of inflammation or infection) and during enzymatic processes associated with osteoclasis remodeling of the bone-coating interfacial zones. Some of these questions were addressed at an ASTM symposium on $CaPO_4$ coatings, and some researchers related that the longer-term clinical studies (less than 10 years' experience) do not support reasons for concern. It will be interesting to reevaluate these questions and answers after 20 years of clinical experience.

Microchannels

Much effort has centered on engineering at the neck of the implant, with the belief that improved engineering may lead to clinical bone maintenance at the crest of the ridge. Different manufacturers have used macrogeometry in this region, and such efforts have had some in vivo effect on bone stability.[249,250] In the manuscript by Bae et al., whereas bone loss around a conventional implant in a dog model was 1.63 mm at 12 months, bone loss around an implant with a small machined thread was 0.56 mm at 12 months.[250] Although it has been recognized for some time that the geometry of the thread and its location on the implant can affect bone retention, limitations remain on the extent of implant threading caused by the notch sensitivity and fatigue resistance of titanium and its alloys. After an implant is broached to receive an internal prosthetic connection, the depth of any thread is limited. If too aggressive, a thread cut into the external aspect of the implant will cause a thin region of metal where the internal connection begins and leaves the implant susceptible to fracture. For this reason, internal connection implants are not deeply threaded in the crestal region. A shallow microgroove (magnitude, 100–1000 µm) or a microchannel (magnitude, 5–50 µm) does not adversely weaken the implant.

The microchannel has produced a unique biological response that is beginning to be understood. Unlike the relatively weak hemidesmisomal attachment associated with machined titanium, the microchannel promotes a connective tissue interface that is more robust and may be able to resist oral biological stresses, such as bacterial invasion. Nevins et al. report human histology that shows connective tissue attachment to the microchannel surface. Furthermore, the fibers in this region appeared to have a functional orientation.[251] This observation was echoed in an animal study.[252,253] This connective tissue has a tenacious attachment to the microchannel surface, frequently tearing within the tissue itself at retrieval and remaining attached to the implant surface rather than pulling off the implant. Evidence suggests that this connective tissue attachment may somehow insulate or protect the underlying bone, leading to stable long-term crestal bone levels. Pecora reports data from a human trial using a split-mouth matched control design. Implants with a laser cut microchannel lost 0.59 mm of bone compared with controls, which lost 1.94 mm of bone.[254] Other reports document similar results.[255–258]

After the success of the implant surfacing with microchannels, abutments were treated with the laser ablation technique to create microchannels on the abutment. The data from these analyses demonstrate a connective tissue attachment to the abutment surface that approximates that seen in cases where the implant alone is surfaced. In a human study, Geurs et al. demonstrate histologic micrographs which show connective tissue attachment to the abutment surface in an oriented fashion.[259] Nevins et al. support this observation in an in vivo canine trial.[260] In one micrograph, the bone is shown growing over the abutment–implant interface and attaching to the microgroove

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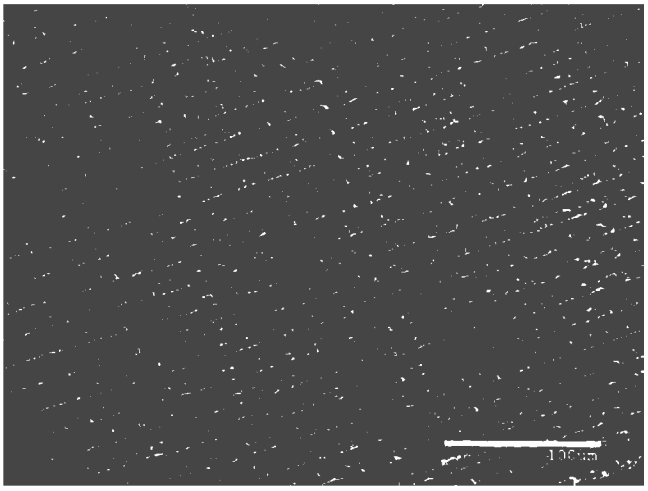


FIGURE 4-14. Microchannel surface. A laser is used to cut very small grooves into the implant surface. Typically, these grooves are 8 or 12 μm wide, which is similar in size to a human fibroblast.

on the abutment. Compared with implant–abutment constructs without microchannels, the treated abutments were associated with greater bone heights, less junctional epithelium migration, connective tissue attachment, and robust fibroblast activity at the abutment–tissue interface (Figure 4-14).

Other Surface Modifications

Surface modification methods include controlled chemical reactions with nitrogen or other elements or surface ion implantation procedures. The reaction of nitrogen with titanium alloys at elevated temperatures results in titanium nitride compounds being formed along the surface. These nitride surface compounds are biochemically inert (like oxides) and alter the surface mechanical properties to increase hardness and abrasion resistance. Most titanium nitride surfaces are gold in color, and this process has been extensively used for enhancing the surface properties of industrial and surgical instruments.[19] Increased hardness, abrasion, and wear resistance can also be provided by ion implantation of metallic substrates. The element most commonly used for surface ion implantation is nitrogen. Electrochemically, the titanium nitrides are similar to the oxides (TiO_2), and no adverse electrochemical behavior has been noted if the nitride is lost regionally. The titanium substrate reoxidizes when the surface layer of nitride is removed. Nitrogen implantation and carbon-doped layer deposition have been recommended to improve the physical properties of stainless steel without affecting its biocompatibility.[261] Again, questions could be raised about coating loss and crevice corrosion.

Surface Cleanliness

A clean surface is an atomically clean surface with no other elements than the biomaterial constituents. Contaminants can be particulates, continuous films (e.g., oil, fingerprints), and atomic impurities or molecular layers (inevitable) caused by the thermodynamic instability of surfaces. Even after reacting with the environment, surfaces have a tendency to lower their energy by binding elements and molecules. The typical composition of a contaminated layer depends on atmospheres and properties of surface. For example, high-energy surfaces (metals, oxides, ceramics) usually tend to bind more to this type of monolayer than polymers and carbon (amorphous).

In the earlier times of dental implantology, no specific protocol for surface preparation, cleaning, sterilization, and handling of the implants was established.[262] Researchers have respectively demonstrated adverse host responses caused by faulty preparation and sterilization, omission to eliminate adsorbed gases, and organic and inorganic debris.[127,128,142,263] According to Albrektsson,[145] implants that seem functional may fail even after years of function, and the cause may be attributed to improper ultrasonic cleaning, sterilization, or handling during the surgical placement.

A systematic study of contamination layers is not available. Lausmaa et al.[129] showed that titanium implants had large variations in carbon contamination loads (20%–60%) in the 0.3- to 1-nm thickness range, attributed to air exposure and residues from cleaning solvents and lubricants used during fabrication. Trace amounts of Ca, P, N, Si, S, Cl, and Na were noted from other studies.[137,138,263–265] Residues of fluorine could be attributed to passivation and etching treatments; Ca, Na, and Cl to autoclaving; and Si to sand and glass beading processes.

Surface Energy

Measurements of surface property values of an implant's ability to integrate within bone include contact angle with fluids, local pH, and surface topography. These are often used for the determination of surface characteristics. Numerous studies were conducted to evaluate liquid, solid, and air contact angles, wetting properties, and surface tensions as criteria to assess surface cleanliness because these parameters have been shown to have a direct consequence on osseointegration.[12,266,267] An intrinsically high surface energy is said to be most desirable. High surface energy implants showed a threefold increase in fibroblast adhesion, and higher energy surfaces such as metals, alloys, and ceramics are best suited to achieve cell adhesion.[12] Surface tension values of 40 dyne/cm and higher are characteristic of very clean surfaces and excellent biological integration conditions.[266] A shift in contact angle (increase) is related to the contamination of the surface by hydrophobic contaminants and decreases the surface tension parameters. Because a spontaneously deposited, host-dependent conditioning film is a prerequisite to the adhesion of any biological element, it is suggested that the wetting of the surface by blood at the time of placement can be a good indication of the high surface energy of the implant.[266]

Passivation and Chemical Cleaning

The ASTM (ASTM B600, ASTM F-86) specifications for final surface treatment of surgical titanium implants require pickling and descaling with molten alkaline base salts. This is often followed by treatment with a solution of nitric or hydrofluoric acid to decrease and eliminate contaminants such as iron. Iron or other elements may contaminate the implant surface as a result of the machining process. This type of debris can have an effect of demineralizing the bone matrix.[268,269] However, these finishing requirements remain very general. Studies of fibroblast attachment on implant surfaces showed great variations, depending on the different processes of surface preparation. Inoue et al.[149] showed fibroblasts developed a capsule or oriented fibrous attachment following the grooves in titanium disks. Contact angles are also greatly modified by acid treatment or water rinsing.[270] Machining operations, polishing, texturing process, residual chemical deposits, and alloy microstructure all inadvertently affect the surface composition. In addition, many ways exist to intentionally modify the surface of the implant.

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They include conventional mechanical treatment (sand blasting), wet or gas chemical reaction treatment, electroplating or vapor plating, and ion beam processing, which leaves bulk properties intact and has been newly adapted to dentistry from thin film technology. Preliminary studies by Schmidt[271] and Grabowski et al.[272] showed modified fibroblast adhesion on nitrogen and carbon-ion implanted titanium. A general rule has been that cleaner is better.

Sterilization

Manipulation with bare fingers or powdered gloves, tap water, and residual vapor-carried debris from autoclaving can all contaminate implant surfaces. Baumhammers,[262] in an SEM study of dental implants, showed contamination of the surface with acrylic materials, powder for latex gloves, and bacteria. Today, in most cases, the manufacturer guarantees precleaned and presterilized implants with high-technology procedures, with the implants ready to be inserted. If an implant needs to be resterilized, then conventional sterilization techniques are not normally satisfactory. It appears at the present time that no sterilization medium is totally satisfactory for all biomaterials and designs. Metal or alloy constituents, inorganic and organic particles, corrosion products, polymers, and precipitates can be absorbed at the surface throughout the manufacturing, polishing, cleaning, sterilization, packaging, and storage processes. Baier et al.[12] correlated the usual type of contaminant found in relation to the sterilization technique used. Baier et al.[266] showed that steam sterilization can cause deposits of organic substances resulting in poor tissue adhesion. Doundoulakis[137] submitted titanium samples to different sterilization techniques, concluded an adverse effect of steam sterilization and degradative effect of endodontic glass bead sterilizers, found that dry heat sterilization leaves organic deposits on the surface, and suggested that ultraviolet (UV) light sterilization may become a good alternative after further evaluation. In addition, accelerated oxide growth on titanium may occur with impurity contamination leading to surface discoloration.[32,127,272] In a study by Keller et al.,[273] corrosion products and films from autoclaving, chemicals, and cytotoxic residues from solutions were identified at the surface of implants submitted to sterilization. They suggested that alteration of the titanium surface by sterilization methods may in turn affect the host response and adhesive properties of the implant. On the other hand, Schneider et al.[274] compared the surface of titanium plasma–sprayed and HA-coated titanium implants after steam or ethylene dioxide sterilization using energy dispersive radiograph analysis and concluded that these techniques do not modify the elemental composition of the surface. Keller et al.[275] studied the growth of fibroblasts on disks of CP titanium sterilized by autoclaving, ethylene oxide, ethyl alcohol, or solely passivated with 30% nitric acid and concluded that sterilization seems to inhibit cell growth, but passivation does not.

Presently, proteinaceous deposits and their action as films can be best eliminated by the radiofrequency glow discharge technique (RFGDT), which seems to be a suitable final cleaning procedure. The implants are treated within a controlled noble gas discharge at very low pressure. The gas ions bombard the surface and remove surface atoms and molecules, which are absorbed onto it or are constituents of it. However, the quality of the surface treated depends on the gas purity. Baier et al.[276] showed that RFGDT is good for cleaning and, at the same time, for granting a high-energy state to the implant, which is related to improved cell adhesion capabilities. Thinner, more stable oxide films and cleaner surfaces have been reported with RFGDT plus improved wettability and tissue adhesion.[276–278] The principal oxide at the surface is unchanged by the RFGDT process.[279] A decrease in bacteria contamination on HA-coated implant surfaces was reported after RFGDT,[280] and studies suggest that RFGDT may enhance calcium or phosphate affinity because of an increase in elemental zone at the surface, resulting in the formation of amorphous $CaPO_4$ compounds.[278]

Recently, a modified UV light sterilization protocol was shown to enhance bioreactivity, which was also effective for eliminating some biological contaminants. Singh and Schaaf[281] assessed the quality of UV light sterilization and its effects on irregularly shaped objects, and they established its effectiveness on spores and its ability to safely and rapidly clean the surface and to grant high surface energy. Hartman et al.[282] submitted implants to various pretreatment protocols (RFGDT, UV light, or steam sterilization) and inserted them in miniature swine. Although RFGDT and UV-sterilized implants showed rapid bone ingrowth and maturation, steam-sterilized implants seemed to favor thick collagen fibers at the surface. On the other hand, Carlsson et al.[283] inserted implants in rabbits and compared the performances of conventionally treated implants with implants treated with RFGDT, found similar healing responses, and further cautioned that the RFGDT process produces a much thinner oxide layer at the surface of the implant and may deposit silica oxide from the glass envelope.

Adequate sterilization of clean, prepackaged dental implants and related surgical components has resulted in an ever-expanding use of gamma radiation procedures. Because gamma radiation sterilization of surgical implants is a well-established methodology within the industry, facilities, procedures, and standards are well known. Most metallic systems are exposed to radiation doses exceeding 2.5 Mrad where the packaging and all internal parts of the assembly are sterilized. This is an advantage in that components remain protected, clean, and sterile until the inner containers are opened within the sterile field of the surgical procedure. The healing screws, transfer elements, wrenches, and implants are all exposed to the gamma sterilization, which reduces opportunities for contamination.

Some ceramics can be discolored and some polymers degraded by gamma radiation exposures. The limits are known for classes of biomaterials, and all types of biomaterials can be adequately sterilized within the industry. Systems control, including prepackaging and sterilization, has been an important part of the success of dental implantology.

Summary

In the 1960s, dental implantology as a clinical discipline was judged by some to be rather disorganized, and treatments provided were often said to be not as successful as hospital-based orthopedic and cardiovascular surgery procedures. One part of this opinion related to the use of standard intraoral dental materials for implants plus general dental operatories for surgical activities (e.g., no gloves, high-speed drills, tap water). The biomaterials discipline evolved rapidly in the 1970s. Successful uses of synthetic biomaterials have been based on experience within the field of dental implantology. The basis for many of the newer and more clinically successful surgical reconstructions evolved within dentistry, with some now recognized as the most successful types of musculoskeletal reconstructive surgery. The biomaterials discipline therefore has evolved significantly over the past decades, and synthetic biomaterials are

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now constituted, fabricated, and provided to health care professionals as mechanically and chemically clean devices that have a high predictability of success when used appropriately within the surgical disciplines. This chapter on biomaterials has been separated into sections related to bulk and surface properties of biomaterials, and emphasis has been placed on the published literature on how these biomaterial properties relate to interactions at the tissue interface.

Surface characterization and working knowledge about how surface and bulk biomaterial properties interrelate to dental implant biocompatibility profiles represent an important area in implant-based reconstructive surgery. This chapter has provided summary information on surface and bulk properties for metallic, ceramic, and surface-modified biomaterials. The authors strongly recommend the reference material listed in addition to a desire to have investigators always provide biomaterial surface and bulk property information as a component of any research studies on tissue response (biocompatibility) profiles.

Acknowledgment

In 1970, Jack E. Lemons was attending his first American and International Associations for Dental Research (AADR/IADR) meeting and was introduced to Ralph Phillips within a group discussion on dental materials. He quickly determined that Lemons knew little about the "dental" and some about the "materials." Phillips included Lemons in the interactions with carefully placed and directed questions and comments so that he was not excluded. This happened repeatedly over the years, until Lemons had the opportunity to reverse the exchange after making a presentation on behalf of the AADR/IADR Dental Materials Group on basic biocompatibility testing, with Phillips as the overview discussant. This opportunity was to coordinate and help direct some of the emerging exchanges among those experienced in the material and biological sciences. Subsequently, ongoing interactions with Phillips fostered many wonderful times with colleagues, students, and friends throughout the world.

Contents of this chapter represent a later stage in which Lemons provided written comments and opinions about implant biomaterials as one extension of dental biomaterials. This chapter is dedicated in part to his memory and most especially to the long-term friendship. The dental implant field, in the authors' opinion, will benefit from a continuation of a multidisciplinary approach to the science, technology, and applications. We wish that Ralph could have continued, and we certainly will miss his counsel.

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CHAPTER 5

Clinical Biomechanics in Implant Dentistry

Martha Warren Bidez and Carl E. Misch

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The discipline of biomedical engineering, which applies engineering principles to living systems, has unfolded a new era in diagnosis, treatment planning, and rehabilitation in patient care. One aspect of this field, biomechanics, concerns the response of biological tissues to applied loads. Biomechanics uses the tools and methods of applied engineering mechanics to search for structure–function relationships in living materials.[1] Advancements in prosthetic, implant, and instrumentation design have been realized because of mechanical design optimization theory and practice.[2] This chapter provides fundamental concepts and principles of dental biomechanics as they relate to long-term success of dental implants and restorative procedures.

Loads Applied to Dental Implants

Dental implants are subjected to occlusal loads when placed in function. Such loads may vary dramatically in magnitude, frequency, and duration, depending on the patient's parafunctional habits. Passive mechanical loads also may be applied to dental implants during the healing stage because of mandibular flexure, contact with the first-stage cover screw, and second-stage permucosal extension.

Perioral forces of the tongue and circumoral musculature may generate low but frequent horizontal loads on implant abutments. These loads may be of greater magnitude with parafunctional oral habits or tongue thrust. Finally, application of nonpassive prostheses to implant bodies may result in mechanical loads applied to the abutment, even in the absence of occlusal loads. So many variables exist in implant treatment that it becomes almost impossible to compare one treatment philosophy with another. However, basic units of mechanics may be used to provide the tools for the consistent description and understanding of such physiologic (and nonphysiologic) loads. Two different approaches may render a similar short-term result; however, a biomechanical approach still can determine which treatment renders more risk over the long term.

Mass, Force, and Weight

Mass, a property of matter, is the degree of gravitational attraction the body of matter experiences. As an example, consider two cubes composed of hydroxyapatite (HA) and commercially pure titanium, respectively. If the two cubes are restrained by identical springs, then each spring will deflect by a certain amount relative to the attraction of gravity for the two cubes. The two spring deflections in this example can be made equal by removing part of the material from the titanium cube. Even though the cubes are of completely different composition and size, they can be made equivalent with respect to their response to the pull of gravity. This innate property of each cube that is related to the amount of matter in physical objects is referred to as *mass*. The unit of mass in the metric (International System of Units) system is the kilogram (kg); in the English system, it is the pound mass (lbm).[3]

In 1687, Sir Isaac Newton described a force in what is now referred to as *Newton's laws of motion*.[3] In his second law, Newton stated that the acceleration of a body is inversely proportional to its mass and directly proportional to the force that caused the acceleration. The familiar relation expresses this law:

$$F = ma$$

where F is force (newtons [N]), m is mass (kilograms), and a is acceleration (meters per second squared [m/sec^2]). In the dental implant literature, force commonly is expressed as kilograms of force. The gravitational constant (a = 9.8 m/sec^2) is approximately the same at every location on Earth; therefore, mass (kilograms) is the determining factor in establishing the magnitude of a static load.

Weight is simply a term for the gravitational force acting on an object at a specified location. Weight and force can be expressed by the same units, newtons or pound force (lbf). If a titanium cube is considered as though placed on the moon, then its weight (force caused by gravity) is different from its weight on the Earth. The mass in the cube has not changed, but the *acceleration caused by gravity* has changed. Recalling Sir Isaac Newton's work, an apple weighs approximately 1 N (0.225 lbf)[4] (Box 5-1).

Forces

Forces may be described by magnitude, duration, direction, type, and magnification factors. Forces acting on dental implants are referred to as *vector quantities;* that is, they possess magnitude and direction. Restated, to state simply that "a force of 75 lb exists on the distal abutment" is not sufficient. The more correct statement is "a force of 75 lb exists on the distal abutment directed axially along the long axis of the implant body." The dramatic influence of load direction on implant longevity and bone maintenance is discussed later in this chapter and others. Typical maximum bite force magnitudes exhibited by adults are affected by age, sex, degree of edentulism, bite location, and especially parafunction[5-9] (Table 5-1).

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A force applied to a dental implant rarely is directed absolutely longitudinally along a single axis. In fact, three dominant clinical loading axes exist in implant dentistry: (1) mesiodistal, (2) faciolingual, and (3) occlusoapical (Figure 5-1). A single occlusal contact most commonly results in a three-dimensional occlusal force. Importantly, this three-dimensional force may be described in terms of its component parts (fractions) of the total force that are directed along the other axes. For example, if an occlusal scheme on an implant restoration is used that results in a large magnitude of force component directed along the faciolingual axis (lateral loading), then the implant is at extreme risk for fatigue failure (described later in this chapter). The process by which three-dimensional forces are broken down into their component parts is referred to as *vector resolution* and may be used routinely in clinical practice for enhanced implant longevity.

Components of Forces (Vector Resolution)

Occlusion serves as the primary determinant in establishing load direction. The position of occlusal contacts on the prosthesis directly influences the type of force components distributed throughout the implant system.

BOX 5-1 Useful Conversion Factors

Mass
1 kg = 2.205 lbm
1 lbm = 0.45 kg

Force
1 N = 1 kg(m/s^2) = 0.225 lbf
1 lbf = 4.448 N

Area
1 m^2 = 10.764 sq ft
1 sq ft = 0.093 m^2
1 sq in = 6.452 × 10^{-4} m^2
Pressure*
1 lbf/sq in (psi) = 144 lbf/sq ft = 6894.8 Pa = 6.89 kPa = 0.0069 MPa
1 Pa = 1 N/m^2 = 1.450 × 10^{-4} psi = 0.021 lbf/sq ft

*Stress uses these same units of measurement.

The dentist should visualize each occlusal contact on an implant restoration in its component parts. Consider the example of a restored dental implant subjected to a premature contact during occlusion. When the contact is broken down into its component parts directed along the three clinical loading axes, a large, potentially dangerous lateral component is observed. Occlusal adjustments consistent with implant-protective occlusion to eliminate the premature contact minimize the development of such dangerous load components.

Angled abutments also result in development of dangerous transverse force components under occlusal loads in the direction of the angled abutment. Implants should be placed surgically to provide for mechanical loading down the long axis of the implant body to the maximum extent possible. Angled abutments are used to improve esthetics or the path of insertion of a restoration, not to determine the direction of load.

Three Types of Forces

Forces may be described as compressive, tensile, or shear. Compressive forces attempt to push masses toward each other. Tensile forces pull objects apart. Shear forces on implants cause sliding. Whereas compressive forces tend to maintain the integrity of a bone–implant interface, tensile and shear forces tend to distract or disrupt such an interface. Shear forces are most destructive to implants and bone compared with other load modalities. In general, compressive forces are accommodated best by the complete implant–prosthesis system. Cortical bone is strongest in compression and weakest in shear[10] (Table 5-2). Additionally, cements and retention screws, implant components, and bone–implant interfaces all accommodate greater compressive forces than tensile or shear. For example, whereas the compressive strength of an average zinc–phosphate dental cement is 83 to 103 MPa (12,000–15,000 psi), the resistance to tension and shear is significantly less (500 psi) (Figure 5-2).

The implant body design transmits the occlusal load to the bone. Threaded or finned dental implants impart a combination of all three force types at the interface under the action of a single occlusal load. This "conversion" of a single force into three different types of forces is controlled completely by the implant geometry. The prevalence of potentially dangerous tensile and shear forces in threaded or finned implants may be controlled optimally through careful engineering design. Cylinder implants in particular are at highest risk for harmful shear loads at the implant–tissue interface under an occlusal load directed along the long axis of the implant body. As a

TABLE 5-1
Maximum Bite Force

Reference	Age (yr)	Number	Incisor	Canine	Premolar	Molar	Comments
Braun et al.[5]	26–41	142				710 N	Between premolar and molar; male subjects 789 N; female subjects 596N
van Eijden[6]	31.1 (±4.9)	7		323–485 N	424–583 N	475–749 N	Second premolar and second molar, left and right (male subjects only)
Dean et al.[7]	Adult	57	150 N			450 N	Converted from figures
Bakke et al.[8]	21–30	20				572 N	Measured in left and right first molar
	31–40	20				481 N	
	41–50	20				564 N	
	51–60	17				485 N	
	61–70	8				374 N	
Braun et al.[9]	18–20					176 N	First molar or first premolar

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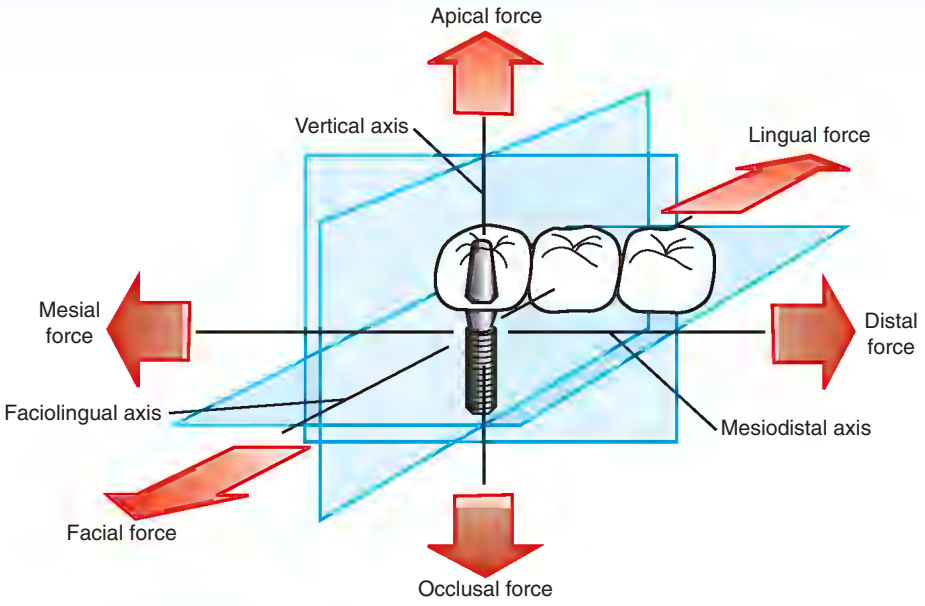


FIGURE 5-1. Forces are three-dimensional, with components directed along one or more clinical coordinate axes: mesiodistal, faciolingual, and occlusoapical (vertical).

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TABLE 5-2
Cortical Bone Strengths in Human Femur Specimens

Type of Force Applied	Strength (MPa)*	Load Direction/ Comments
Compressive	193.0 (13.9)	Longitudinal
	173.0 (13.8)	30 degrees off axis
	133.0 (15.0)	60 degrees off axis
	133.0 (10.0)	Transverse
Tensile	133.0 (11.7)	Longitudinal
	100.0 (8.6)	30 degrees off axis
	60.5 (4.8)	60 degrees off axis
	51.0 (4.4)	Transverse
Shear	68.0 (3.7)	Torsion

*Standard deviations are listed in parentheses.
Data from Reilly DT, Burstein AH: The elastic and ultimate properties of compact bone tissue, *J Biomech* 8:393, 1975.

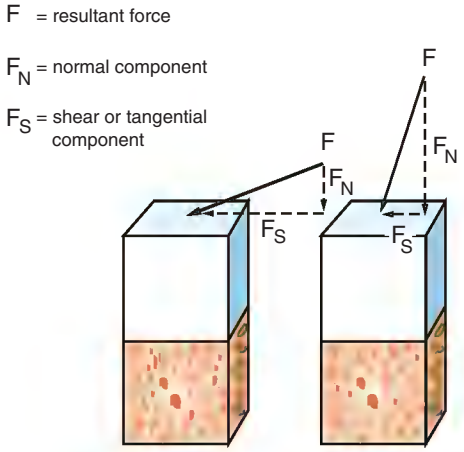


FIGURE 5-2. Force can be resolved into a combination of normal and shear force components in a given plane. Depending on the direction of load application, the same magnitude of force has different effects.

consequence, cylinder implants require a coating to manage the shear stress at the interface through a more uniform bone attachment along the implant length. Bone loss adjacent to cylindrical implants and coating degradation results in a mechanically compromised implant.

Offset loading on single-tooth or multiple-abutment restorations results in moment (bending) loads (described later under Force Delivery and Failure Mechanisms). As a result, an increase in tensile and shear force components is often found. Compressive forces typically should be dominant in implant prosthetic occlusion.

Multiple abutment restorations, particularly with distal cantilevers, produce a remarkably complex load profile in the prosthesis and in the bone–implant interface. These clinical realities underscore the need for optimizing dental implant design to provide the maximum functional surface area to dissipate such forces.

Stress

The manner in which a force is distributed over a surface is referred to as *mechanical stress*. Thus, the familiar relation defines stress:

$$\sigma = F/A$$

where σ is stress (pounds per square inch; pascals), F is force (newtons; pound force), and A is area (square inches; square meters). The internal stresses that develop in an implant system and surrounding biological tissues under an imposed load may have a significant influence on the long-term longevity of the implants in vivo. As a general rule, a goal of treatment planning should be to minimize and evenly distribute mechanical stress in the implant system and the contiguous bone.

The magnitude of stress depends on two variables: (1) force magnitude and (2) cross-sectional area over which the force is

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dissipated. It is rare that a dentist can control the force magnitude completely. The magnitude of the force may be decreased by reducing these significant magnifiers of force: cantilever length, offset loads, and crown height. Night guards to decrease nocturnal parafunction; occlusal materials that decrease impact force; and overdentures, rather than fixed prostheses, that can be removed at night are further examples of force reduction strategies. The functional surface area over which the force is distributed, however, is controlled completely through careful treatment planning.

A *functional cross-sectional* area is defined as that surface that participates significantly in load bearing and stress dissipation. This area may be optimized by (1) increasing the number of implants for a given edentulous site and (2) selecting an implant geometry that has been designed carefully to maximize functional cross-sectional area. An increase in functional surface area serves to decrease the magnitude of mechanical stress imposed on the prosthesis, implant, and biological tissues.

Stress components are described as normal (perpendicular to the surface and given the symbol σ) and shear (parallel to the surface and given the symbol τ). One normal stress and two shear stresses act on each plane (x, y, z); therefore $\tau_{xy} = \tau_{yx}$, $\tau_{yz} = \tau_{zy}$, and $\tau_{xz} = \tau_{zx}$. Thus any three-dimensional element may have its stress state completely described by three normal stress components and three shear components.

The question arises as to what are the peak stresses or maximum stresses that an implant and the surrounding interfacial tissues experience. Peak stresses occur when the stress element is positioned in a particular orientation (or geometric configuration) in which all shear stress components are zero. When an element is in this configuration, the normal stresses are given a particular name, *principal stresses,* and are indicated as σ_1, σ_2, and σ_3. By convention, maximum principal (σ_1) stresses represent the most positive stresses (typically peak tensile stresses) in an implant or tissue region and minimum principal (σ_3) stresses, the most negative stresses (typically peak compressive stresses). Sigma 2 (σ_2) represents a value intermediate between σ_1 and σ_3. Determination of these peak normal stresses in a dental implant system and tissues may give valuable insights regarding sites of potential implant fracture and bone atrophy.

Deformation and Strain

A load applied to a dental implant may induce deformation of the implant and surrounding tissues. Biological tissues may be able to interpret deformation or a manifestation thereof and respond with the initiation of remodeling activity.

The deformation and stiffness characteristics of the materials used in implant dentistry, particularly the implant materials, may influence interfacial tissues, ease of implant manufacture, and clinical longevities. Elongation (deformation) of biomaterials used for surgical dental implants ranges from 0 for aluminum oxide ceramics to up to 55 for annealed 316-L stainless steel[11] (Table 5-3). Related to deformation is the concept of strain, a parameter believed to be a key mediator of bone activity.

Under the action of a tensile force (F), the straight bar (of original gauge length, l_0) undergoes elongation to a final length ($l_0 + \Delta l$) (Figure 5-3). Engineering strain, which is unitless, is defined as elongation per unit length and is described as:

$$\varepsilon = l - l_0 = \Delta l$$
$$l_0 l_0$$

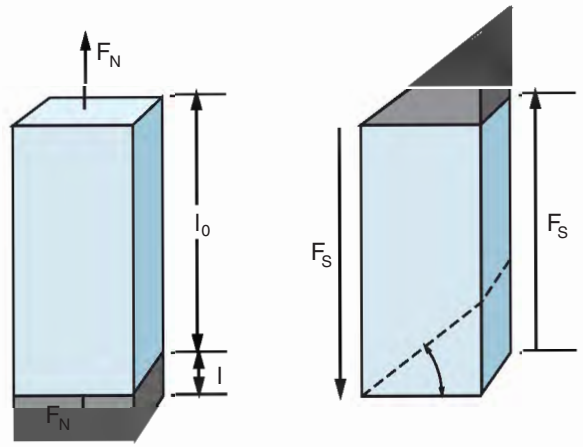


FIGURE 5-3. Under action of tensile force (F_N), the straight bar (originally l_0) is elongated by an amount Δl. Engineering strain (ε) is the deformation per unit length. Shear strain γ is the change in a right angle of a body or stress element under action of a pure shearing load (F_S).

where Δl is elongation; l_0 is original gauge length; and l is final length after elongation, Δl. Shear strain, g, describes the change in a right angle of a body or stress element under the action of a pure shearing load.

All materials (biological and nonbiological) are characterized by a maximum elongation possible before permanent deformation or fracture results. Furthermore, biological materials exhibit strain rate dependence in that their material properties (e.g., modulus of elasticity, ultimate tensile strength) are altered as a function of the rate of loading (and subsequent deformation rate).

Experimental observation also has demonstrated that lateral strain also accompanies axial strain under the action of an axial load. Within an elastic range (defined later in this section), these two strains are proportional to one another as described by Poisson's ratio, μ. For tensile loading:

$$\mu = \frac{\text{Lateral strain}}{\text{Axial strain}}$$

The material and mechanical properties described provide for the determination of implant-tissue stress-strain behavior according to established relationships in solid mechanics theory.[12]

Stress-Strain Relationship

A relationship is needed between the applied force (and stress) that is imposed on the implant and surrounding tissues and the subsequent deformation (and strain) experienced throughout the system. If any elastic body is subjected experimentally to an applied load, then a load-versus-deformation curve can be generated (Figure 5-4, *A*). Dividing the load (force) values by the surface area over which they act and the change in the length by the original length produces a classic engineering stress-strain curve (Figure 5-4, *B*). Such a curve provides for the prediction of how much strain will be experienced in a given material under the action of an applied load. The slope of the linear (elastic) portion of this curve is referred to as the *modulus of elasticity (E),* and its value indicates the stiffness of the material under study.

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TABLE 5-3
Mechanical Properties of Selected Surgical Implant Biomaterials

	Biomaterial												
				Co Alloy (Wrought)		Fe-Cr-Ni 316-L			Al_2O_3				
Property	**Ti (Wrought)**	**Ti-Al-V (Wrought)**	**Co-Cr-Mo (Cast)**	**Annealed Worked**	**Cold**	**Annealed**	**Cold Worked**	**C-Si**	**Sapphire**	**Alumina**	**UHMW Polyethylene**	**PMMA**	**PTFE**
Density (g/mL)	—	4.5	8.3	9.2	9.2	7.9	7.9	1.5–2.0	3.99	3.9	0.94	1.2	2.2
Hardness (Vickers)	R_b100	—	300	240	450	170–200	300–350	—	—	HV23.000	D65	M60–100	D50–65
Yield strength (MPa)	170–480 (25–70)	795–827 (115–120)	490 (71)	450 (62)	1050 (152)	240–300 (35–44)	700–800 (102–116)	—	—	—	—	—	—
Ultimate tensile strength (MPa)	240–550 (35–80)	860–896 (125–130)	690 (100)	950 (138)	1540 (223)	600–700 (87–102)	1000 (145)	350–517 (51–75)	480 (70)	400 (58)	21–44 (3.0–6.4)	55–85 (8.0–12.3)	14–34 (2–5)
Elastic modulus (GPa) ($psi \times 10^3$)	96 (14)	105–117 (15–17)	200 (29)	230 (34)	230 (34)	200 (29)	200 (29)	28–34 (4.0–4.9)	414 (60)	380 (55.1)	1 (0.145)	2.4–3.3 (0.3480–0.479)	0.4 (0.058)
Endurance limit (fatigue) (MPa) ($psi \times 10^3$)	—	170–240 (24.6–35)	300 (43)	—	240–490 (35–71)	300 (43)	230–280 (33.3–40.6)	—	—	—	—	—	—
Elongation (%)	15–24	10–15	8	30–45	9	35–55	7–22	0	0	0	400	2–7	200–400

PMMA, Polymethylmethacrylate; *PTFE,* polytetrafluoroethylene; *UHMW,* ultrahigh molecular weight polyethylene.
From Lemons JE, Bidez MW: Biomaterials and biomechanics in implant dentistry. In McKinney RV, editor: *Endosteal dental implants,* St Louis, 1991, Mosby.

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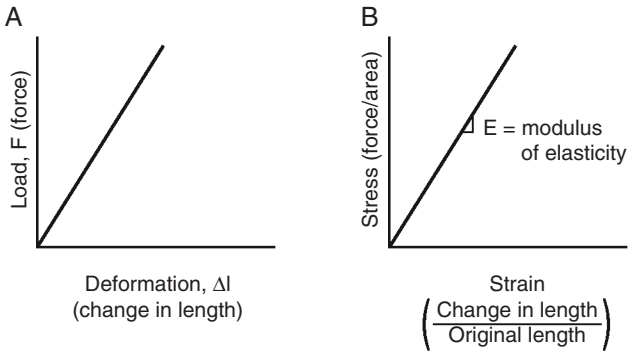


FIGURE 5-4. **A,** Load-versus-deformation curve may be generated for any elastic body experimentally subjected to a load. **B,** Dividing load values by the surface area and the deformation of the original gauge length of the specimen produces a stress-strain curve.

The closer the modulus of elasticity of the implant resembles that of the contiguous biological tissues, the less the likelihood of relative motion at the tissue–implant interface. The cortical bone is at least five times more flexible than titanium. As the stress magnitude increases, the relative stiffness difference between bone and titanium increases. As the stress magnitude decreases, the stiffness difference becomes much less. Restated, the viscoelastic bone can stay in contact with more rigid titanium more predictably when the stress is low. In terms of full-arch kinematics, the practitioner should consider that the mandible flexes toward the midline on opening. A prosthesis and implant support system that is splinted from molar to molar must provide similar movement if the interface is to remain intact.

After a particular implant system (i.e., a specific biomaterial) is selected, the only way for an operator to control the strain experienced by the tissues is to control the applied stress or change the density of bone around the implant (Figure 5-5). Such stress (force/area) may be influenced by the implant design, size, implant number, implant angulation, and restoration. The macrogeometry of the implant (i.e., the amount and orientation of functional surface area available to dissipate loads) has a strong influence on the nature of the force transfer at the tissue–implant interface. Surgical grafting procedures may increase the quantity and quality of bone and allow placement of a larger implant with more bone contiguous to the interface implant. The applied stress also is influenced by the restoration, including the size of occlusal tables, stress breakers, use of overdenture versus fixed prosthesis, and occlusal contact design. Generally, the greater the magnitude of stress applied to a dental implant system, the greater the difference in strain between the implant material and bone. In such cases, the implant is less likely to stay attached to the bone, and the probability of fibrous tissue ingrowth into the interfacial region to accommodate the range of difference becomes greater. The density of bone is related not only to the bone strength but also to the modulus of elasticity (stiffness). The stiffer the bone, the more rigid it is; the softer the bone, the more flexible the bone. Therefore, the difference in stiffness is less for commercially pure titanium (or its alloy) and division 1 dense bone compared with titanium and division 4 soft bone. Decreasing stress in softer bone is more important for two primary reasons: (1) to reduce the resultant tissue strains resulting from the elasticity difference and (2) because softer bone exhibits a lower ultimate strength.

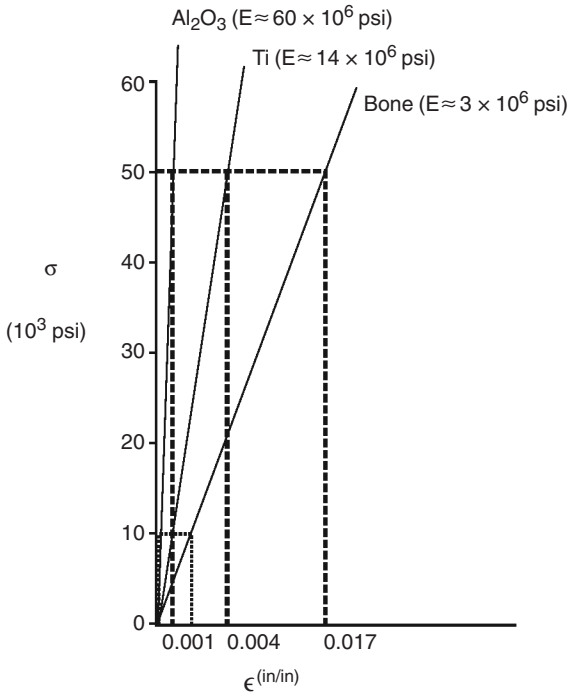


FIGURE 5-5. After a particular implant system is selected, the only way to control strain (σ) on tissues is to control applied stress (ε). The greater the magnitude of stress applied to the system, the greater the difference in strain between implant material and bone. *E,* Modulus of elasticity.

Hooke's law is the name given to the relationship between stress and strain; in its simplest form, the law is described mathematically as the following:

$$\sigma = E\varepsilon$$

where σ is normal stress (pascal or pounds per square inch), *E* is the modulus of elasticity (pascal or pounds per square inch), and ε is normal strain (unitless). A similar relationship exists for shear stress and shear strain, where the constant of proportionality is the modulus of rigidity *(G)* expressed by the following:

$$\tau = G_\gamma$$

where τ is shear stress (pascal or pounds per square inch), *G* is the modulus of rigidity (pascal or pounds per square inch), and γ is shear strain (unitless).

Impact Loads

When two bodies collide in a small interval of time (fractions of a second), large reaction forces develop. Such a collision is described as *impact*. In dental implant systems subjected to occlusal implant loads, deformation may occur in the prosthodontic restoration, in the implant itself, and in the contiguous interfacial tissues. The nature of the relative stiffness of these components in the overall implant system largely controls the response of the system to impact load. The higher the impact load, the greater the risk of implant and bridge failure and bone fracture.

Rigidly fixed implants generate a higher interfacial impact force with occlusion compared with natural teeth, which possess a periodontal ligament. Soft tissue–borne prostheses have the least impact force because the gingival tissues are resilient.

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Occlusal material fracture is a significant complication of fixed prostheses on natural teeth. The incidence of occlusal material fracture is greater on implants and may approach rates as high as 30%.

Various methods have been proposed to address the issue of reducing implant loads. Skalak[13] has suggested the need for using acrylic teeth along with osteointegrated fixtures partially to mitigate high-impact loads that might damage bony tissues adjacent to the implant. Weiss[14] has proposed that a fibrous tissue–implant interface provides for physiologic shock absorption in a fashion similar to that exhibited by a functioning periodontal ligament. At least one implant design has attempted to incorporate shock absorption capability in the design itself by the use of an "intramobile element" of lower stiffness compared with the rest of the implant.[15] Misch[16] advocates an acrylic provisional restoration with a progressive occlusal loading to improve the bone–implant interface before the final restoration, occlusal design, and masticatory loads are distributed to the system. Only limited data exist concerning impact forces on natural dentition and tooth-supported bridgework.[17,18]

Force Delivery and Failure Mechanisms

The manner in which forces are applied to implant restorations within the oral environment dictates the likelihood of system failure. The duration of a force may affect the ultimate outcome of an implant system. Relatively low-magnitude forces, applied repetitively over a long time, may result in fatigue failure of an implant or prosthesis. Stress concentrations and, ultimately, failure may develop if insufficient cross-sectional area is present to dissipate high-magnitude forces adequately. If a force is applied some distance away from a weak link in an implant or prosthesis, then bending or torsional failure may result from moment loads. An understanding of force delivery and failure mechanisms is critically important to the implant practitioner to avoid costly and painful complications.

Moment Loads

The moment of a force about a point tends to produce rotation or bending about that point. In Figure 5-6, the moment is defined as a vector *(M)* (vectors are described in terms of magnitude and direction), the magnitude of which equals the product of the force magnitude multiplied by the perpendicular distance (also called the *moment arm*) from the point of interest to the line of action of the force. This imposed moment load also is referred to as a *torque* or *torsional load* and may be destructive to implant systems. Torques or bending moments imposed on implants because of, for example, excessively long cantilever bridge or bar sections may result in interface breakdown, bone resorption, prosthetic screw loosening, or bar or bridge fracture. The negative effect of cantilevers has been reported for more than 30 years.[19,20] Proper restorative design must include consideration of forces and the moment loads caused by those forces.

Clinical Moment Arms

A total of six moments (rotations) may develop about the three clinical coordinate axes previously described (occlusoapical, faciolingual, and mesiodistal axes) (Figure 5-7). Such moment loads induce microrotations and stress concentrations at the crest of the alveolar ridge at the implant–tissue interface, which lead inevitably to crestal bone loss.

Three clinical moment arms exist in implant dentistry: (1) occlusal height, (2) cantilever length, and (3) occlusal width. Minimization of each of these moment arms is necessary to prevent unretained restorations, fracture of components, crestal bone loss, and complete implant system failure.

Occlusal Height

The occlusal height serves as the moment arm for force components directed along the faciolingual axis (Figure 5-8, *A*)—working or balancing occlusal contacts, tongue thrusts, or in passive loading by cheek and oral musculature (Figure 5-8, *B*), as well as force components directed along the mesiodistal axis (Figure 5-8, *C*).

In division A bone, initial moment load at the crest is less than in division C or D bone because the crown height is greater in division C and D bone. Treatment planning must take into account this initially compromised biomechanical environment (Table 5-4). The moment contribution of a force component directed along the vertical axis is not affected by the occlusal height because no effective moment arm exists. Offset occlusal contacts or lateral loads, however, introduce significant moment arms (see Figure 5-8, *E*).

Cantilever Length

Large moments may develop from vertical axis force components in prosthetic environments designed with cantilever extensions or offset loads from rigidly fixed implants. A lingual force component also may induce a twisting moment about the implant neck axis if applied through a cantilever length (Figure 5-8, *D*).

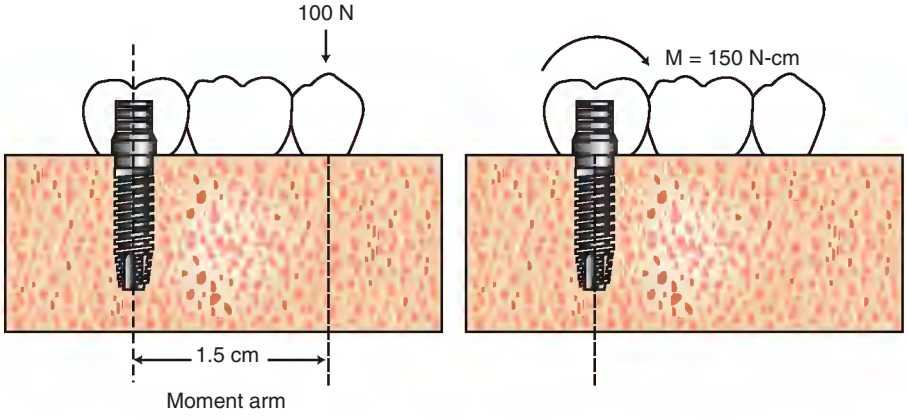


FIGURE 5-6. The moment of a force is defined as a vector *(M)*, the magnitude of which equals the product of the force magnitude multiplied by the perpendicular distance (moment arm) from the point of interest to the line of action of the force.

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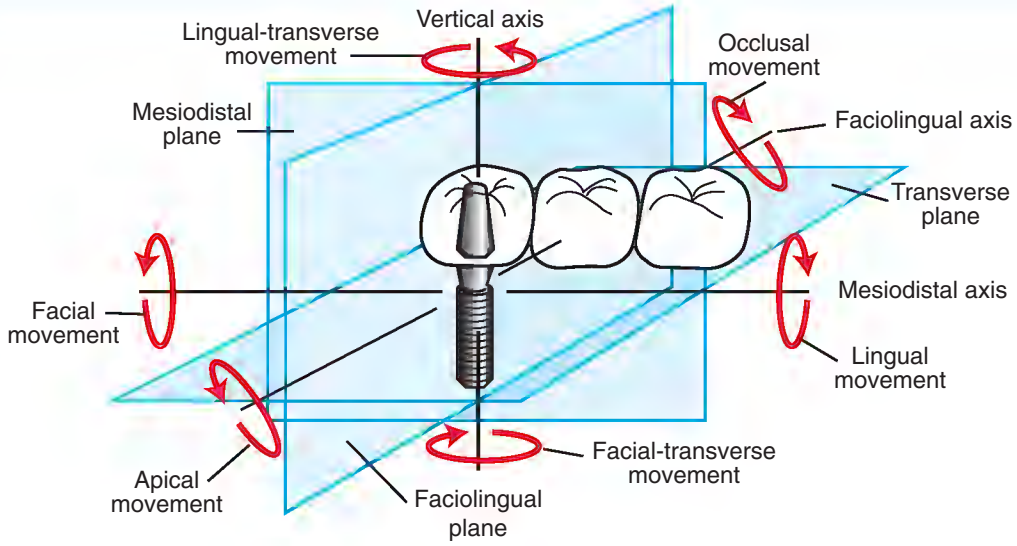


FIGURE 5-7. Moment loads tend to induce rotations in three planes. Clockwise and counterclockwise rotations in these three planes result in six moments: lingual-transverse, facial-transverse, occlusal, apical, facial, and lingual.

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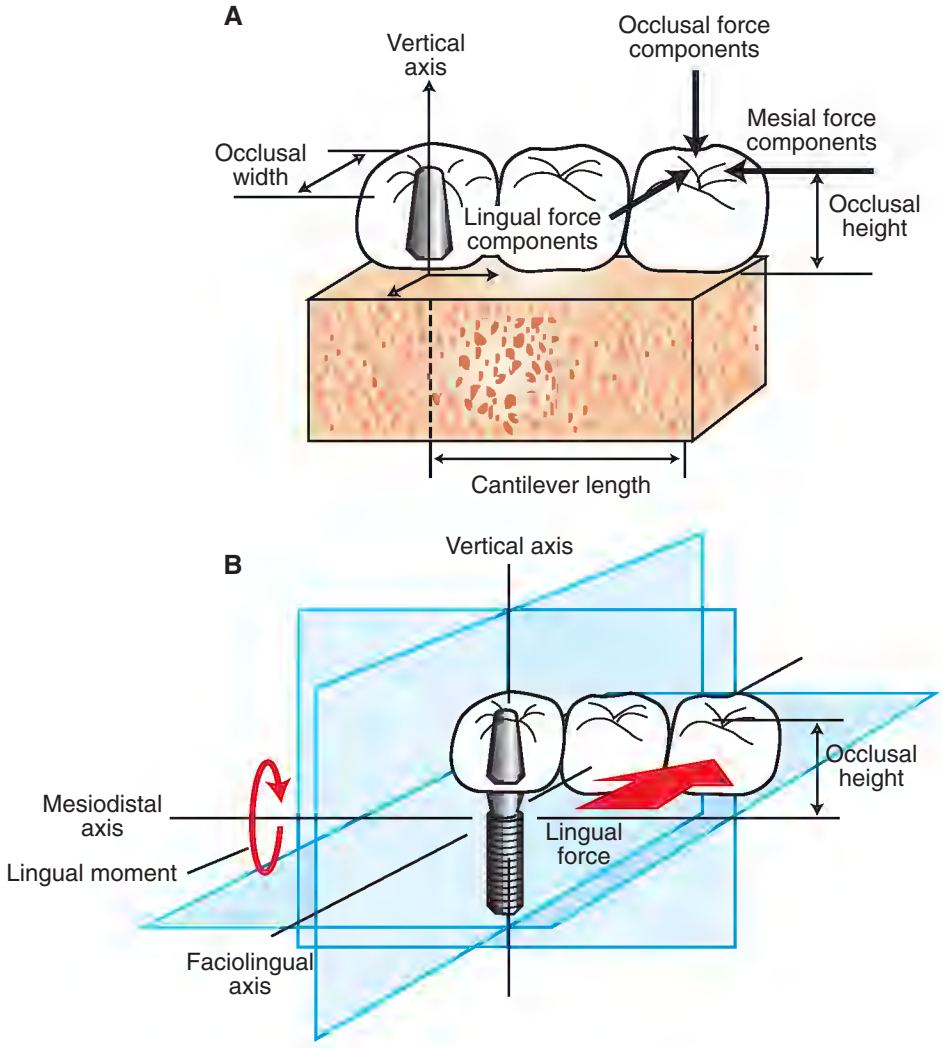


FIGURE 5-8. **A,** Three clinical moment arms contribute to torsional (moment) loads on dental implants: occlusal height, occlusal width, and cantilever length. **B,** Occlusal height serves as moment arm for force components directed along faciolingual axis and force components directed along mesiodistal axis **(C).**

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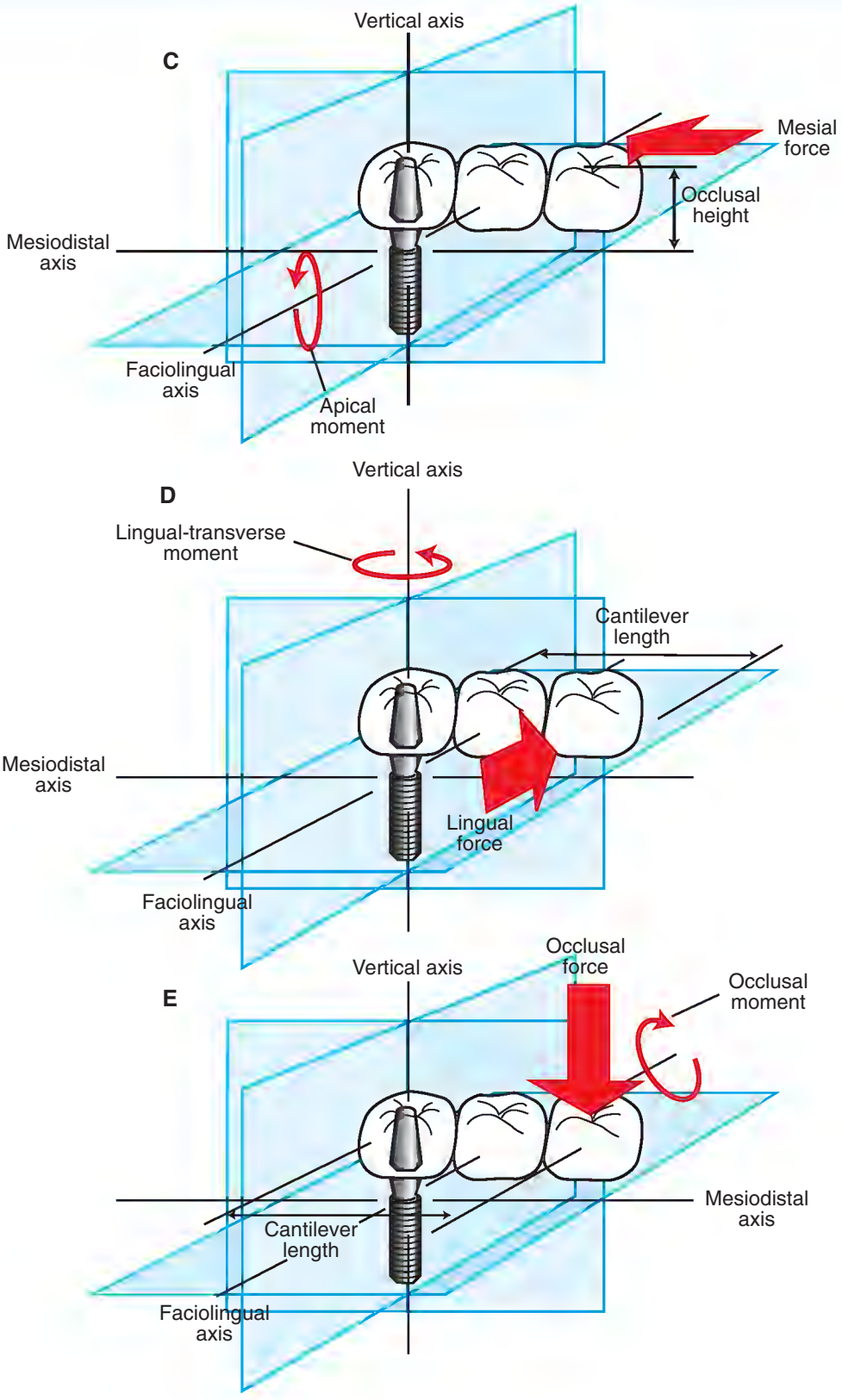


FIGURE 5-8, cont'd. **D,** Lingual force component also may induce twisting moment about the implant neck if applied through the cantilever length. **E,** Moment of force along the vertical axis is not affected by occlusal height because its effective moment arm is zero if positioned centrically.

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TABLE 5-4
Moment Load at Crest When Subjected to Cantilever Forces in Relation to Crown Height

Influences on Moment		Imposed Moments (N/mm) at Implant Crown-Crest Interface					
Occlusal Height	Cantilever Length	Lingual	Facial	Apical	Occlusal	Facial-Transverse (mm)	Lingual-Transverse (mm)
10	10	100	0	50	200	0	100
10	20	100	0	50	400	0	200
10	30	100	0	50	600	0	300
20	10	200	0	100	200	0	100
20	20	200	0	100	400	0	200
20	30	200	0	100	600	0	300

An implant with a cantilevered mesobar extending 1, 2, and 3 cm has significant ranges of moment loads. A 100-N force applied directly over the implant does not induce a moment load or torque because no rotational forces are applied through an offset distance. This same 100-N force applied 1 cm from the implant results in a 100 N-cm moment load. Similarly, if the load is applied 2 cm from the implant, then a 200 N-cm torque is applied to the implant–bone region, and at 3 cm, a 300 N-cm moment load results. For comparison, recall that implant abutments typically are tightened with 30 N-cm of torque.

Cantilever prostheses attached to splinted implants result in a complex load reaction. In its simplest form, a class 1 lever action may be expressed. If two implants 10 mm apart are splinted together, and a 20-mm distal cantilever is designed with a 100-N load, then the following forces result. The 100-N load is resisted with a 200-N tensile force by the mesial implant, and the distal implant acts as a fulcrum with a 300-N compressive load (Figure 5-9, *A*). If the position and amount of distal load remain the same but the distal implant is positioned 5 mm anterior, then the resultant loads on the implants change (Figure 5-9, *B*). The anterior implant must resist a 500-N tensile force, and the distal, fulcrum implant receives a 600-N compressive force. Therefore, whereas the tensile force is increased 2.5 times on the anterior implant, the compressive force is increased twofold. Because bone and screws are weaker under the action of tensile forces, both implants become more at risk for complications.

Similar principles regarding class 1 lever forces apply to cantilever loads with anterior splinted implants placed on a curve with distal extended prostheses. The Nobel Biocare prosthetic protocol uses four to six anterior implants placed in front of the mental foramen or maxillary sinuses and uses a full-arch fixed prosthesis with cantilevered segments.[21-23] Specific cantilever lengths are not stated, although two to three premolars are recommended. The cantilever length is suggested to be reduced when four rather than six implants are used to support the restoration[24] or when implants are in the softer bone of the maxilla.[25] A line is drawn from the distal of each posterior implant. The distance to the center of the most anterior implant is called the *anteroposterior distance* (A-P spread).[26] The greater the A-P spread is between the center of the most anterior implant or implants and the most distal aspect of the posterior implants, the smaller is the resultant loads on the implant system from cantilevered forces because of the stabilizing effect of the A-P distance. According to Misch,[25] the amount of stress applied to the system determines the length of this distal cantilever. Because stress equals force divided by area, both aspects must be considered. The magnitude and direction of force are determined by parafunction, crown height, masticatory dynamics, gender, age, and arch location. The functional surface area is determined by the number of implants, width, length, design, and bone density, which determines the area of contact and bone strength. Clinical experiences suggest that the distal cantilever should not extend 2.5 times the A-P spread under ideal conditions (e.g., parafunction absent or five division A implants). One of the greatest determinants for the length of the cantilever is the magnitude of the force. Patients with severe bruxism should not undergo restoration with any cantilevers, regardless of other factors.

A square arch form involves smaller A-P spreads between splinted implants and should have shorter-length cantilevers. A tapered arch form has the largest distance between anterior and

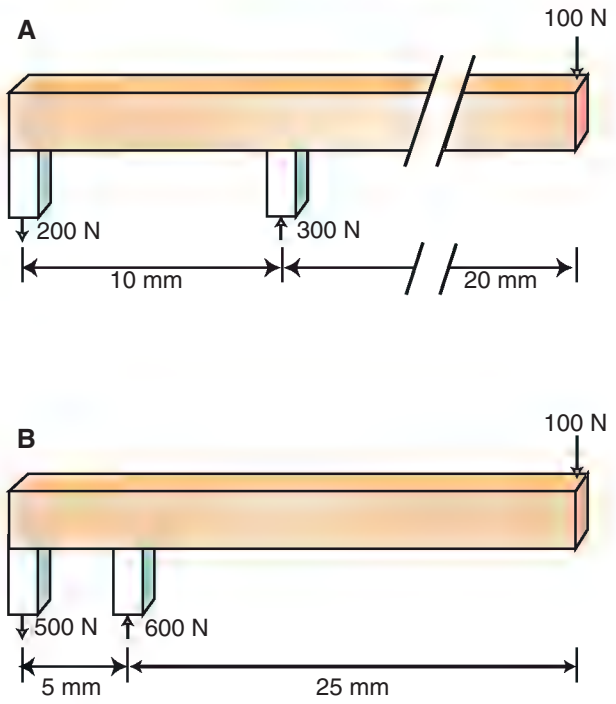


FIGURE 5-9. **A,** If two implants are designed 10 mm apart and splinted together with a 20-mm distal cantilever, then a 100-N load is resisted by a 200-N force by the mesial implant, and the distal implant acts as a fulcrum with a 300-N load. **B,** If implants are 5 mm apart, then the anterior implant must resist a 500-N force and the distal fulcrum implant receives a 600-N force.

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posterior implants and may have the longest cantilever design. The maxilla has less dense bone than the mandible and more often has an anterior cantilever with the prosthesis. As a result, more distal implants may be required in the maxilla to increase the A-P spread for the anterior or posterior cantilever than in the mandible, and sinus augmentation may be required to permit posterior placement of the implant.

Occlusal Width

Wide occlusal tables increase the moment arm for any offset occlusal loads. Faciolingual tipping (rotation) can be reduced significantly by narrowing the occlusal tables or adjusting the occlusion to provide more centric contacts.

In summary, a vicious, destructive cycle can develop with moment loads and result in crestal bone loss. As crestal bone loss develops, occlusal height automatically increases. With an increased occlusal height moment arm, the faciolingual micro-rotation and rocking increase and cause even more stress to the crestal bone. Unless the bone increases in density and strength, the cycle continues to spiral toward implant failure if the biomechanical environment is not corrected.

Fatigue Failure

Fatigue failure is characterized by dynamic, cyclic loading conditions. Four fatigue factors significantly influence the likelihood of fatigue failure in implant dentistry: (1) biomaterial, (2) macrogeometry, (3) force magnitude, and (4) number of cycles.

Fatigue behavior of biomaterials is characterized graphically in what is referred to as an *S-N curve* (a plot of applied stress versus number of loading cycles) (Figure 5-10, *A*). If an implant is subjected to an extremely high stress, then only a few cycles of loading can be tolerated before fracture occurs. Alternatively, an infinite number of loading cycles can be maintained at low stress levels. The stress level below which an implant biomaterial can be loaded indefinitely is referred to as its *endurance limit*. Titanium alloy exhibits a higher endurance limit than commercially pure titanium (Figure 5-10, *B*).

The geometry of an implant influences the degree to which it can resist bending and torsional loads and ultimately fatigue fracture. Implants rarely, if ever, display fatigue fracture under axial compressive loads. Morgan et al.[27] reported fatigue fractures of Brånemark dental implants caused by cyclic buccolingual loads (lateral loading) in an area of weak bending strength within the fixture (i.e., reduced moment of inertia [defined later]). The fracture of the implant body occurred in three of the patients studied, and fracture of the abutment screws for the Brånemark implant occurred in fewer than three patients. Fifteen acrylic or composite tooth fractures occurred on 10 to 20 of the fixed prostheses supported by implants over a 1- to 5-year period.[28–31]

The geometry also includes the thickness of the metal or implant. The fatigue fracture is related to the fourth power of the thickness difference. A material two times thicker in wall thickness is approximately 16 times stronger. Even small changes in thickness can result in significant differences. Often the weak link in an implant body design is affected by the difference in the inner and outer diameter of the screw and the abutment screw space in the implant.[32]

To the extent that an applied load (stress) can be reduced, the likelihood of fatigue failure is reduced. As described previously, the magnitude of loads on dental implants can be reduced by careful consideration of arch position (i.e., higher loads in the posterior compared with anterior mandible and maxilla),

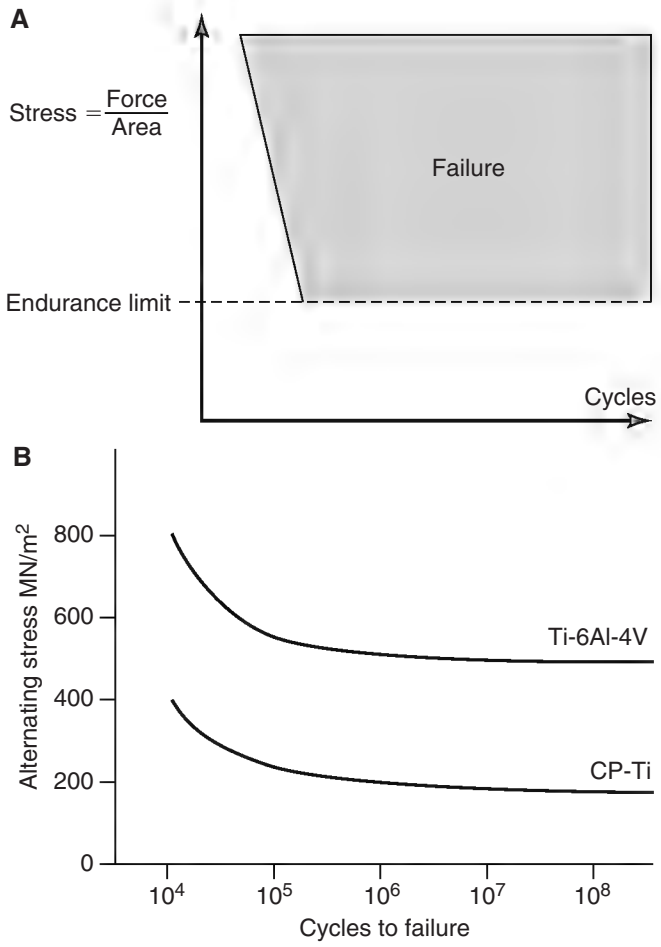


FIGURE 5-10. **A,** Fatigue behavior of biomaterials is characterized by a plot of applied stress versus number of loading cycles, an S-N curve. **B,** Endurance limit defines the stress level below which an implant biomaterial may be loaded indefinitely without failure. Titanium alloy is two to four times stronger in fatigue conditions than commercially pure titanium.

elimination of moment loads, and increase in surface area available to resist an applied load (i.e., optimize geometry for functional area, or increase the number of implants used).

Finally, fatigue failure is reduced to the extent that the number of loading cycles is reduced. Thus, aggressive strategies to eliminate parafunctional habits and reduce occlusal contacts serve to protect against fatigue failure.

Moment of Inertia

Moment of inertia is an important property of cylindrical implant design because of its importance in the analysis of bending and torsion. The bending stress in a cylinder is given by the following equation:

$$\sigma = \frac{MY}{I}$$

where M is moment (newton-centimeters), γ is the distance from the neutral axis of bending (centimeters), and I is the moment of inertia (centimeters to the fourth power).

Root form implants have varying cross-sectional geometries. The root form implant may be modeled as a hollow circle because a channel exists in the implant body to allow for

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abutment screw engagement. In the distal (apical) region of a root form implant, the cross-sectional geometry may more closely represent a solid circle. In some designs, vents that penetrate transversely through the cross-sectional geometry may interrupt the apical geometry.

The bending stress (and likelihood of bending fracture) decreases with increasing moment of inertia. Consider the mathematical formulations for the solid versus hollow cylindrical cross-sectional geometry:

$$\text{Solid circle (cylinder in the middle region): } 4\,I = \pi R^4$$

$$\text{Hollow circle (cylinder in apical region): } 4\,I = \pi\left(R^4 R_i^4\right)$$

where R is the outer radius (centimeters) and R_i is the inner wall radius.

Summary

The most common complications in implant-related reconstruction are related to biomechanical conditions. Implant healing failures may result from micromovement of the implant from too much stress. Early crestal bone loss may be related to occlusal overload conditions. Prostheses or abutment screws may become loose from bending or moment forces. Implant or component fracture may occur from fatigue conditions. Prosthesis failure may result from all of the foregoing or bending fracture resistance. In addition, the manifestation of biomechanical loads on dental implants (moments, stress, and strain) controls the long-term health of the bone–implant interface. Knowledge of basic biomechanical principles is thus required for the dentist.

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CHAPTER 6

Bone Response to Mechanical Loads

Girish Ramaswamy, Martha Warren Bidez, and Carl E. Misch

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In an effort to optimize the interaction between bone and dental or skeletal implants, many researchers have focused their attention on the implant-tissue interface.[1–19] The importance of the events that take place at the interfacial "zone" between an implant and the host tissue cannot be overstated. This complex interaction involves not only biomaterial and biocompatibility issues but also the alteration of the mechanical environment that occurs when placement of an implant disturbs the normal physiologic distribution of forces, fluids, and cell communication. The purpose of this chapter is to describe the current state of understanding regarding the biological and biomechanical response of bone to mechanical loads, with particular emphasis on the dental implant–bone interface.

Biological Response

The implant-tissue interface is an extremely dynamic region of interaction. This interface completely changes character as it goes from its genesis (placement of the implant into the prepared bony site) to its maturity (healed condition). The biomechanical environment plays an immediate role in the quality and compositional outcome of the new interface. For example, extensive research shows that if the implant is stable in the bone at the time of placement, then the interface is more likely to result in osteointegration.[15,20] Relative movement (or micromotion) between the implant and the bone at the time of placement is more likely to favor the development of a fibro-osseous interface.[11,18] The healing stage of the interface, however, is only the beginning of its dynamic nature. Functional loading of the implant brings additional biomechanical influences that greatly affect the composition of this junction.

A topic of intense research for many years is the transduction of loading-induced strain at the interface into a signal that can direct the interfacial tissues to respond or remodel. It has been proven that bone responds to both hormonal and biomechanical (functional loading) regulation. These two regulating mechanisms are often in opposition to each other. Research has shown that even in instances in which a large demand exists for calcium (the primary objective for hormonal regulation), functional loading can compete and maintain bone mass.[21] Researchers have theorized that the actual strain (see Chapter 22) that is perceived by the bone tissue initiates a chain of events that results in a biological response. For tissue strain to influence bone adaptation at the bone-implant interface, it must elicit some sort of a chemical or biological response in a strain-sensitive population. The current hypothesis is that bone cells in conjunction with the extracellular matrix (ECM) comprise the strain-sensitive population and that each plays a vital role in the mediation of the interface. Based on this rationale, the objective of a good implant design would be to establish and maintain a strain environment within the host bone tissue and at the interface that favors osteointegration of the implant.

Mechanotransduction

Mechanotransduction is a multistep process that includes (1) mechanocoupling (transduction of mechanical forces into signals sensed by sensor cells), (2) biochemical coupling (conversion of mechanical signal into a biochemical signal to elicit a cellular response such as gene activation), (3) transfer of a signal from sensor to effector cells, and (4) the effector cell response.[22] Recent studies have led to the current consensus that osteocytes embedded within lacunae in bone matrix act as mechanosensors and help translate mechanical loads into biochemical signals.[23–25] Osteocytes are the most abundant cells and inhabit an extensive lacunocanalicular network that enables them to communicate with other osteocytes, as well as with periosteal and endosteal osteoblasts.[24–26] Furthermore, osteocytes have higher sensitivity to mechanical stimulation than osteoblasts.[27–29]

The strains experienced at the tissue level in vivo during normal activities (0.04%–0.3%) are much less than the strain levels (1%–10%) required to elicit a cellular response.[30,31] Initially, shear stress caused by fluid flow in the canalicular spaces was believed to be the primary driver of biochemical coupling in bone, with strain being the dominant stimulus.[23,32] Later, You et al.[33] proposed a model for the amplification of physiologically induced strains to levels that would initiate intracellular biochemical responses. The model suggested that drag forces on the transverse tethering fibers[34,35] during fluid flow through the pericellular space (filled with matrix between osteocyte cell membrane and canalicular wall) will produce a tensile stress, which will in turn create a hoop strain in the intracellular actin cytoskeleton that is two orders of magnitude higher than the strains at the whole-bone level. This model was further modified using updated ultrastructural data on the cytoskeleton, transverse tethering fibers, and their structural rigidity.[36] Cowin[37] compared and reviewed the two models by focusing on the relationship between the bone microstructure and the mechanism by which osteocytes sense the fluid flow as the result of mechanical loading. Possible mechanoreceptors, mechanisms by which osteocytes sense mechanical stimuli, and intracellular signaling pathways are discussed in several research groups.[38–40] Regulation of osteoblastic activity by osteocytes has been proposed to occur through gap junctions,[41–44] with the stimulation of gap junctions mediated by prostaglandin E_2 (PGE_2).[45–49]

Whereas loading of bone decreases osteocyte apoptosis, disuse and supraphysiologic strains increases it followed by

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haversian remodeling.[50–52] Bone disuse, even for short durations, may rapidly induce a hypoxic state of stress in osteocytes, which when extended may lead to apoptosis. This hypoxia can be reversed by short-term physiologic loading, which suggests that mechanical loading at such magnitudes plays a key role in osteocyte viability.[53] This may adversely affect bone strength independent of bone loss.[54] Hypoxic osteocytes may also mediate disuse-induced bone resorption by increasing osteopontin expression.[55]

Biomechanically Based Bone-Remodeling Theories

Biomechanically based bone-remodeling theories largely fostered the desire to optimize the effects of strain at the bone-implant interface to encourage osteointegration. In 1887, Meier[56] described the systematic structure of trabecular bone in the femoral head. In 1892, Wolff[57] described these events as a law of nature and stated that the trabecular bone will place or displace itself in relationship to the functional pressures. In 1895, Roux[58] suggested that the tissue changes to loading were a result of a cellular-regulation process. Frost[59] proposed the theory of the mechanostat. He postulated that bone mass is a direct result of the mechanical use of the skeleton. This agrees with Wolff's law[57] that essentially states "form follows function." Frost established a mechanical-adaptation chart relating trivial loading, physiologic loading, overloading, and pathologic loading zones to ranges of microstrain (Figure 6-1). His studies showed that strains in the range of 50 to 1500 microstrain (με) stimulated increases in cortical bone mass until the strains were reduced to the threshold range (or minimum effective strain). This process of the mechanostat would effectively switch the bone modeling *on* and *off*. This phenomenon led him to the flexure drift hypothesis in which he proposed that long bones (e.g., femur) were geometrically curved to minimize the strain distribution down the long axis of the bone.[60] Frost suggested that the curvature of the long bones canceled the bending moment caused by the eccentric pull of the muscles.

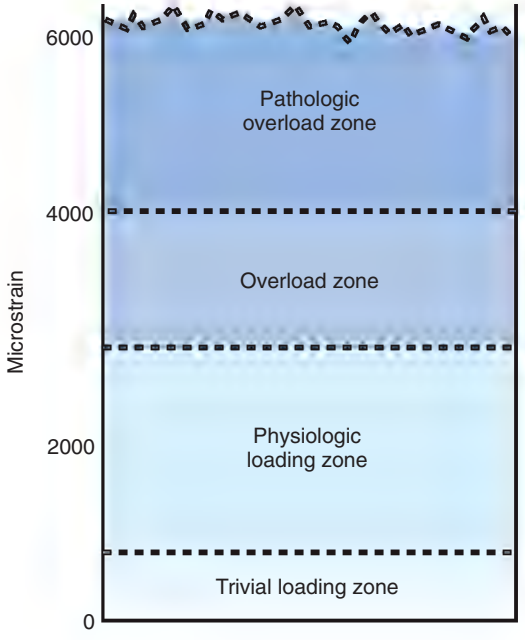


FIGURE 6-1. Mechanostat chart. (Adapted from Frost HM: Bone "mass" and the "mechanostat": a proposal, *Anat Rec* 219:1-9, 1987.)

Bone may reduce strains by bone apposition or reduction, by bone formation or resorption, and by changing modulus of elasticity or stiffness by changing mineral content.[61–63] Necrosis of bone cells appears to determine the upper equilibrium level. Whereas cell destruction can be observed when stresses exceed 6.9 μ 10 N/mm^2, a stress of 2.48 μ 10 N/mm^2 will cause an increase in bone growth.[64]

Turner et al.[23] and Turner[65] summarized the rules governing bone adaptation as (1) dynamic (not static) loading drives bone adaptation; (2) whereas short-term loading has an anabolic effect, increased duration degrades bone adaptation; and (3) whereas abnormal strains evoke bone adaptation, bone becomes accustomed to routine strains and remodeling ceases.

Dynamic loading has consistently been found to have more osteogenic potential than static loading.[66] Dynamic axial loading for short durations, which produced strains within the physiological range that were added to normal activity, led to adaptive straightening of growing rat ulnae. Reduced and increased periosteal bone formation were observed at moderate and higher peak strains, respectively.[67] Similar studies observed adaptive osteogenic response to be proportional to the strain rate and local surface strain.[68,69]

Contrary to the previously stated anabolic responses by rat ulna, both static and dynamic axial loading have been found to cause a reduction in longitudinal bone growth.[70,71] Growing male rats[70] receiving 10-minute bouts of static loading at 17 N, static loading at 8.5 N, or dynamic loading at 17 N exhibited shorter bone growth than the control subjects. The suppression was mainly visible in the hypertrophic zone and was proportional to the load magnitude. A later study[71] investigated the growth plate biology after the application of three different compressive loads (4 N, 8.5 N, and 17 N) for 10 min/day for 8 days on rat ulnae. The longitudinal mineralization rate was completely suppressed and never recovered in the 17-N rats, but other groups showed significant suppression that recovered within 1 week after loading. From their results, the authors suggested that even low-magnitude compressive loads suppress growth rate (Figure 6-2), which supported Hert's proposal[72] and deviates from Frost's chondral growth force response curve.[73]

Studies show that adaptive osteogenic response attains saturation after the initial few cycles during continuous cyclic loading despite further increases in magnitude of load and cycle number.[74] Dynamic loading in short bouts (i.e., with rest periods inserted between loading) have been found to induce an increase in the number and activity of osteoblasts[75,76] and enhance osteogenesis in normal and aged skeletons[76–79] during normal activities such as walking. This consequently improves the biomechanical integrity of the bone despite only slight increments in bone mineral density and content.[80] Rest-inserted loading decreased the threshold for lamellar bone formation,[81] reduced the number of cycles required to stimulate bone formation, and promoted an increased osteogenic response at any load magnitude (Figure 6-3).[82]

Recently, Gross et al.[82] hypothesized that rest periods between each cycle in cyclic loading enhances fluid flow through the canalicular network, thereby extending the communication range of osteocytes by improving transport of signaling molecules between them. Furthermore, rest-inserted loading may also turn on synchronized activity among osteocytes.

Osteogenic response has been found to vary with respect to anatomical site and even at different regions within the same

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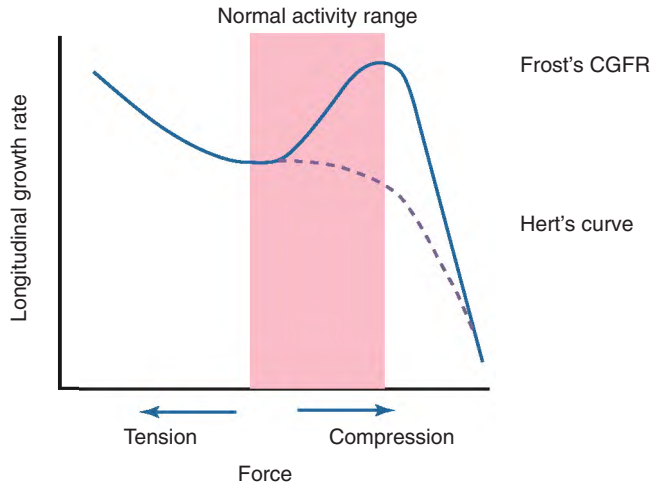


FIGURE 6-2. Comparison between Frost's chondral growth force response (CGFR) curve and Hert's curve. *Shaded region* shows the forces experienced during normal activities. (Adapted from Ohashi N, Robling AG, Burr DB, et al: The effects of dynamic axial loading on the rat growth plate, *J Bone Miner Res* 17:284-292, 2002.)

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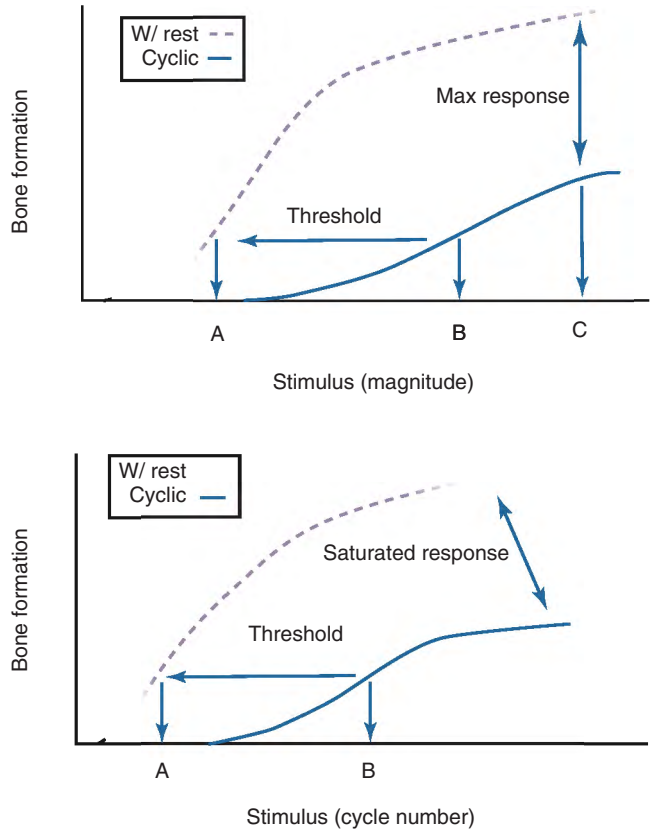


FIGURE 6-3. Summary of recent studies on anabolic effects of rest insertions between mechanical loading cycles. (Adapted from Gross TS, Poliachik SL, Ausk BJ, et al: Why rest stimulates bone formation: a hypothesis based on complex adaptive phenomenon, *Exerc Sport Sci Rev* 32:9-13, 2004.)

bone. Axial compressive dynamic loading of adult female rat ulnae led to greater periosteal lamellar bone formation distally and lower bone formation proximally compared with the mid-diaphysis. Strain thresholds and periosteal lamellar bone formation correlated with the peak strains experienced in rat ulnae being higher distally than proximally with intermediate values at the diaphysis.[83] Results from a previous study showed that treadmill exercise increased cancellous bone at the distal tibia more markedly than the proximal tibia, but vertebra showed no change.[84] A more recent study in mice revealed that the metaphyseal region in the distal femur showed an increased osteogenic response compared with the cortical bone at the middiaphysis.[85] Loading of the knee increased bone formation and mineral apposition on the medial side of the tibial diaphysis compared with the lateral and posterior sides.[86]

Small increases in such mechanical signals to which bones are exposed during regular activities such as standing produce a local, rather than systemic, adaptive anabolic response in cancellous bone without any effect on cortical bone.[87,88] Anabolic effects on trabecular bone were attributed to an increase in bone mineral content and trabecular number, but decreases in trabecular spacing indicated the creation of new trabeculae and thickening of existing ones. In addition, researchers observed the adaptation of trabecular bone from rod shaped to plate shaped, primarily in the weight-bearing direction, consequently exhibiting increased strength and stiffness when measured longitudinally.[89] Short bursts of such stimuli inhibit bone resorption by reducing osteoclastic activity and concurrently increase bone formation, maintaining the bone matrix properties.[90] This anabolic response is not controlled by matrix strain magnitude but by applied frequency.[91] Controlled compressive load producing a peak pressure of 1 MPa was applied for 10, 25, or 50 cycles/day at a frequency of 0.5 Hz for 1 month on the distal femoral condyles of rabbits. The loaded limbs showed increased bone volume fraction, trabecular thickness, mean intercept length, and mineral apposition rate compared with unloaded contralateral limbs.[92] Such low-magnitude, high-frequency mechanical signals (whole-body vibrations) have high potential in the treatment of osteoporosis.[93]

Mechanical stimulation has also been used to accelerate bone formation during fracture and trauma. Whereas in vivo dynamic axial compression loading of low magnitude after a short delay increased the strength of fracture callus, immediate loading and shear movement inhibited and delayed the healing process.[94,95] Alternate axial compression and distraction, called *dynamization*, was found to be more effective than either technique applied alone; this combination stimulated callus at both central (influenced by distraction) and peripheral (influenced by compression) regions in a closed transverse fracture in rat tibiae.[96]

Indicators of the Biological Response

The characterization of the biological responses resulting from cellular deformation is equally as diverse as the deformation methodologies. These include changes in the concentration of intracellular mediators and cellular proliferation.

Changes in Concentration of Intracellular Mediators

Numerous investigators have reported fluctuation in the concentrations of intracellular second-messenger molecules.[97–112] In general, cell surface receptors relay information by activating a chain of events that alters the concentration of one or more small intracellular-signaling molecules often referred to as

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second messengers or *intracellular mediators*. In turn, these messenger molecules pass the signal on by altering the behavior of selected cellular proteins. Some of the most widely used intracellular mediators are cyclic AMP (cAMP), Ca^{2+}, and cyclic GMP (cGMP).[113] PGE_2 and prostacyclin are paracrines that are released by osteoblasts in response to mechanical strain.[97,104–108] They are essential for bone formation by mechanical loading[114–119] and are also increased by fluid shear stress[120–125] in a dose-dependent manner. The anabolic effect of mechanical stimulation in vivo has been shown to be greatly depressed by the addition of indomethacin, a chemical that blocks the production of these prostaglandins (PGs).[109] Increase in messenger ribonucleic acid (mRNA) of c-fos and insulin-like growth factor 1 (IGF-1) in osteocytes immediately after mechanical stimulation led to the study involving compressive dynamic loading of the eighth caudal vertebrae in rats. When indomethacin and N^G-monomethyllarginine (L-NMMA), inhibitors of PG and nitric oxide (NO), respectively, were administered individually, c-fos (a marker for mechanical responsiveness in osteocytes) was suppressed partially, but combined administration resulted in drastic suppression.[126]

This suggested that PG might be produced by NO-dependent and NO-independent mechanisms. Rats injected with NO donors showed increased osteogenic response only when loaded, which suggested that NO requires other molecules such as PG induced by mechanical loading for bone.[117] Human bone cells from patients with osteoporosis subjected to pulsating fluid flow showed reduced long-term release of PGE_2, suggesting that long-term adaptive response of these bone cells to mechanical stimuli may have been affected.[127]

Harrell and Binderman[99] observed that isolated osteoblasts, grown on a polystyrene plate that had an orthodontic jackscrew glued to its bottom, responded to continuous strain by increasing PGE_2 concentrations followed in minutes by an increase in cAMP release. Rodan et al.[100] agreed that mechanical strain affected the second-messenger cAMP and also reported changes in cGMP and calcium ions. Yeh and Rodan[97] suggested that PGs might be involved in the transduction of mechanical strain but did not apply physiological levels of strain to their samples. Fluid shear experiments by Reich and Frangos[101] and cyclic biaxial strain studies by Brighton et al.[98] have demonstrated that osteoblasts respond with an increase in cellular levels of inositol triphosphate.

Osteoblasts form bone by secreting many extracellular matrix proteins, including type I collagen, osteopontin, osteocalcin, osteonectin, biglycan, and decorin. Osteopontin was first purified from rat bone matrix and is considered to play an important role in the cascade of events required for the formation of bone matrix.[110] In vitro studies have revealed osteoblasts to be more responsive to fluid forces than mechanical strain, associating increased osteopontin expression with increases in force magnitude without any dependence on strain magnitude or rate.[128] Recently, experiments on the femoral epiphyses of rabbits have shown that cyclic loading can influence endochondral bone formation by accelerating formation of secondary ossification centers and increase expression of RUNX2 (an important transcription factor of osteoblasts) and extracellular proteins, including osteopontin, type X collagen, and decorin.[129] Osteocalcin, also known as *bone Gla protein*, is widely used as a marker for bone metabolism. Studies have shown that the production of osteocalcin can be stimulated by mechanical stress both in vivo[112] and in vitro.[113] Experiments on bone marrow stromal cells have revealed that shear caused by fluid flow enhances maturation of osteoblasts by stimulating the expression of osteocalcin,[130] osteopontin, and bone sialoprotein[131] but not proliferation of stromal cells.

Parathyroid hormone (PTH) has been found to play a vital role in bone adaptation to mechanical stimuli. Rats with thyroparathyroidectomy did not show any osteogenic response caused by mechanical loading of vertebrae,[132] but the response could be restored by a single PTH injection before loading. However, the restoration did not occur when PTH was injected 3 days after mechanical stimulation. Expression of c-fos was observed only in loaded rats injected with PTH,[132] further highlighting the importance of PTH in mechanical adaptation of bone. In vitro studies on mouse osteoblasts provided further insights into the interactive effects of PTH and pulsating fluid flow on PGE_2 and NO production. Although fluid flow stimulated a twofold rise in PGE_2 and NO production, PTH induced a similar effect on PGE_2 but reduced NO production by degrading the enzyme activity of NO synthase. When applied together, the stimulatory effects of fluid flow were nullified. According to the authors, the results suggested that PTH enhances NO-independent PGE_2 production but inhibits stress-induced NO production by degrading NO synthase, in turn reducing NO-dependent PGE_2 production.[133] PTH may also regulate mechanotransduction by influencing the influx of extracellular calcium in hypotonic osteocytes.[134]

Changes in Cellular Proliferation

As previously discussed, the response of osteoblast-like cells to mechanical strain has been shown to be variable. Many studies have reported increases in cell proliferation,[98,102,135–137] total protein production, and DNA synthesis[135,136,138,139] in response to mechanical strain. A review by Burger and Veldhuijzen[31] suggested that at high magnitudes of strain, osteoblasts proliferate and decrease their production of osteoblast phenotypic markers, such as alkaline phosphatase and bone matrix proteins. At lower magnitudes of strain, osteoblasts exhibit a more differentiated state, with an increase in alkaline phosphatase and matrix protein production and a decrease in proliferation. Strains of physiological magnitude (1000 με) applied by cyclic dynamic stretching on human osteoblast cultures increased cell proliferation and osteoblast activities related to matrix production but decreased alkaline phosphatase and osteocalcin release.[140–142] The frequency and cycle number affect proliferation of bone cells and expression of various osteoblast genes in a different manner.[143,144] Applying uniaxial strain at a constant frequency, the cell number increased up to 1800 cycles. At a constant cycle rate, frequency variation produced only slight differences. Frequencies of 1 Hz and 300 cycles were optimum, having the maximum positive effect of cell proliferation.[144]

In addition to experiments correlating increased proliferation with increased or altered strain levels, several investigators have focused their attention on the timing of the proliferative response. Studies conducted by Lanyon[145] have shown that cellular metabolism is activated within the first few minutes of loading. Raab-Cullen et al.[146] investigated the pattern of gene expression in the tibial periosteum shortly after in vivo controlled external load application. They documented that mRNA expression was altered within 2 hours after loading and that the pattern of specific mRNA expression first reflected proliferation and subsequently differentiation. Cyclic equibiaxial stretching[147] of 7-day osteoblast cultures increased apoptosis independent of the strain range (0.4%–2.5%), but more mature cell culture (2 weeks) increased proliferation. This study revealed

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the importance of the differentiation stage of osteoblasts in their response to mechanical stimulation.

Chondrogenesis at the periosteum of long bones possesses both osteogenic and chondrogenic potential and holds clinical significance in the repair of articular cartilage and in fracture healing.[148–151] Dynamic fluid pressure was found to increase proliferation of periosteal chondrocytes from immature rabbits in vitro.[152] The possible chondrogenic effects stimulated by continuous passive motion of joints after periosteal arthroplasty via dynamic fluid pressure were investigated using periosteal explants suspended in agarose gel. Whereas low-level pressure application increased chondrogenesis and type II collagen in a dose-dependent manner, high-pressure completely inhibited these activities.[153]

Changes in Cellular Morphology and Organization

Ives et al.,[154] using human and bovine endothelial cells, found that the cells responded differently to various types of strain. The cells oriented themselves parallel to the direction of shear strain induced by fluid flow but perpendicular to the axis of mechanical deformation on a cyclically stretched polyurethane membrane. Investigations by Buckley et al.,[136] using osteoblast-like cells stimulated by cyclic mechanical strain, also resulted in the alignment of the cells perpendicular to the strain vector. This perpendicular alignment was noted at 4 hours after loading and was significant by 12 hours. They suggested that the preferred orientation might have resulted from a mechanical effect on the osteoblast, wherein cell attachments were broken in the maximum strain direction, leaving only those attachments already present in the least strained conformation. A second hypothesis suggested that the cells may have resolved their focal contacts and migrated in an attempt to minimize the strain to which they were subjected.

Another study involving osteoblast-like cells was reported by Carvalho et al.[155] They investigated cytoskeletal organization in mechanically strained alveolar bone cells isolated from the alveolar processes of Sprague-Dawley rats. The earliest change in cytoskeletal organization was noted at 30 minutes after the initiation of strain. They observed that the cells oriented themselves perpendicular to the long axis of the applied mechanical strain.

In vitro studies on osteoblastic and osteocytic cell lines subjected to unidirectional and oscillatory fluid shear stresses showed that stress fibers formed and aligned in osteoblasts within 1 hour of unidirectional stress but were delayed in the latter type of stress. Osteocytes show alignment for unidirectional stress and dendritic morphology for oscillatory stress only after 24 hours.[156]

Altered Expression and Reorganization of Osteoblast Integrins

Although changes in the distribution of the cytoskeleton in mechanically strained cells have been reported, the exact mechanism for the initial detection and transduction of mechanical force into a biological signal has yet to be determined. One possible transduction pathway is the ECM integrin cytoskeletal axis.[22,155,157] To understand how the cells interact with the ECM, attention must be given to the nature of the attachment.

Integrins are the primary receptors used by animal cells to attach to the ECM,[158] and they function as transmembrane linkers that mediate bidirectional interactions between the ECM and the actin cytoskeleton. Integrins are composed of two noncovalently associated transmembrane glycoprotein subunits called α and β, both of which contribute to the binding of the matrix protein. Electron micrographs of isolated integrins suggest that the molecule has approximately the shape shown in Figure 6-4, with the globular head projecting more than 20 nm from the lipid bilayer. After the binding of a typical integrin to its ligand in the matrix, the cytoplasmic tail of the β chain binds to both talin and α-actinin and thereby initiates the assembly of a complex of intracellular attachment proteins that link the integrin to actin filaments in the cell cortex[37,158] (see Figure 6-4). This process is thought to be how local contacts form between cells and the ECM. If the cytoplasmic tail of the β chain is removed or mutated using recombinant DNA techniques, then the integrins can still bind to the matrix, but the strength of the bond is decreased, and the integrins no longer cluster at the focal contacts.[158]

The connection between integrins and the actin cytoskeleton is considered to be a possible pathway for sensing mechanical signals and producing a response in bone.[159–161] The interactions that integrins mediate between the ECM and the cytoskeleton play an important part in regulating the shape, orientation, and movement of the cells.[162] Schwartz and Ingber[163] suggested a direct link between mechanical strain and cellular response. Integrins of endothelial cells subjected to shear stress were shown to realign with the direction of flow, suggesting that cell adhesion is a dynamic process responding to mechanical strain.[164] Wang et al.[165] demonstrated that a physical strain applied directly to integrins using a magnetic twisting device was shown to be resisted by the cytoskeleton. Pavalko et al.[161] performed in vitro studies on MC3T3-E1 osteoblasts to analyze the role of actin and actin–membrane interactions in altering gene expression because of mechanical loading. Observations of reorganization of actin filaments into contractile stress fibers, formation of focal adhesions, and recruitment of β_1-integrins and α-actinin to focal adhesions revealed a critical role played by actin cytoskeleton in altering gene expression (upregulation of cyclooxygenase-2 and c-fos) in osteoblasts as a response to fluid shear stress. Increase in the number and size of stress fibers and focal adhesion complexes associated with mechanical strain indicated a combined change in both cytoskeleton and ECM favoring tighter adhesion of osteoblasts to the latter.[160] Both cell adhesion and mechanical stimulation induce expression of integrin-binding proteins—osteopontin, fibronectin, and bone sialoprotein—by osteoblasts but via different mechanisms at different time frames after stimulation. Although strain-induced (dynamics biaxial strain of 1.3% at 0.25 Hz) osteopontin expression was dependent on cytoskeletal integrity, cell adhesion was not.[166–168] These observations indicate that the ECM integrin cytoskeletal system may be part of the cascade responsible for the transduction of mechanical strain into a biological response.

Other studies have shown that several intracellular signaling pathways are activated coincident with a clustering of integrins at the focal contacts between the cells and the matrix. These clustered integrins may generate intracellular signals by initiating the assembly of a signaling complex just inside the plasma membrane, similar to that of growth factor receptors. Many cells in culture will not respond to growth factors unless the cells are attached via integrins to the ECM molecules.[158,169] Recent investigations have related the extracellular signal-regulated kinase (ERK) pathway (one of the mitogen-activated protein [MAP] kinases identified) to growth and differentiation of osteoblasts,[170] differentiation of mesenchymal stem cells toward osteogenic lineage,[171] and mechanotransduction.[172–179] Whereas

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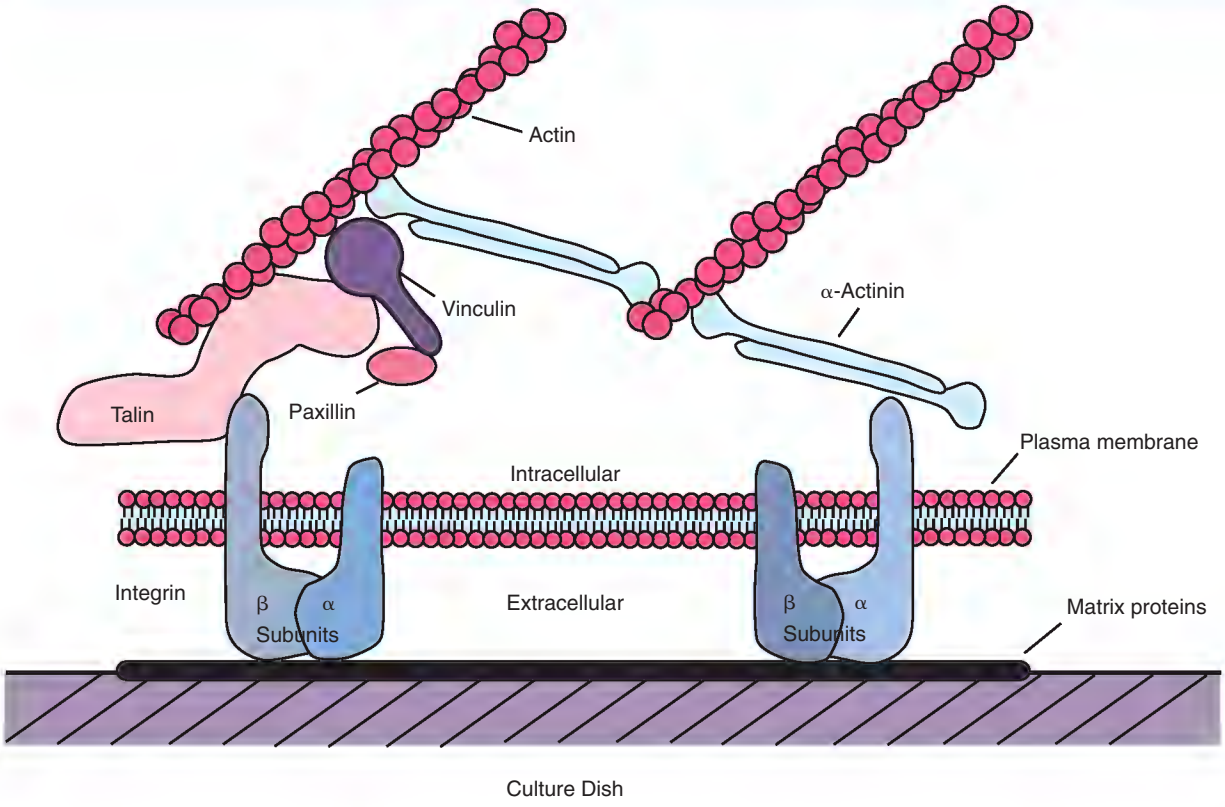


FIGURE 6-4. Diagram illustrating cytoskeletal components at point of attachment with extracellular matrix in vitro. (Adapted from Duncan RL, Turner CH: Mechanotransduction and the functional response of bone to mechanical strain, *Calcif Tissue Int* 57:344-358, 1995.)

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fluid flow applying physiological strain levels on human osteoblasts rapidly induced ERK phosphorylation and clustering of $\alpha v\beta_3$ integrins in vitro,[176] the mechanism behind the regulation of osteocyte apoptosis by mechanical stimulation involves and requires the activation of an integrin–cytoskeleton–Src–ERK pathway.[179] These results have led researchers to suggest that both mechanical (e.g., fluid flow, cyclic stretching) and chemical (e.g., hormones, growth factors) stimuli may act through the same intracellular signaling pathways.[176,179]

Numerous subunits have been characterized, and different combinations of α and β subunits function as receptors for a variety of extracellular proteins.[180,181] The β_1-integrin subunit is often expressed in bone cells both in vitro and in vivo.[181] Carvalho et al.[155] demonstrated that changes in the organization of the β_1-subunit were induced by the application of strain as early as 4 hours from its onset. They compared the expression of the β_1-integrin subunit mRNA from strained cultures with unstrained controls.

Changes in Gene Expression

To characterize the biological response of osteoblast-like cells to external mechanical loading, many researchers are investigating strain-induced alterations in patterns of osteoblast gene expression. Several authors have reported that the initial response to strain is a rapid increase in c-fos mRNA expression, indicative of increased proliferation, paired with a rapid decline in levels of mRNA encoding bone matrix proteins, such as type I collagen, osteopontin, and osteocalcin.[146,182] A "rebound" effect or reversal of this trend is usually seen with time as the proliferation tapers off, accompanied by an increase in expression of the matrix proteins.[146,182–184]

The term *matrix proteins* refers to both collagenous and noncollagenous proteins. Type I collagen is the most abundant protein in the organic matrix of bone. This molecule is composed of one α_2 and two α_1 chains. These three chains are initially assembled into a triple helical structure within the cell and are subsequently bundled into fibrils once secreted from the cell. These extracellular fibrils are arranged in a specific, repeating orientation that produces the typical banded appearance common to type I collagen. Intermolecular cross-links stabilize this pattern and produce a porous, repeating, three-dimensional structure.[21] Active osteogenesis involves the expression of genes that result in the production of collagen type I protein.[184] This trait makes the type I collagen molecule a valuable indicator of differentiated osteoblastic activity. Cyclic pressure increases mRNA expression for type 1 collagen and accumulation of calcium by improving osteoblast function without affecting the cell number.[185] Cyclic stretching of rat calvarial osteoblasts increased collagen production at lower strains (500 με) and inhibited production at higher strain levels (1500 με).[186]

In the past 20 years, noncollagenous proteins have received increased attention. Researchers have suggested that these minor components of organic bone matrix may play a role in regulating bone function, expression, and turnover.

Osteocalcin (bone Gla protein) is a noncollagenous protein that binds calcium and has been isolated from bone, dentin, and other mineralized tissues. It is specifically synthesized by differentiated osteoblasts and, similar to type I collagen, is an ideal marker for osteoblast phenotypic expression.[187]

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Another noncollagenous protein that is generating great interest is osteopontin. This bone sialoprotein is synthesized by primary osteoblasts and has been shown to play a role in cell attachment and spreading. Osteopontin contains a binding sequence that appears to be recognized by an integrin cell surface receptor related to the vitronectin receptor.[187]

Both osteocalcin and osteopontin are regulated by a number of hormones and growth factors. The most common promoter of osteocalcin and osteopontin expression and secretion is 1,25-dihydroxyvitamin D_3 ($1,25[OH]_2D_3$), which directly influences the genes of both proteins. This is possible because the genes for both osteopontin and osteocalcin contain regions that recognize vitamin D.[183] A study by Harter et al.[183] analyzed the expression and production of bone matrix proteins in human osteoblast-like osteosarcoma cells in response to 1 to 4 days of chronic, intermittent, mechanical strain. Northern analysis for type I collagen detected an increase in collagen message after 48 hours of strain. Immunofluorescent labeling of type I collagen indicated that secretion was also enhanced. In the absence of vitamin D, osteopontin message levels were increased severalfold by the application of mechanical load. This increase in osteopontin expression was doubled when the cells were subjected to mechanical load in the presence of vitamin D.

Osteocalcin secretion was also increased with cyclic strain. Osteocalcin levels were not detectable in vitamin D–untreated control cells; however, after 4 days of induced load, significant levels of osteocalcin were observed in the medium. With vitamin D present, osteocalcin levels were four times higher in the medium of strained cells compared with unstrained controls. This study demonstrates that mechanical strain of osteoblast-like cells is sufficient to increase the transcription and secretion of matrix proteins via mechanotransduction without hormonal induction.[183] Osteoblasts in mechanically loaded mouse periodontium showed increased expressions of osteocalcin, type I collagen, and alkaline phosphatase.[188] The first two were more responsive and were found to be stimulated within a short time after loading. The authors suggested that mechanical stimulation drives rapid differentiation of committed osteoblast precursors to produce an anabolic skeletal adaptation.[189] Weight loading of chicks at the prepubertal stage led to development of shorter bones with narrower growth plates but with increased mineralization and vascular penetration. Increased osteopontin and matrix metalloproteinases (MMP9 and MMP13) led to the speculation by the authors that MMPs allowed greater penetration of blood vessels carrying osteoblasts and osteoclasts, but osteopontin increased osteoclast numbers, thereby increasing resorption at the growth plate region.[190]

Disruption of genes can alter the normal bone formation response to mechanical stimulation as observed in mice lacking thrombospondin 2[191] that showed contrasting behavior compared with wild-type mice with increase in endocortical bone formation despite higher strains at the periosteal surface.

Frost[59] has reported that the mechanism for the biomechanical response of osteoblasts is not discrete. Osteoblastic products such as interleukin-1 (IL-1) can stimulate osteoblasts. He groups these cells as basic multicellular units (BMUs). These BMUs are most prevalent on periosteal and endosteal surfaces, and the periosteal BMUs are most sensitive to biomechanical stimuli.

Limitations of Previous Studies

Although these cell culture studies generate promise for the quantitative delineation of the mechanically induced cellular response of bone, the enthusiasm for all of these studies must be tempered in light of the experimental models that were used. Virtually all of these models used some form of polyurethane membrane, collagen ribbon, or silastic plate as the substrate on which the cells were grown and mechanically stimulated. Given the complex host-biomaterial interactions within the human body, the cellular response of isolated bone cells on polyurethane membranes or collagen ribbons may be significantly different from bone cells in intimate contact with a contemporary implant biomaterial, such as titanium or titanium alloy. Investigations are in progress to confirm the effects of mechanical strain on the cells of the bone-implant interface in an experimental system that allows growth of osteoblastic-like cells on the surface of an actual implant material.[192]

Additional limitations can be found in the methodologies mentioned previously. In many of the experiments, the imposed strains were not quantified. Some of the other studies that did report strain magnitudes used levels of strain that were either supraphysiological (>7000 με)[22] or subphysiological (<1500 με)[22] in nature.

The experimental techniques that have been discussed so far, such as strain gauges being applied to living bone, organ cultures, and cell culture, can provide illuminating data, but all of the techniques have drawbacks and sources of error. Strain gauges are technique sensitive and are difficult to use with biological tissues because of moisture, heat, irregularity of surface, and sometimes poor access to the application site. Their application to animal models can introduce further complications caused by the unpredictability of the behavior of the animal. Movements and loads artificially created when the animal is anesthetized may not give accurate data concerning physiological loads, but the animal may pull wires loose when it is awake.

Organ culture analysis may retain some of the spatial accuracy needed to test strain in the matrix; however, perfusion is necessary to maintain the organ tissue, and not much working time exists before the organ culture dies. Isolated cell culture models can give very useful information related to the release of certain biological mediators in response to the cells' environment. However, again, organization has been lost, and this departure from the in vivo situation must be kept in mind when the results of such experiments are analyzed.

All of these experimental techniques are very valuable despite their individual drawbacks. When they are used in combination and their limitations are understood, helpful insight can be obtained and used to further understand functional loading and its biological ramifications.

Biomechanical Response

A compelling argument has been presented for strain-induced biological response of bone to mechanical load. The question remains: What controls the magnitude of strain imparted to the dental implant–bone interface?

Strain has been generically defined in relation to deformation and applied stress. The discussion of strain must be necessarily extended for biological structures. The mechanical properties of the trabecular and cortical bone found within the oral environment exhibit a high degree of variation as a function of load direction, rate, and duration. In addition, the structural density of the bone has a significant influence on its stiffness (modulus of elasticity) and ultimate strength. As such, the mechanical strain exhibited in bone is ultimately a function of the bone density.

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Dependence on Direction of Loading

The degree to which the mechanical properties of cortical bone are dependent on its structure is referred to as *anisotropy*. This concept is illustrated in Figure 6-5, which illustrates how a material may exhibit directionally dependent mechanical properties (e.g., modulus of elasticity). A material is said to be *orthotropic* if it exhibits different properties in all three directions and *isotropic* if the properties are the same in all three directions. *Transversely isotropic* describes a material in which two of the three directions exhibit the same mechanical properties.

Reilly and Burstein[193] and Yoon and Katz[194] have reported bone to be transversely isotropic (referring to Figure 6-5, E_1 and E_2 are the same). Knets and Malmeister[195] and Ashman et al.[196] have described bone as *orthotropic* (i.e., $E_1 = E_2 = E_3$). The mandible has been reported as transversely isotropic, with the stiffest direction oriented around the arch of the mandible[197] (see Figure 6-5). These authors suggest that cortical bone of the mandible functions as a long bone that has been molded into a curved-beam geometry. The stiffest direction (around the arch) thus corresponds to the long axis of the tibia or femur.

Early studies on the mandibular and supraorbital bone reported elastic constants of cortical bone in all three orthogonal directions at both locations to be different, suggesting the anisotropy of craniofacial bone. Comparing properties from both locations, mandibular bone along a longitudinal direction was stiffer than bone from a supraorbital region, which may be the result of a difference in function.[198] Cancellous bone in human mandible exhibited transverse isotropy by compression tests and symmetry along inferosuperior directions. Elastic modulus was greatest in the mesiodistal direction (907 MPa), lowest in the inferosuperior direction (114 MPa), and intermediate in the buccolingual direction (511 MPa).[199] Finite element (FE) analysis of mandibular bone around implants indicated an increase in stresses and strains because of anisotropy. A compressive and shear anisotropy of 3% and 1% in cortical bone and 40% and 38% for cancellous bone, respectively, increased stresses by 20% to 30% in the cortical crest. Although tensile and radial-hoop shear stress increased by three- to fourfold in the cancellous bone along the lingual side, anisotropy decreased radial-vertical interface shear stress by 40% on the buccal side near the apex in cancellous bone.[200]

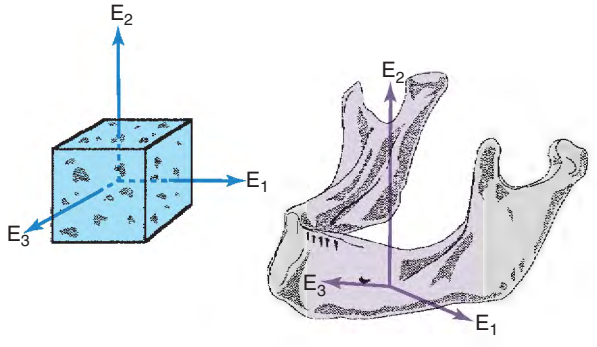


FIGURE 6-5. Cortical bone of the human mandible has been reported as transversely isotropic, with the stiffest direction oriented around the arch of the mandible (E_3). (From Ashman RB, Van Buskirk WC: The elastic properties of a human mandible, *Adv Dent Res* 1:64-67, 1987.)

Such data raise interesting questions regarding the primary loads that the mandible experiences: occlusal loads or flexural loads imposed during opening and closing of the mouth. Clinical experience has qualitatively revealed that the actual mandible has more compact bone at the inferior border, less compact bone on the superior aspect, and greater quality of trabecular bone, especially between the mental foraminae. In addition, the presence of teeth or implants significantly increases the trabecular bone amount and density within the residual alveolar bone. Several models have analyzed stress distributions around implants and supporting bone in mandible as an effect of differences in load directions.[201,202] Experiments and models have suggested that off-axial loads produced during occlusal loading produce higher strains in the cervical region and cause significant concern regarding crestal bone loss, cervical tooth loss, and failure of osseointegration.[203–205] Off-axial loads also induce adaptive bone remodeling around oral implants as shown by experimental and FE analysis in dog mandibles.[206,207] The experimental study revealed a significant remodeling difference between axial and nonaxial loading. Although axial loads produced a uniform and mild remodeling response that decreased from the coronal aspect to the apex of the implant, nonaxial loads induced more dynamic remodeling in the surrounding cortical bone and more severely in trabecular bone.[206] The FE analysis (incorporating vertical and horizontal loads and a moment) attributed this difference in response to the horizontal component of the stress experienced by the loads. Horizontal compressive stresses were found to induce more intense remodeling than tensile stresses in the same direction. In addition, stress distributions revealed that stresses decreased from periosteum to endosteum in the cortical bone and then increased along trabecular bone toward the apex of the implant.[207]

Nanoindentation is a new method used to measure the material properties (hardness and indentation modulus) of bone at a microstructural level.[208–210] Cortical bone shows elastic anisotropy at a lamellar level as shown by nanoindentation experiments on human tibial cortical bone.[211] Indentation experiments in 12 different directions in three principal planes for osteonal and interstitial lamellae revealed variation in indentation modulus along different directions in each plane.[211]

At small strains, trabecular bone elicits a nonlinear response that varies with respect to the anatomical site and type of loading. The nonlinearity measured by the reduction in tangent modulus was found to differ based on mode of loading (tension or compression) and was positively correlated with density in tension. Yield strains are higher in compression than tension for trabecular bone[212,213] in long bones. Microdamage is reported to occur before apparent yield in trabecular bone. Yield is said to occur at 88 to 121 MPa in compression and 35 to 43 MPa in tension at local principal strains of 0.46% to 0.63% for the former and 0.18% to 0.24% in the latter.[213] Comparison of apparent and tissue level yield strains in trabecular bone from femoral neck specimens by FE models revealed that apparent and tissue level yield strains were equivalent in tension but not in compression, and the equivalence was attributed to the highly oriented structure.[214] In compression, yield strains at tissue level were found to be 17% higher than at apparent level. This could lead to residual strains, local tissue yielding, and damage accumulation, degrading the apparent mechanical properties of trabecular bone.[215] An increase in compressive or shear strain could increase the number of microcracks but not the mean length. Any change in the mode of loading can cause cracks to propagate beyond microstructural barriers.[216]

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Dependence on Rate of Loading

A material is said to be *viscoelastic* if its mechanical behavior is dependent on the rate of load application. McElhaney[217] investigated the strain rate dependence of bone (graphically illustrated in Figure 6-6). A significant difference can be noted in both ultimate tensile strength and modulus of elasticity over a wide range of strain rates, with bone acting both stiffer and stronger at higher strain rates. Restated, bone fails at a higher load but with less allowable elongation (deformation) at higher compared with lower strain rates. Thus, bone behaves in a more brittle fashion at higher strain rates. Bovine cortical bone has been found to be three to four times more brittle under dynamic load than under a quasistatic load. This brittleness was attributed to a possible shear stress on the fibers in the bone at a high-velocity loading.[218] A similar idea of a change in failure mode because of increasing brittleness at higher strain rates was observed in a study on a galloping horse.[219] Variations in properties such as stiffness, strength, and ultimate strain of human trabecular bone from proximal tibiae[220] and vertebrae[221] were explained using linear and power function relations to strain rate. Compared with compression, strain rate was found to have a higher effect on the change in trabecular bone properties in shear.[222]

Carter and Hayes[223] have reported both strength and elastic modulus of human bone to be proportional to strain rate raised to the 0.06th power. Strain rate to which bone is normally exposed varies from 0.001 sec^{-1} for slow walking to 0.01 sec^{-1} for higher levels of activity. Although closure speeds of the human mouth have been reported by one author,[224] no data are available regarding human mandibular or maxillary bone strain rates in vivo.

At a microstructural level, modulus measured by nanoindentation of human cortical bone (osteons and interstitial bone tissue) was found to increase with increase in loading rates.[225] The difference in modulus at different loading rates was observed to be higher than that predicted by early uniaxial tensile and compression studies at the continuum level.[220,226] However, a previous study investigating the viscoelasticity of cortical bone found modulus to be a function of strain rate raised to the 0.06th power,[227] which compared well with the early macroscopic studies.[226] Similarly, an increase in mechanical properties with increasing strain rates was found in cortical bone from lateral and medial aspects of human femur.[228]

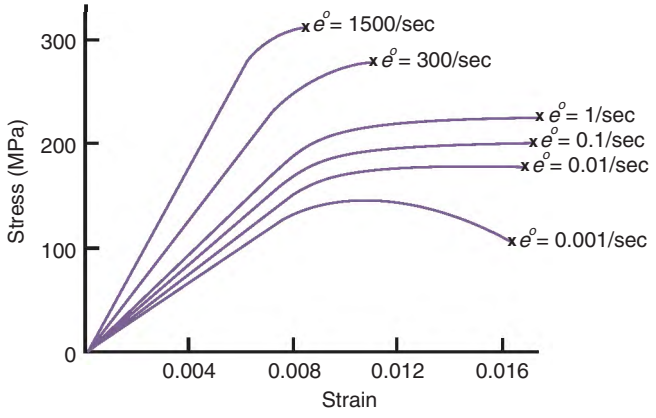


FIGURE 6-6. Strain rate dependence of bone. (From McElhaney JH: Dynamic response of bone and muscle tissue, *J Appl Physiol* 21:1231, 1966. Used by permission.)

Dependence on Duration of Loading

Carter and Caler[229] have described bone damage or fracture caused by mechanical stress as the sum of both the damage caused by creep or time-dependent loading and cyclic or fatigue loading and the relative interaction of these two types of damage.

Creep refers to the phenomenon whereby a material continues to exhibit increasing deformation as a function of time when subjected to a constant load. Carter and Caler[230] have reported the creep-fracture curve for adult human bone at a constant stress of 60 MPa (Figure 6-7). Over approximately 6 hours, a threefold increase in strain was observed. Such data raise the question of whether resorption or failure in the dental bruxer or "clencher" patient may be partially (or wholly) the result of an accumulation of creep damage.

Mixed results have been reported of the effects of creep on fatigue damage of trabecular bone. Although Moore et al.[231] concluded that creep does not contribute to fatigue failure in bovine trabecular bone except for possible effects on low-density osteoporotic bone, recent study on cadaveric vertebrae revealed that trabecular bone does not fully recover from residual strains[232] (time for complete recovery is 20-fold greater than duration of applied loads) caused by creep (static or cyclic loading) and may lead to nontraumatic fractures. Both static and cyclic loading led to similar residual strains of the order of magnitude of initially applied elastic strain.[232]

Fatigue strength of a material refers to an ultimate strength below which the material may be repetitively subjected for an infinite number of cycles without failure. Carter et al.[233,234] have investigated the fatigue properties of human cortical bone. Fatigue failure has been reported for in vivo bone at relatively low cycles (10^4–10^8 cycles).[235–237] Given the high magnitude of cycles encountered in oral function, the relatively low in vivo fatigue life reported in bone (i.e., accumulated fatigue damage) is likely accommodated in vivo through the normal process of bone remodeling.

Excessive cyclic loading of bones is known to cause microcrack growth and increase fracture risk.[238,239] Fatigue failure of cortical and trabecular bone has been characterized by a

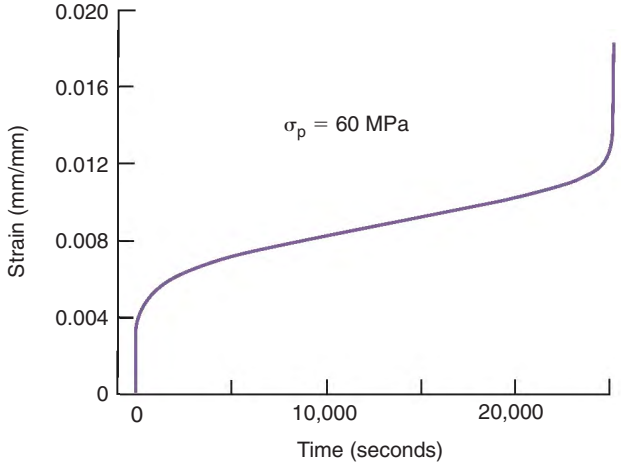


FIGURE 6-7. Creep curve for adult human cortical bone at constant stress of 60 MPa. (From Carter DR, Caler WE: Cycle dependent and time dependent bone fracture with repeated loading, *J Biomech Eng* 105:166, 1983. Used by permission.)

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continuous reduction in modulus, with increasing number of cycles with a drastic drop closer to failure and increasing plastic strain.[229,230,240–242]

Cortical bone has been observed to behave in an increasingly nonlinear form, with the cyclic energy dissipation increasing with number of cycles in both tensile and compressive cyclic loading.[240,243–245] Threshold levels of 2500 and 4000 με in compression were noticed, below which bone exhibited viscoelastic behavior and above which a microdamage accumulation started.[240] Resistance to fracture is a combination of resistance against initiation and propagation of cracks. Discontinuities in osteons and other features such as haversian canals or Volkmann's canals have been suggested to act as microstructural barriers and slow or stop the propagation of cracks.[245,246–252] Osteonal lamellae in cortical bone are hypothesized to play a key role in preventing propagation of smaller cracks, but they may be areas of weakness in cases of longer cracks.[253,254] Cortical bone typically exhibits cyclic softening during cyclic loading, which refers to the nonelastic strain amplitude greater than zero after the initial few cycles, along with a simultaneous rise in stress amplitudes (Figure 6-8). Because of viscoelastic behavior and crack formation, this value stabilizes after the initial few cycles but undergoes a drastic increase before the final failure owing to macroscopic crack growth.[245]

Models relating modulus reduction to microcrack growth have also been proposed.[255–257] Tests have supported a strain-based failure criterion in bovine trabecular bone, with maximum strain attained during the cyclic loading being a better indicator of normalized modulus and linearly related to secant modulus and residual strain.[258] A threshold of 0.5% was observed to attain plasticity in strain, change mechanical properties, and begin the accumulation of microdamage in cyclic and uniaxial compression loading.[259,260]

Rats subjected to external loads by orthodontic tooth movement at different times of the day were found to exhibit increased bone formation on the side experiencing tension and an increase in osteoclast formation on the compression side during light periods than dark periods. Inhibition of proliferation and differentiation of chondrocytes by mandibular retractive force was also higher in light periods. Based on these results, the authors suggested that bones and cartilage are more metabolically active during rest periods than during activity; furthermore, orthodontic treatment by force application during rest periods may be more effective than when subjects are active.[261–263]

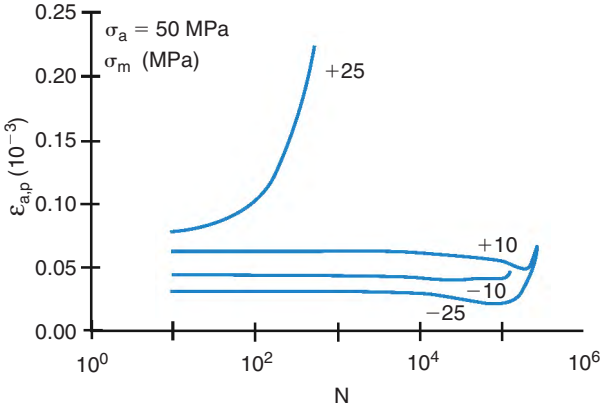


FIGURE 6-8. Increase in nonelastic strain amplitude with increase in mean stress and cycle number. (Adapted from Fleck C, Eifler D: Deformation behaviour and damage accumulation of cortical bone specimens from the equine tibia under cyclic loading, *J Biomech* 36:179-189, 2003.)

Dependence on Species and Anatomical Location

Large variations have been noted in experimental measurements of elastic modulus and ultimate compressive strength of trabecular bone. The strength of human mandibular trabecular bone[264] is lower than the proximal femoral trabecular bone reported in previous studies.[265] In the proximal part of the femur, the thickness of the cortical bone wall gradually reduces from the shaft to the metaphyseal region. At the femoral head, the cortical bone represents only a thin shell. Three sets of lamellae arrangement of cancellous bone can be observed in this region, and the cancellous network shows a sheet and strut architecture lined up along the compression and tension lamellae. The trabecular bone in this region is thus the primary structure to dissipate and transfer loads.

Trabecular architecture being either "rodlike" or "platelike"—depending on the anatomical site—could be responsible for the intersite differences.[266] Although vertebrae have the former architecture, femoral neck and proximal tibiae have the latter.[267] Experimental data suggest that rodlike structure is more susceptible to large deformations by bending and rotation of trabeculae than platelike structures. A comparative study of compressive and tensile yield strains in trabecular bone from vertebra, the proximal tibia, the femoral neck, and the femoral greater trochanter revealed that compressive and tensile yield strains were higher at the femoral neck and vertebra, respectively, but yield strains within an anatomical site were found to vary less[266,268] despite huge variations in elastic modulus and yield stress.[266,269–271] Volume fraction (density) and architecture had very little effect in the variations of apparent-level yield strains, which was predominantly influenced by tissue yield strains.[213]

Nonlinearity of trabecular bone, measured as percent reductions in tangent modulus at 0.2% and 0.4% strains, was found to differ at four different sites—vertebra, proximal tibia, and proximal femora from human and bovine proximal tibia. The percent reductions were found to be higher in tension than compression at all sites at 0.4% strain and only in bovine proximal tibiae at 0.2% strain.[272] Occasional overloading of trabecular bone (up to 3% strain) degrades its mechanical properties and increases the risk of fracture.[273] This damage behavior may apply to lumbar and lower thoracic vertebral bodies that are predominantly occupied by trabecular bone and play an important role in causing vertebral fractures.[274] A study of different sites showed the femoral neck to possess the highest resistance to fracture initiation for both tension and shear loading in a comparison among the femoral neck, femoral shafts, and tibial shafts; the femoral shaft possessed the least.[275]

In the edentulous mandible, trabecular bone is continuous with the inner surface of the cortical shell. In the dentate mandible, trabecular bone is surrounded by a thick cortical shell and dense alveolar bone under the teeth. FE models of the human mandible[276,277] have shown that cortical bone plays a major role in the dissipation of occlusal loads. Thus, load patterns on trabecular bone and microstructure of trabecular bone may contribute to differences in the mechanical behavior of the mandible compared with other anatomical regions. Given that implants do not routinely engage apical cortical bone, attention to trabecular bone mechanical properties is paramount.

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Mechanical loads in the mandible are different from those typically experienced by long bones. In the long bones, such as the femur and tibia, loads are primarily axial. In contrast, muscle loads in the mandible may be large and include dorsoventral shear, twisting about the long axis of the mandible, and transverse, increasing in magnitude from posterior to anterior in the mandible.[278] The regional differences observed in the mechanical properties within the human mandible likely reflect the difference in load carried by the different regions of the mandible. With muscle attachments located posteriorly on the mandible, the anterior mandible experiences a large moment load, even in the absence of occlusal loads, caused by the buccolingual flexure of the mandible. Thus, significantly higher densities are to be expected in the anterior compared with posterior mandible. Study on the material properties of human dentate mandible and maxilla revealed regional and directional variations in the properties in both anatomical sites.[279,280] In the mandible,[279] the direction of maximum stiffness varied at different regions being parallel to the occlusal plane at the corpus to vertical orientation at the ramus. Among the corpus, symphysis, and ramus—although symphysis had the thicker cortex, lesser density, anisotropicity, and stiffness—the ramus showed the opposite properties; the material properties of the corpus were between the two others. Such regional variations left questions about relationships between the material properties and mandibular function as suggested by the authors. Edentulation produces a change in all of these material properties in the mandible.[281] In the maxilla,[280] alveolar regions were thicker, less dense, and less stiff; cortical bone from the body of the maxilla was thinner, denser, and stiffer. Elastic properties, specifically principal stiffness direction, were more variable in the maxilla than the mandible. Stress and strain distributions along different orientations and between working and balancing sides of the mandible to gain a better understanding of its function augmented the previous studies. Whereas The results from the balancing side suggested bending and twisting of the mandible during mastication and transducer biting, the working side was found to undergo torsion. The lingual aspect was stiffer than the buccal side.[282]

Although two- to threefold higher bite (occlusal) forces are present in the posterior compared with the anterior mandible, both apparent density and ultimate compressive strength of trabecular bone are lowest in the posterior mandible.[283] These data suggest that the large, multiple-root structure of molar teeth serves to dissipate such posterior occlusal loads as opposed to concomitantly higher ultimate strengths in the bone itself. Current clinical practice routinely places the same-size dental implant diameter and geometry in the posterior and anterior mandible. This practice appears contraindicated given the inherent strength variations within human mandibular bone.

Dependence on Side Constraint

The biomechanical response of trabecular bone in the mandible is highly dependent on the presence or absence of cortical plates as a "side constraint." Qu[264] showed a 65% higher stiffness (elastic modulus) for trabecular bone of the mandible when constrained by cortical plates as compared with unconstrained test values (Figure 6-9). In these tests, fluid was allowed to escape circumferentially so that stiffness trends were lower compared with additional hydrostatic stiffening effects afforded by a constraining test mode. These results are supported by the work of Linde and Hvid,[284] who reported a 19% greater stiffness of trabecular bone specimens (from the proximal tibia) tested when constrained by the surrounding trabecular bone compared with comparable unconstrained tests.

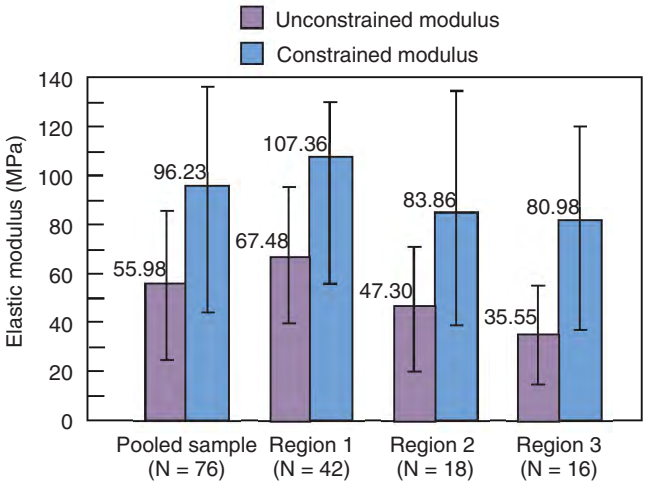


FIGURE 6-9. Ultimate compressive strength of human mandibular trabecular bone.

Dental implant patients exhibit variation in the integrity of the buccal and lingual cortical plates. In some instances, one or both plates are completely absent. Treatment planning for such patients should incorporate consideration of the significantly compromised mechanical stiffness (and likely, strength) of the trabecular bone in such anatomical sites.

Dependence on Structural Density

Trabecular bone is a porous, structurally anisotropic, inhomogeneous material. A 25-year literature base documents the work of numerous investigators,[285–296] who have reported in vitro data used in the development of mathematical relationships between elastic modulus and structural density, as well as ultimate strength and structural density. Vertebral trabecular bone was found to be highly anisotropic and stiffer in the superoinferior direction,[297] suggesting that trabecular bone should not be considered transversely isotropic. The anisotropy was found to increase with decrease in apparent density to maintain stiffness in the load-bearing direction as suggested by the authors. In addition, structural Young's modulus in all three directions was found to have good correlations explained by power-law models with apparent density. Whereas compressive yield strains of human vertebral trabecular bone depend on apparent density, tensile yield strains do not.[298–300] Whereas buckling of individual trabeculae dominates as the on-axis compressive failure mode at lower densities, axial yielding takes over as the major failure mode at higher densities.[298]

Qu[264] specifically reported on the mechanical properties of mandibular trabecular bone. The study design used cylindric trabecular bone specimens (5 mm in diameter and 5 mm high) from the human mandibles. These tests were mechanically tested in compression in the occlusal-apical direction and were performed at a constant strain rate of 0.01 sec^{-1} under both nondestructive and destructive testing conditions. In the nondestructive tests, the trabecular bone specimens were constrained by cortical plates in the buccal and lingual directions and by trabecular bone in the mesial and distal directions. Before the destructive test, the cylindric specimens were measured and weighed to determine the apparent (structural) density.

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TABLE 6-1
Relationship between Compressive Strength and Apparent Density of Trabecular Bone in the Human Mandible

Region	Compressive Strength
Pooled sample	$S = 153.4 - 401.6\,\rho + 340\,\rho^2 - 90.9\,\rho^3$ ($r = 0.88$, $p < 0.0001$)
Region 1	$S = 139.0 - 366.6\,\rho + 135.7\,\rho^2 - 85.9\,\rho^3$ ($r = 0.91$, $p < 0.0001$)
Region 2	$S = 129.6 + 390.3\,\rho + 392.7\,\rho^2$ ($r = 0.90$, $p < 0.0001$)
Region 3	No correlation

ρ, Density; *r*, relations; *S*, Compressive strength.

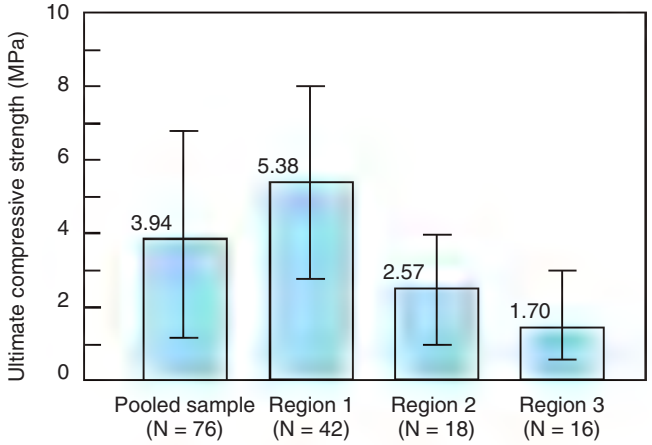


FIGURE 6-10. Elastic modulus for constrained and unconstrained test conditions in human mandibular trabecular bone.

Regional differences were noted in the human mandibular trabecular bone elastic modulus and ultimate compressive strength, exhibiting up to 47% to 68% higher mean values in the anterior (region 1) compared with the posterior region of the mandible (Table 6-1). No differences were observed in elastic modulus and ultimate compressive strength in the region between the premolars and molars (regions 2 and 3) (Figure 6-10). The compressive strength was correlated at a high level of significance ($r = 0.88$, $p < 0.0001$) with the trabecular apparent density for a best-fit cubic relationship.

Based on clinical experience with varying densities of available trabecular bone, Misch[285] defined two types of trabecular bone in his clinical classification scheme for the mandible and maxilla: (1) *coarse* (division 2 [D2]) in the anterior mandible and (2) *fine* trabecular bone in the posterior mandible (division 3 [D3]). Qu[264] found a significant difference between apparent density in region 1 (anterior mandible) and in regions 2 and 3 (posterior mandible). No significant difference was noted between region 2 and region 3. The results of the study by Qu thus provide quantitative validation of Misch's classification scheme for trabecular bone in the oral environment.

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CHAPTER 7

Radiographic Imaging in Implant Dentistry

Randolph R. Resnik and Carl E. Misch

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The use of diagnostic imaging in implant dentistry has changed tremendously over the years. Comprehensive and accurate radiographic assessment is a crucial aspect of dental implant treatment planning. Various imaging techniques have been used to evaluate bone quality, quantity, and anatomic structures in relation to the proposed implant sites. Traditionally, implant clinicians have relied on two-dimensional conventional radiograph modalities in implant dentistry. However, with the advent of computed tomography (CT), a new era in all phases of the radiographic imaging survey of implant patients has become available. These technological advances have significantly increased the level of detailed information available to implant clinicians in the diagnosis, treatment planning, surgical, and prosthetic phases of dental implant treatment. This chapter reviews the various radiographic technologies and their diagnostic contributions specific to implant dentistry relative to presurgical evaluation, treatment planning, and postoperative assessment.

Classification of Radiographic Imaging Techniques

The goal of radiographic imaging in implant dentistry is to acquire the most practical and comprehensive information that can be used for the various phases of implant treatment. The implant team must assess each individual patient on which imaging modality should be used, and the decision should be based on sound and practical information.

Phase 1

Phase 1 is termed *presurgical implant imaging* and involves all past radiologic examinations and new radiologic surveys chosen to assist the implant team in determining the patient's final comprehensive treatment plan. The objectives of this phase of imaging include all necessary surgical and prosthetic information to determine the quantity and quality of bone, identification of vital structures, prosthetic needs, proposed implant sites, and the presence or absence of disease.

Phase 2

Phase 2 is termed the *surgical and intraoperative implant imaging* phase and is focused on assisting in the surgical and prosthetic intervention of the patient. The objectives of this phase of imaging are to evaluate the surgery sites during and immediately after surgery, assist in the ideal position and orientation of dental implants, evaluate the healing and integration phase of implant surgery, and ensure that abutment position and final prosthesis fabrication are correct.

Phase 3

Phase 3 is termed the *postprosthetic implant imaging*. This phase commences just after the prosthesis placement and continues indefinitely. The objectives of this phase of imaging are to access the long-term maintenance, integration, and function of the implants, which includes the evaluation of the implant complex and surrounding crestal bone levels.

Imaging Modalities

The decision to image the patient is based on the patient's clinical needs. To obtain a radiologic survey of a particular area of interest, the imaging modality is selected that yields the necessary diagnostic information related to the patient's surgical and prosthetic needs. Maximizing the ratio of benefit to risk for acquiring information from imaging examinations is a fundamental tenet of radiology. Examinations known to produce this result are not necessarily the examinations that cost the least, are in proximity to the dentist, or produce the lowest radiation exposure.[1–3] However, they enable the implant team to acquire necessary information that is crucial to the success of the implant procedures.

Many imaging modalities have been reported in the literature as useful for dental implant imaging, including devices recently developed specifically for dental implant imaging (Box 7-1).[4,5] These imaging modalities can be classified as analog or digital

BOX 7-1 Types of Imaging Modalities

- Periapical radiography
- Panoramic radiography
- Occlusal radiography
- Cephalometric radiography
- Conventional tomographic radiography
- CT (three dimensional)
- CBCT
- Medical CT
- MRI (three dimensional)
- Interactive CT (three dimensional)

CBCT, Cone-beam computed tomography; *CT,* computed tomography; *MRI,* magnetic resonance imaging.

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and either two or three dimensional. In the past, radiographic imaging was limited to analog two-dimensional imaging. Analog imaging modalities are two-dimensional systems that use radiographic film or intensifying screens as the image receptors. However, the image quality of these systems is plagued by many disadvantages such as resolution quality, limited field of view (FOV), time consuming, excessive radiation exposure, and being highly dependent on operator characteristics.[6–8]

In the past, intraoral radiographs along with panoramic images were used as the sole determinants of implant diagnosis and treatment planning. Two-dimensional imaging techniques in the field of dentistry have inherent disadvantages and have been shown to exhibit high false-negative and false-positive images.[9–11] With the advancement of radiographic technology, various three-dimensional imaging systems are now available to the dental profession, allowing implant teams an infinite amount of diagnostic information.

Presurgical and Diagnostic Imaging (Phase 1)

The goal of presurgical radiographic evaluation is to assess the available bone quality and quantity, angulation of bone, and selection of potential implant sites and to verify the absence of pathology. However, there exists no ideal two-dimensional radiographic imaging technique in the field of oral implantology that would be acceptable for all patients. When selecting a radiographic modality for preoperative assessment, a careful examination of the available imaging options should be evaluated for selection as per the patient's needs. In dental and medical radiology, a recommended principle when selecting the appropriate radiographic modality is based on radiation dosage. The "as low as reasonably achievable" (ALARA) principle should always be adhered to, which states that the diagnostic imaging technique selected should include the lowest possible radiation dose to the patient. However, patient care and treatment planning should not be jeopardized in response to radiation dose. Advances in technology that permit reduced radiation doses to obtain a similar radiographic image over recent years have dramatically reduced this concern.

All of the modalities identified in Box 7-1 have been shown in the literature to have been used in the first diagnostic phase of treatment.[4,5] However, the radiographic modality selected should allow for presurgical implant treatment planning with high-resolution and dimensionally accurate three-dimensional information about the patient at the proposed implant sites.

The imaging modalities listed in Box 7-1 can be subdivided into planar two-dimensional and three-dimensional imaging modalities. Planar imaging modalities include periapical, bitewing, occlusal, and cephalometric imaging and are simply two-dimensional projections of the patient's anatomy. Three-dimensional imaging techniques include CT, cone-beam computed tomography (CBCT), and magnetic resonance imaging (MRI), which enable the dentist to view a volume of the patient's anatomy. These techniques are quantitatively accurate, and three-dimensional models of the patient's anatomy can be derived from the image data and used to produce stereolithographic surgical guides and prosthetic frameworks.

This phase of implant imaging is intended to evaluate the current status of the patient's teeth and jaws and to develop and refine the patient's treatment plan. Evaluation of the patient by members of the dental implant team is accomplished with a review of the patient's history, a thorough clinical examination, and evaluation of the patient's radiologic examinations. The dental implant team should be able to rule out any existing pathology and establish a tentative clinical objective that meets the patient's functional and esthetic needs.

BOX 7-2 Objectives of Preprosthetic Imaging

- Identify pathology
- Determine bone quality
- Determine bone quantity
- Determine ideal implant position
- Determine ideal implant orientation

The objective of this phase of treatment is to develop and implement a treatment plan for the patient that allows for the restoration of the patient's function and esthetics by the accurate and strategic placement of dental implants. The patient's functional and esthetic needs can be transformed physically into a three-dimensional diagnostic template, which enables the implant team to identify the specific sites of prospective implant surgery in the imaging examinations. The specific objectives of preprosthetic imaging are listed in Box 7-2.

Periapical Radiography

Technique

Periapical radiographs are high-resolution images of a limited region of the mandibular or maxillary alveolus.[12] There exist two intraoral projection techniques that may be used in periapical radiology: the paralleling and bisecting the angle techniques. Although both methods are used in dentistry today, the paralleling technique is generally preferred in implant dentistry because of less distortion and magnification. The paralleling technique necessitates placing the film or sensor parallel in relation to the long axis of the implant, tooth, or osseous structure in question. Additionally, the central ray of the x-ray beam is directed perpendicular to the film or sensor. When used in oral implantology, this technique reduces geometric distortion and magnification. If the bisecting the angle or poor technique is used in obtaining images, the resultant images will have inaccurate vertical and horizontal measurements.[13] The paralleling technique eliminates distortion and usually limits magnification to less than 10%. On occasion, the bisecting the angle technique is necessary to observe the apical region of bone or the implant because of the anatomy of the surrounding region.

One of the most significant recent advances in dental radiology is the advent of digital technology, which has allowed reduction of numerous limitations of conventional intraoral radiography. The advantages of digital radiography and the uses in oral implantology are well documented[14,15] (Table 7-1). With the use of digital radiography, implant surgical procedures and prosthetics have been simplified with increased efficiency.

Digital radiology is an imaging process wherein the film is replaced by a sensor that collects the data. The analog information received is then interpreted by specialized software, and an image is formulated on a computer monitor. The resultant image can be modified in various ways, such as gray scale, brightness, contrast, and inversion. Color images may be formed to enhance the digital image for better evaluation. Computerized software programs (i.e., Dexis Implant) are now available that allow for calibration of magnified images, thus ensuring accurate measurements (Figure 7-1).

Compared with conventional radiographs, the most current digital systems have significantly less radiation[16,17] with superior

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FIGURE 7-1. Digital radiographic system that includes a digital sensor and computer. (Courtesy Dexis, LLC.)

TABLE 7-1
Comparison of Film versus Digital-Based Images

	Film	Digital
Image	Analog	Analog ~ digital
Cost	Film, chemicals	Up front
Radiation	High	50%–90% less
Viewing	Delayed	Immediate
Resolution	14–18 Ln/mm	12–20 Ln/mm
Gray scale	16 shades	256 shades
Film	Thin, flexible	Thin, cord
Enhancement	Unchangeable	Wide range
Storage	Chart	Computer

Data from Park ET, Williamson GF: Digital radiography: an overview, *J Contemp Dent Pract* 3:1–13, 2002.

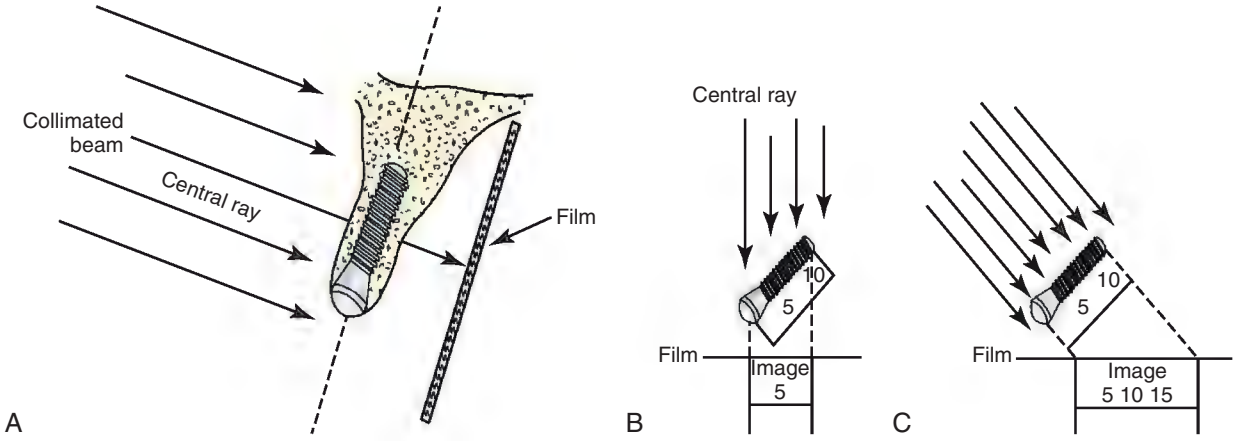


FIGURE 7-2. Film positioning. **A,** The central ray is perpendicular to the bone and film, resulting in no distortion. **B,** The central ray is perpendicular to the film but not to the implant, resulting in foreshortening. **C,** The central ray is perpendicular to the object but not the film, resulting in elongation.

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resolution.[15] However, with respect to oral implantology, the most significant advantage of digital radiography is the instantaneous speed in which images are formed, which is highly useful during surgical placement of implants and the prosthetic verification of component placement.

Advantages

Periapical radiology is an excellent radiologic modality that has many advantages over other radiographic techniques in implant dentistry. This type of radiography exhibits a very low radiation dose, especially if the images are obtained digitally. The resultant images have high resolution and can be modified in various ways, such as the gray scale, brightness, contrast, and inversion. Color images may be formed for enhancement of evaluation and density readings. Most computer software programs are now available to allow for calibration of magnified images, thus ensuring accurate measurements.

Disadvantages

Periapical radiology does have inherent disadvantages. Because the cortical plates in the mandible are thick, the mandibular canal and bone density are difficult to access. Image shape distortion and magnification may be present when unequal magnification of the object exists. This occurs when the total area in question (e.g., alveolar bone, implant) does not have the same focal spot-to-object distance. When the x-ray beam is perpendicular to the object but the object is not parallel to the film, foreshortening will occur. If the x-ray beam is oriented perpendicular to the object but not the film, elongation will occur. These basic and important concepts help to minimize distortion and magnification when using intraoral radiographs[18] (Figure 7-2).

Image magnification may be assessed by placing a known-dimension radiographic marker (e.g., 5-mm ball bearing) at the crestal region of the desired implant location. When the marker is elongated, so is the implant site. For example, a ball bearing radiographic measurement of 8 mm relates to a 62% magnification (5 mm/8 mm = 62%). Therefore, the image below the ball bearing may represent a 60% magnification of dimension. Most digital radiographic systems have built-in magnification programs that allow for the determination of this distortion (Figure 7-3).

The most significant disadvantage of periapical radiology leading to image distortion is difficulty in film positioning. In certain situations, the opposing landmark of available bone in implant dentistry is beyond the lingual muscle attachments in the mandible or beyond the palatal vault in the maxilla. As such, the image most often must be foreshortened to visualize

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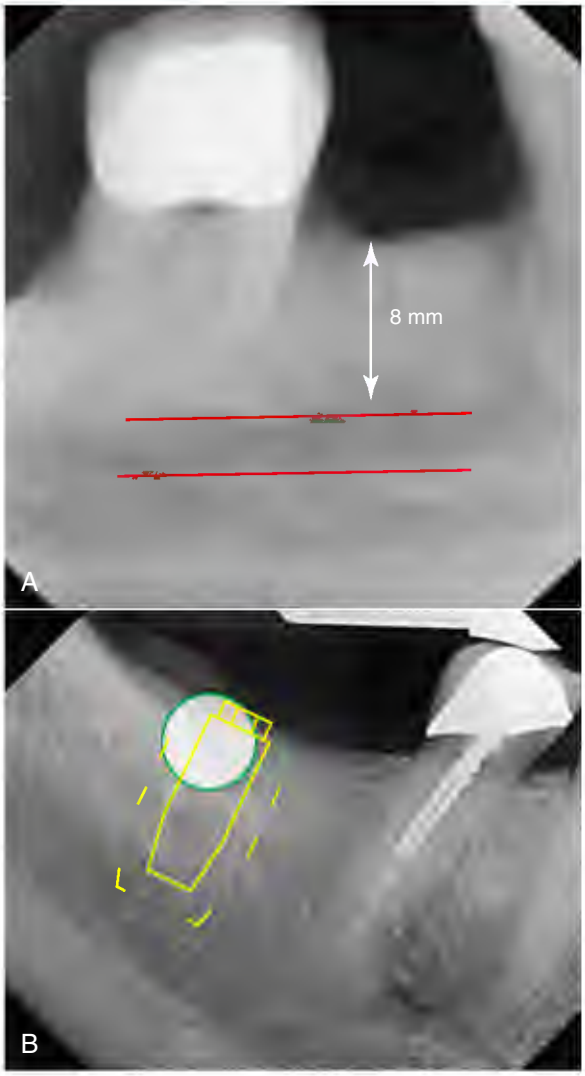


FIGURE 7-3. **A,** Direct measurements of vital structures may be made directly on the calibrated digital images. Studies have shown that on plain film intraoral radiographs, more than 50% of the time the mandibular canal and mental foramen are indistinguishable. However, this limitation has been drastically reduced with the advent of digital imaging. **B,** Image magnification can be determined by imaging a known-diameter radiographic marker, and the appropriate size implant (adjusted for magnification) may then be selected and placed into the edentulous area.

the opposing cortical plate, and the actual available bone height may be difficult to determine.

The bone density at the crest is also a factor to evaluate crestal bone loss with radiographic indexes. In D4 bone, no cortical plate is present on the crest, and fine trabecular bone is primarily present. Burnout effects are common when standard kilovolt (kVp) and milliampere (mA) settings are used, making crestal bone loss evaluation with digital intraoral systems of benefit in these situations[19,20] (Box 7-3).

Phase 1 and Phase 2

Periapical imaging is often used in phase 1 and 2 treatment. The evaluation of small edentulous spaces, alignment and orientation of the implant during surgery, and confirmation that the implant is not invading an adjacent tooth root or mandibular canal during surgery are major benefits of periapical images.

BOX 7-3 Periapical Radiographic Images

Advantages
- Low radiation dose
- Minimal magnification with proper alignment and positioning
- High resolution
- Inexpensive

Limitations
- Distortion and magnification
- Minimal site evaluation
- Difficulty in film placement
- Technique sensitive
- Lack of cross-sectional imaging

Indications
- Evaluation of small edentulous spaces
- Alignment and orientation during surgery
- Recall and maintenance evaluation

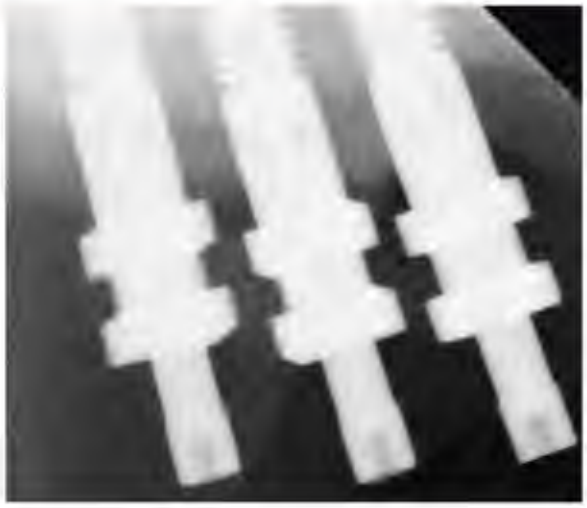


FIGURE 7-4. Verification of direct transfer coping placement before final impression. Note the ideal angulation from thread alignment.

Ideally, a digital periapical radiograph should be taken immediately after surgery when possible. This image type can be used as a baseline to evaluate bone levels and healing.

Abutment and Prosthetic Component Imaging

When evaluating for transfer impressions along with two-piece abutment component placement, radiographs should be taken to verify complete seating. Intraoral radiographs should be used because of their high geometric resolution to evaluate for any fit discrepancy. However, care must be taken so that the x-ray beam is directed at a right angle to the longitudinal axis of the implant. Even a slight angulation may allow a slight gap to remain unnoticed. When positioning is difficult for periapical radiographs, bitewing or panoramic radiographs may be used (Figures 7-4 and 7-5).

Postprosthetic Imaging (Phase 3 Treatment)

A postprosthetic radiograph ideally needs to be taken to act as a baseline for future evaluation of component fit verification

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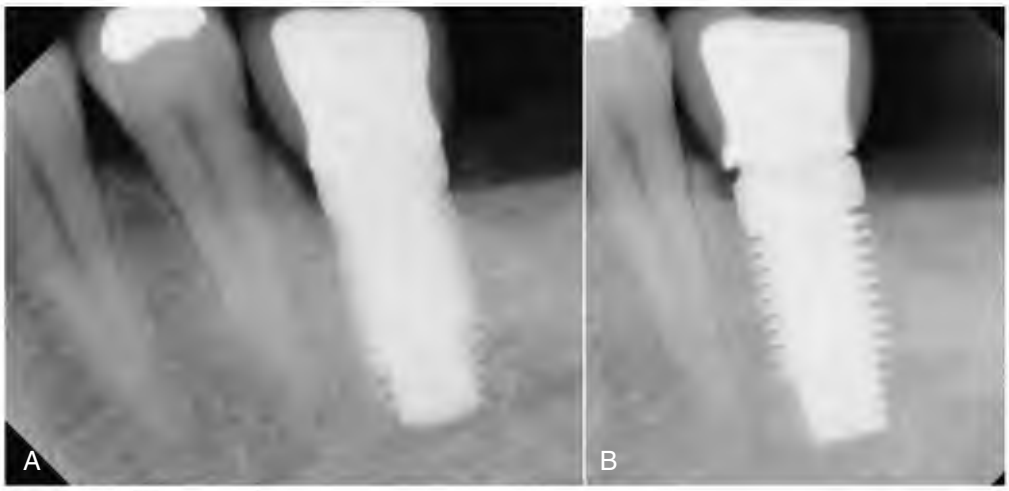


FIGURE 7-5. Seating of a final prosthesis. **A,** Poor x-ray angulation showing a false-negative or complete seating of the prosthesis. Note the diffuse threads. **B,** A corrected angulation image exposes the seating problem.

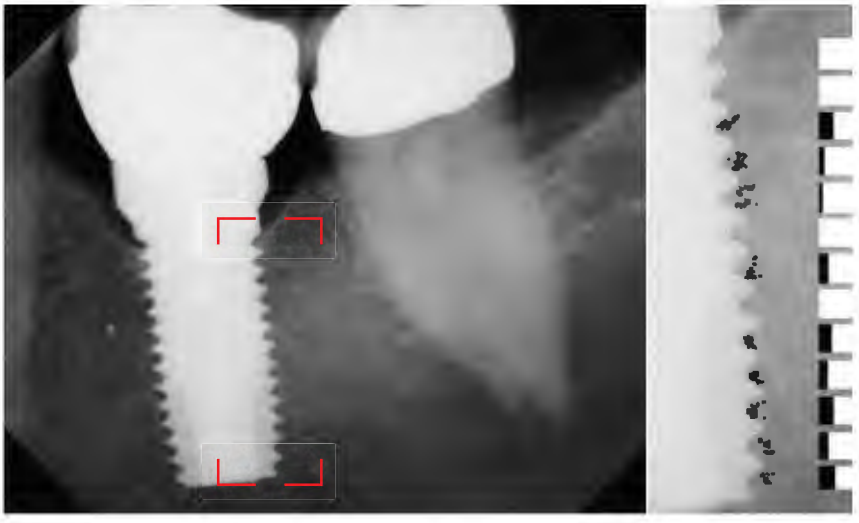


FIGURE 7-6. Specialized digital image modification programs (e.g., DexBone; Dexis) allow viewing of any subtle changes in bone density around the implant interface.

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and for marginal bone level evaluation. Care must be taken to ensure that adequate fit of all components is made. In addition, the marginal bone level must be determined for future evaluation. Additionally, the postprosthetic image may be used to verify the absence of cement, which may lead to tissue irritation, bone loss, and infection.

Recall and Maintenance Imaging

For the evaluation of implant success, immobility and radiographic evidence of bone adjacent to the implant body are the two most accurate diagnostic aids in evaluating success. Follow-up or recall radiographs should be taken after 1 year of functional loading and yearly for the first 3 years.[21] Multiple studies have shown that in the first year, marginal bone loss and a higher rate of failure are seen.

Radiographically, lack or loss of integration is usually indicated as a radiolucent line around the implant. However, false-negative diagnoses may be made when the soft tissue surrounding an implant is not wide enough to overcome the resolution of the radiographic modality. False-positive diagnoses may also be made when a "Mach band effect" results from an area of lower radiographic density adjacent to an area of high density (implant), which results in a more radiolucent area than is actually present.[22] However, studies have shown that the possibility of the Mach band effect is significantly reduced with digital image processing. Additionally, digital radiography has been shown to have an advantage over conventional radiography with respect to "edge enhancement," which is the ability to detect space between the implant and the surrounding bone (Figure 7-6).[23] Because of the variability of operator-controlled problems, a strict quality assurance protocol should be used to maintain ideal image quality over time. Proper positioning along with documentation of kVp and mA settings should be documented for future reference.

In recall radiographic examinations, the marginal bone level is compared with the immediate postprosthetic radiographs. Therefore, radiographs similar in geometry, density, and contrast are paramount. To ensure accuracy, standardized periapical radiographs are essential; however, reproduction of positioning is very difficult.[24] Numerous film-holding devices have been

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FIGURE 7-7. Alveolar bone level evaluation. **A,** Ideal positioning showing ideal thread orientation. **B,** Improper angulation showing diffuse thread orientation.

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documented that attach to the implant, abutment, or prosthesis to standardize image geometry.[25–28] When proper projections are achieved, implant threads on both sides of the implant are clearly seen. If the threads are not clearly seen in the radiographs, modification of the beam angle needs to be made. If diffuse threads are present on the right side of the implant, then the beam angle was positioned too much in the superior direction. If the threads are diffuse on the left side, then the beam angle was from an inferior angulation (Figure 7-7). With digital enhanced radiographs, numerous techniques have been postulated to measure bone levels around implants. Computer-assisted measurements, rulers, calipers, and suprabony thread evaluation have been shown to have highly reproducible results.[29,30]

In summary, periapical radiology:

- Is a useful high-yield preliminary modality used for evaluation of local bone or dental disease
- Has inherent advantages of less radiation, instantaneous speed, and superior resolution
- Is of limited value in determining quantity of bone because the image may be magnified or distorted and does not depict the third dimension of bone (width)
- Is of limited value in determining bone density or mineralization (the lateral cortical plates prevent accurate interpretation and cannot differentiate subtle trabecular bone changes)
- Is of value in identifying critical structures but of little use in depicting the spatial relationship between the structures and the proposed implant site
- Is useful during the prosthetic and maintenance phases of treatment (Figure 7-8)

Occlusal Radiography

Occlusal radiographs are planar radiographs produced by placing the film intraorally parallel to the occlusal plane with the central x-ray beam perpendicular to the film for the mandibular image and oblique (usually 45 degrees) to the film for the maxillary image. Occlusal radiography produces high-resolution planar images of the body of the mandible or the maxilla.[12] Maxillary occlusal radiographs are inherently oblique



FIGURE 7-8. Periapical radiograph depicting the incomplete seating of a two-piece prosthetic abutment.

and so distorted that they are of no quantitative use for implant dentistry for determining the geometry or the degree of mineralization of the implant site. In addition, critical structures such as the maxillary sinus, nasal cavity, and nasal palatine canal are demonstrated, but the spatial relationship to the implant site generally is lost with this projection (Box 7-4).

Because the mandibular occlusal radiograph is an orthogonal projection, it is a less distorted projection than the maxillary occlusal radiograph. However, the mandibular alveolus generally flares anteriorly and demonstrates a lingual inclination posteriorly, producing an oblique and distorted image of the mandibular alveolus, which is of little use in implant dentistry. In addition, the mandibular occlusal radiograph shows the widest width of bone (i.e., the symphysis) versus the width at the crest, which is where diagnostic information is needed most (Figure 7-9). The degree of mineralization of trabecular bone is

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FIGURE 7-9. **A,** Occlusal radiographs have been postulated to show the width of bone in the anterior region. **B,** However, occlusal radiographs actually show the widest buccolingual distance *(red arrows)* not in the same plane. Actual width of bone *(green arrow)*.

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BOX 7-4 Occlusal Radiographic Images

Advantages
- Evaluation for pathology (sialiths)

Limitations
- Does not reveal true buccolingual width in mandible
- Difficulty in positioning

Indications
- None

not determined from this projection, and the spatial relationship between critical structures, such as the mandibular canal and the mental foramen, and the proposed implant site is lost with this projection. As a result, occlusal radiographs rarely are indicated for diagnostic presurgical phases in implant dentistry.

Cephalometric Radiography

Cephalometric radiographs are oriented planar radiographs of the skull. The skull is oriented to the x-ray device and the image receptor using a cephalometer, which physically fixes the position of the skull with projections into the external auditory canal. The geometry of cephalometric imaging devices results in a 10% magnification of the image with a 60-inch focal object and a 6-inch object-to-film distance.[12]

A lateral cephalometric radiograph is produced with the patient's midsagittal plane oriented parallel to the image receptor. This radiograph demonstrates a cross-sectional image of the alveolus of the mandible and the maxilla in the midsagittal plane.[19] With a slight rotation of the cephalometer, a cross-sectional image of the mandible or maxilla can be demonstrated in the lateral incisor or in the canine regions. Unlike panoramic or periapical images, the cross-sectional view of the alveolus demonstrates the spatial relationship between occlusion and esthetics with the length, width, angulation, and geometry of the alveolus and is more accurate for bone quantity determinations. Implants often must be positioned in the anterior regions adjacent to the lingual plate.

The lateral cephalometric radiograph is useful because it demonstrates the geometry of the alveolus in the midanterior region and the relationship of the lingual plate to the patient's skeletal anatomy (Figures 7-10 and 7-11) The width of bone in the symphysis region and the relationship between the buccal cortex and the roots of the anterior teeth also may be determined before this bone is harvested for ridge augmentation. Together with regional periapical radiographs, quantitative spatial information is available to demonstrate the geometry of the implant site and the spatial relationship between the implant site and critical structures such as the floor of the nasal cavity, the anterior recess of the maxillary sinus, and the nasal palatine canal. The lateral cephalometric view also can help evaluate a loss of vertical dimension, skeletal arch relationship, anterior crown-to-implant ratio, soft tissue profile, anterior tooth position in the prosthesis, and resultant moment of forces. As a result, cephalometric radiographs are a useful tool for the development of an implant treatment plan, especially for completely edentulous patients. However, this technique is not useful for demonstrating bone quality and only demonstrates a cross-sectional image of the alveolus where the central rays of the x-ray device are tangent to the alveolus.

Disadvantages of cephalometric radiographs include cross-sectional information limited to the midline area and difficulty in cephalometric machine accessibility. Any nonmidline structure is superimposed on the contralateral side. This radiographic technique is operator technique sensitive and, if improperly

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FIGURE 7-10. A limited projection of the mandibular symphysis region is useful for preoperative evaluation of the width of the bone in the midsymphysis. It may also be a useful guide for the determination of the occlusal vertical dimension.

positioned, will result in a distorted view. Because lateral cephalometric radiographs use intensifying screens, resolution and sharpness are compromised compared with intraoral radiographic techniques (Box 7-5).

Panoramic Radiography

Panoramic radiography is a curved plane tomographic radiographic technique used to depict the body of the mandible, maxilla, and maxillary sinuses. In the past, this modality was probably the most used diagnostic modality in implant dentistry. However, for quantitative presurgical implant imaging, panoramic radiography is not the most diagnostic. This radiographic technique produces an image of a section of the jaws of variable thickness and magnification. The image receptor traditionally has been radiograph film but may be a digital storage phosphor plate or a digital charge–coupled device receptor.[20,31,32] Nonetheless, panoramic images offer many advantages (Box 7-6).

The significant limitations of panoramic radiographs can be classified into two categories: (1) distortions inherent in the panoramic system and (2) errors in patient positioning. Panoramic radiography is characterized by a single image of the jaws that demonstrates vertical and horizontal magnification along with a tomographic section thickness that varies according to the anatomical position. The x-ray source exposes the jaws from a negative angulation (8%–9%), which produces inherent magnification. The horizontal magnification is nonuniform and cannot be accurately determined because of varying positions of the patient and the focal spot–object distance and the relative location of the rotation center of the x-ray system. Clinical studies have shown that nonuniform magnification may be present in the range of 15% to 220%.[33–35] Structures of the jaws become magnified more as the object-to-film distance increases and the object–x-ray source distance



FIGURE 7-11. **A,** An alternative technique to the standard lateral cephalometric unit is the use of an occlusal film (size 2) held by the patient using a standard intraoral radiographic unit. **B,** The resultant image.

decreases. Structures that are located obliquely in relation to the implant receptor produce aspects of the structures that are magnified more when they are farther from the image receptor and less when they are closer to the image receptor.[36–38] Uniform magnification of structures produces images with distortion that cannot be compensated for in treatment planning. The posterior maxillary regions are generally the least distorted regions of a panoramic radiograph. The tomographic section thickness of panoramic radiography or trough of focus is thick (≈20 mm) in the posterior regions and thin (6 mm) in the anterior region.[38]

Traditional panoramic radiography is a high-yield technique for demonstrating dental and bone disease. However, panoramic radiography does not demonstrate bone quality or mineralization and is misleading quantitatively because of magnification. Because the third-dimension cross-sectional view is not demonstrated, the relationship between the vital structures and dimensional quantitation of the implant site is not easily depicted.

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BOX 7-5 Lateral Cephalometric Images

Advantages
- Height and width in anterior region
- Low magnification
- Skeletal relationship
- Crown–implant ratio (anterior)
- Tooth position in prosthesis
- Evaluation of the quantity of bone in anterior region prior to symphysis grafting

Limitations
- Availability
- Image information limited to midline
- Reduced resolution and sharpness
- Technique sensitive

Indications
- Used in combination with other radiographic techniques for anterior implants
- Symphysis bone graft evaluation

BOX 7-6 Panoramic Radiographic Images

Advantages
- Easy identification of opposing landmarks
- Initial assessment of vertical height of bone
- Convenience, ease, and speed in performance in most dental offices
- Evaluation of gross anatomy of the jaws and any related pathologic findings*

Limitations
- Distortions inherent in the panoramic system
- Errors in patient positioning
- Does not demonstrate bone quality
- Misleading measurements because of magnification and no third dimension
- No spatial relationship between structures

Panoramic radiography is a popular and widely available technique in dentistry, and as such, dentists have developed means to compensate for its shortcomings. Implant companies often market magnified overlays with a preset 25% magnification for evaluation of an implant size that are placed on a panoramic film for comparison with vital structure positions. However, these should not be used as the only presurgical assessment of dental implant treatment planning. Because of the inherent disadvantages of panoramic radiographs, most clinical studies substantiate the inaccuracies of direct measurements.[39,40]

Patient positioning is also a determining factor in the inaccuracies of panoramic radiographs that lead to geometric distortion. With knowledge, most errors in patient positioning can be corrected (Table 7-2). However, in a given plane, horizontal distortion cannot be determined, and measurements are completely unreliable. The horizontal dimensions are affected by the rotation center of the beam that changes with relation to the object-to-film distance[16](Figure 7-12).

The vertical dimensions depend on the x-ray source as the focus with the amount of distortion determined by the distance of the patient's arch to the film. However, vertical magnification may be determined by imaging a known-diameter object close to the alveolar ridge. The magnification factor can be calculated at the given site by dividing the actual diameter of the object by the diameter measured on the radiographic image. Diagnostic templates that have 5-mm ball bearings or wires incorporated around the curvature of the dental arch and worn by the patient during the panoramic x-ray examination enable the dentist to determine the amounts of magnification in the radiograph (Figure 7-13).

A technique for evaluating the panoramic radiograph for mandibular posterior implants and comparison with the clinical evaluation during surgery was developed by identifying the mental foramen and the posterior extent of the inferior alveolar canal.[41] However, studies have demonstrated that the mandibular foramen cannot be identified 30% of the time on the radiograph film and, when visible, may not be identified correctly.[42–45] The maxillary anterior edentulous region is generally oblique to the film and is often the most difficult area of a panoramic radiograph to evaluate because of the curvature of the alveolus

TABLE 7-2
Common Panoramic Positioning Problems and Corrections

Problem	Cause	Correction
Blurred Magnified	Patient positioned too far posterior	Make sure anterior teeth are properly in holder
Blurred Narrow anterior region	Patient positioned too far anterior	Make sure anterior teeth are in holder
Exaggerated curve of Spee Anterior foreshortening Condyles not seen Spine forms "gazebo" effect	Patient's chin tipped down too far	Correctly align ala-tragus
Flattened curve of Spee Hard palate superimposed	Patient's chin tipped too far upward	Correctly align ala-tragus
Radiopaque show over anterior region	Patient slumped too far forward	Straighten neck
Ramus larger on one side Uneven pattern of blurring	Patient's head rotated in machine	Patient's midsagittal plane should be perpendicular to floor
Large radiolucency over maxilla	Patient's tongue not in floor of mouth	Patient places tongue in root of mouth, swallows

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and the inclination of the bone. The dimensions of inclined structures in panoramic radiographs are not reliable. Studies on panoramic x-ray units have demonstrated that objects in front of and behind the focal trough are blurred, magnified, reduced in size, or distorted to the extent of being unrecognizable.

The x-ray source for this image comes from below the position of the mandible; therefore, the position of the mandibular canal in relation to the crest of the ridge is variable, depending on its buccolingual position in the mandibular body. In other words, when the canal runs lingual within the body, the position displayed on the film is more crestal compared with a nerve that is positioned more buccal even though they are the same vertical distance from the crest of the ridge. As a result, the lingual-positioned canal may have enough vertical height to place an implant, but the panoramic film indicates inadequate height of bone.

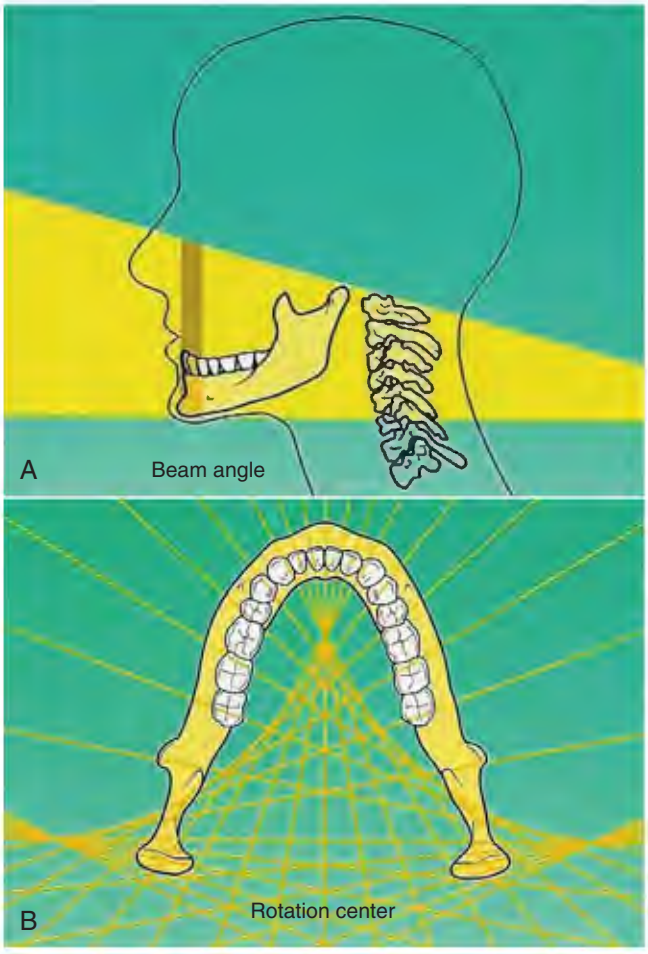


FIGURE 7-12. **A,** All panoramic beam angles are approximately at 8 degrees, which gives the image inherent magnification. **B,** Because of the curvature of the arch, panoramic machines have changing rotational centers.

The primary advantage of the panoramic radiograph is that it is a screening tool to evaluate for pathology within the hard tissues. It may also be beneficial to ensure that root tips and other structures are not in the surgical site. As a general rule, sinus pathology is difficult to observe on this film, and other tools are usually necessary (e.g., CT scans).

When the 25% average magnification is accounted for on the film, it may categorize the patient into three different groups: (1) there is obviously enough vertical bone to place and implant, (2) there is obviously not enough vertical bone to place an implant, or (3) the amount of vertical bone necessary to place an implant is not obvious.

In category I, an implant may be inserted, but the panoramic film cannot determine the width or angulation. It is best to reflect the soft tissues and visually inspect the necessary landmark (e.g., mental foramen) when performing the surgery. Category 2 patients require bone augmentation or other treatment options rather than inserting the implant in inadequate bone. Category 3 patients require further evaluation to determine if an implant option is viable or whether bone augmentation is necessary.

Computed Tomography

Computed tomography is a digital radiographic modality that has revolutionized radiographic imaging. The resultant CT data produced allows the clinician to generate many different sections of tissue interest that are free of blurring and overlapping images of adjacent structures. A finely collimated x-ray beam is used, and the data obtained are reformatted via mathematical algorithms to produce the images of interest.

History

The CT scan was invented by Sir Godfrey Hounsfield, an electrical engineer, in 1972.[46] The first CT scanners appeared in medical imaging departments during the mid 1970s and were



FIGURE 7-13. Panoramic radiograph with 5-mm ball bearings on the crest of a division A mandible.

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so successful that they largely replaced complex tomography by the early 1980s.

In dentistry, CT scanners were introduced in the 1990s and have become so popular that they are replacing most two-dimensional radiographic modalities that dentistry has been so dependent on in the past.

Image Development

Computed tomography images are a result of data collected by numerous detectors and ionizing chambers in the CT unit. The data collected by the detectors correspond to a composite of the absorption characteristics of the tissues and structures imaged. This information is transformed into images (raw data), which are reformatted into a voxel (digital) volume for evaluation and analysis.

The integration of digital imaging systems in the field of implant dentistry has significantly increased clinicians' diagnostic capabilities. A digital two-dimensional image is described by an image matrix that has individual picture elements called *pixels.* A digital image is described by its width and height and pixels (i.e., 512 × 512). For larger digital images (i.e., 1.2 M × 1.2 M, where *M* is megapixels), the image is alternatively described as a 1.5-M image. Each picture element, or pixel, has a discrete digital value that describes the image intensity at that particular point. The value of a pixel element is described by a scale, which may be as low as 8 bits (256 values) or as high as 12 bits (4096 values) for black-and-white imaging systems or 36 bits (65 billion values) for color imaging systems.[9–11] Black-and-white digital images are displayed optimally on a dedicated black-and-white monitor. Generally, 8 bits or 256 levels can be displayed effectively on a monitor. A digital three-dimensional image is described by an image matrix that has individual image or picture elements called *voxels.* A digital three-dimensional image is described not only by its width and height of pixels (i.e., 512 × 512) but also by its depth and thickness. An imaging volume or three-dimensional characterization of the patient is produced by contiguous images, which produce a three-dimensional structure of volume elements (i.e., CT, MRI, and interactive computed tomography [ICT]).

Each volume element has a value that describes its intensity level. Typically, three-dimensional modalities have an intensity scale of 12 bits or 4096 values. The two-dimensional digital images are composed of pixels (2-D) and voxels (3-D) picture elements. Pixels and voxels possess attributes of size, location, and gray-scale value. Each voxel and pixel displayed is characterized by a numerical value that represents the density of the tissues. This is termed the *CT number.* A specific shade of gray or density value is assigned to each CT number that comprises the images (Figure 7-14).

Computed tomography images are inherently three-dimensional images that are typically 512 × 512 pixels with a thickness described by the slice spacing of the imaging technique. Each voxel has a value, referred to in Hounsfield units, that describes the density of each image. The range of these units are −1000 (air) to + 3000 (enamel) Hounsfield units (Box 7-7). Most CT scanners are standardized with a Hounsfield value of 0 for water. The CT density scale is quantitative and meaningful in identifying and differentiating structures and tissues (Box 7-8).

Types of Computed Tomography Scanners

Medical

In medical radiology departments, the CT scan is the most common diagnostic imaging modality to evaluate hard and soft tissues. Advances in speed and image quality were apparent in the early 1990s with the advent of spiral and helical CT scanners. However, since its introduction in 1998, multislice (multirow detector CT) has revolutionized the field of medical CT. These CT scanning units are tomographic machines that are classified as 4-, 8-, 12-, 16-, 32-, or 64-slice machines. The number of slices corresponds to the number of times the x-ray beam rotates around the patient's head to acquire the CT data. The CT numbers, or Hounsfield units, are then reconstructed mathematically and formatted into images. However, because these images consist of a series of incremental images grouped together, CT spiral slices produce "average" reconstructed images based on multiple x-rays transversing the scanning area. With this reconstruction of images, a small gap between each slice is present, which contributes to an inherent error within medical scanners.

In the 1980s, cross-sectional reconstruction of the CT images dramatically improved the diagnosis and treatment planning in oral implantology. These reformatted images allowed three-dimensional evaluation of vital structures and related oral anatomy.[47–50] However, even though these advances enhanced diagnostic skills, there were inherent shortcomings to medical scanners used for dental purposes. Because medical scanners were not developed for dental reformatting, there existed inherent errors such as distortion, magnification, and positioning problems that led to inaccuracies when reformatted.[51] In addition, there existed no prosthetic information that could be gathered to predict the final prosthetic outcome. This was overcome with the advent of sophisticated scanning appliances, stereolithographic resin bone models,[52] interactive software, computer-generated surgical guides, and CT-based image-guided navigation systems, which allowed for ideal placement and prosthetic outcome to be established.

Although the clinical problems of medical scanners have been remedied, there still existed numerous disadvantages, including radiation exposure and availability. The amount of radiation exposure of medical scans has been a controversial topic for many years and has been shown to be very excessive. The availability has dramatically improved over the years with the advent of cone-beam computed technology (Box 7-9 and Figure 7-15, *A*).

Cone-Beam Computed Tomography

To overcome some of the disadvantages of conventional medical CT scanners, a new type of CT specific for dental applications has recently been developed[53,54] (Table 7-3). This type of advanced tomography is termed *cone-beam volumetric tomography* (CBVT) or cone-beam computed tomography (CBCT) (Figure 7-15, *B*). Because conventional CT is associated with radiation doses, this medical imaging technique has always been under significant criticism when used for implant treatment planning. However, with the advent of cone-beam technology, the limitations of medical CT have been overcome.[55] Recently, with the U.S. Food and Drug Administration's approval of cone-beam technology, there exists the ability to provide more accurate diagnostic images along with a fraction of the radiation exposure with conventional CT and adherence to the ALARA principle.[56] Cone-beam scanners are made for "in-office" installation and use, allowing the doctor and patient the convenience of onsite scanning capabilities (Figure 7-16).

Cone-beam computed tomography scanners use a rotating x-ray source that generates a conical-shaped beam that can be modified to acquire a desired area of interest. The attenuated

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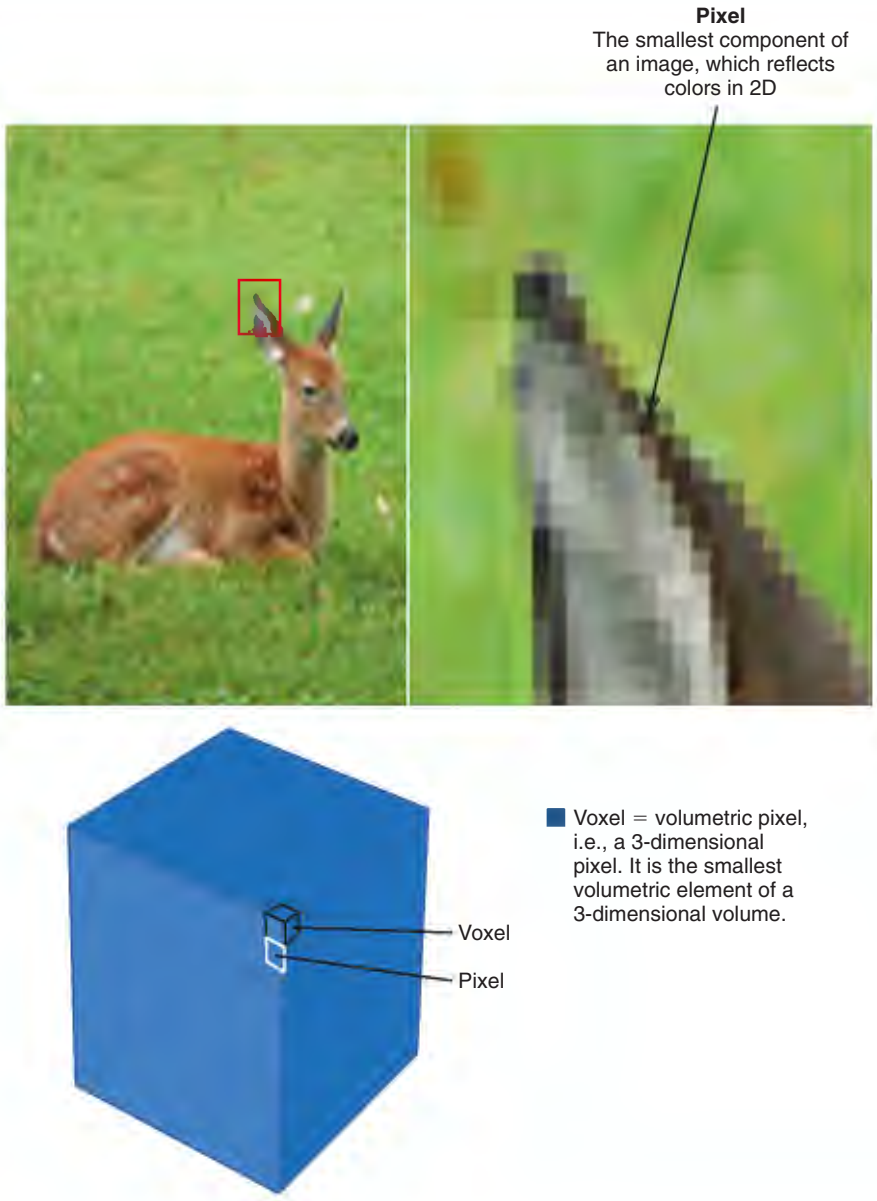


FIGURE 7-14. The final computed tomography image depends on the pixel (two-dimensional [2D]) and the voxel (three-dimensional [3D]) size.

BOX 7-7 Bone Quality

DENSITY	HOUNSFIELD UNITS
D1	1250
D2	850–1250
D3	350–850
D4	150–350
D5	<150

BOX 7-8 Tissue Characterization

MATERIAL	HOUNSFIELD UNITS
Air	1000
Water	0
Muscle	35–70
Fibrous tissue	60–90
Cartilage	80–130
Trabecular bone	150–900
Cortical bone	900–1800
Dentin	1600–2400
Enamel	2500–3000

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BOX 7-9 Computed Tomography

Advantages

- Negligible magnification
- Relatively high-contrast image
- Various views
- Three-dimensional bone models
- Interactive treatment planning
- Cross-referencing

Limitations

- Cost
- Technique sensitive
- Indications
- Interactive treatment planning
- Determination of bone density
- Vital structure location
- Subperiosteal implant fabrication
- Determination of pathology
- Preplanning for bone augmentation

TABLE 7-3
Comparison of Medical Spiral Scanners and Cone-Beam Computed Tomography

	Medical	Cone Beam
Scanning time	≈10 min	≈36 sec
Radiation exposure	More	Less
Scan	Multiple slices	One rotation
Exposed field	One arch at a time	Both arches simultaneously
Scatter	More	Less
Positioning	Very technique sensitive	Not as critical

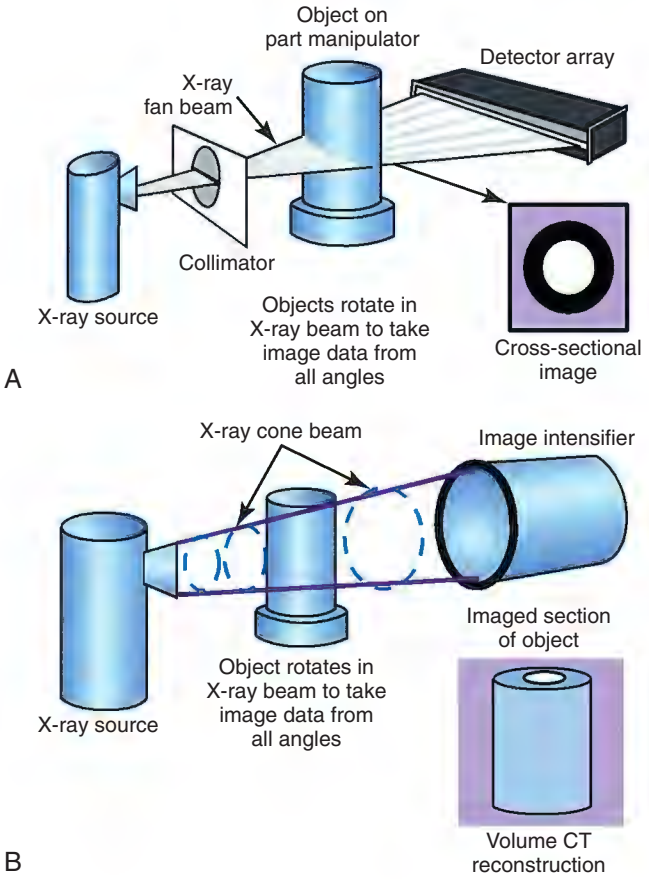


FIGURE 7-15. **A,** A conventional computed tomography (CT) scan uses a very narrow "fan beam" that rotates around the patient, acquiring one thin slice (image) with each revolution. Because of the numerous revolutions needed, the radiation dose is increased. **B,** Cone-beam volumetric tomography captures all data in one rotation, thus reducing radiation and avoiding distortion and errors in reformatting.



FIGURE 7-16. A Prexion in-office cone-beam computed tomography scanner. The scan is completed in less than 20 seconds.

x-ray beam data are collected by a single collector. These data are then converted to various shades of gray, which are displayed on a computer screen. Reconstruction of these images can be in any plane by simply realigning the image or voxel data. This allows viewing of the data in axial, sagittal, coronal, panoramic, three-dimensional, and soft tissue images (Figure 7-17).

Focal Spot

The clarity of CT scan images is not dependent on the voxel size. Actually, a CBCT unit may have a very small voxel size; however, image quality may be compromised because of a large focal spot. The focal spot is the area of the x-ray tube that emits the x-rays. In general, the smaller the focal spot, the sharper the final image quality. Thus, a larger source or focal spot will result in projections of shadows of the scanned area, which will result in blurring of the object. This penumbra or blurring of the edges creates a shadow with resultant poor image quality and clarity. Current CBCT units have focal spots ranging from 0.15 to 0.7 mm (Figure 7-18)

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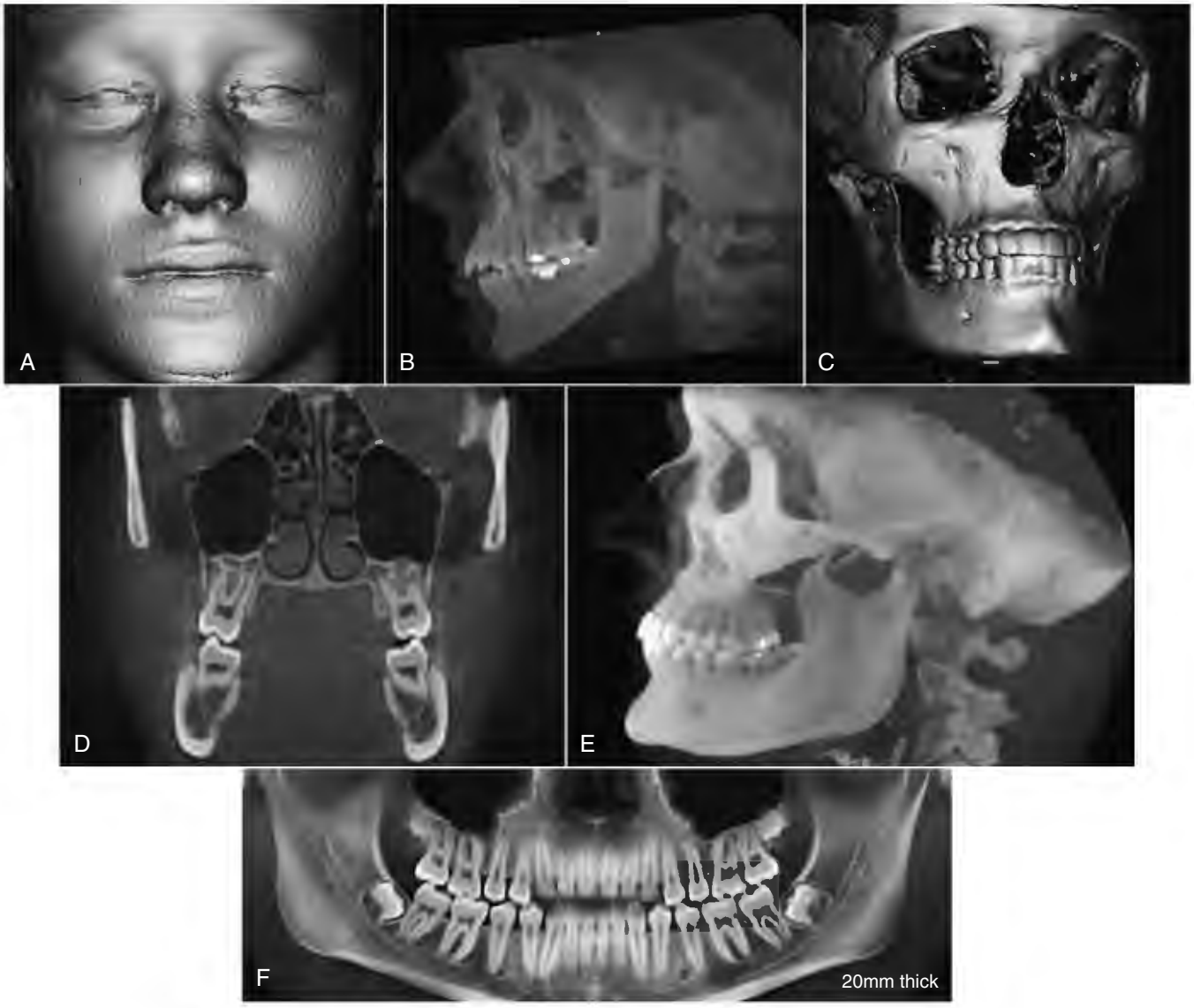


FIGURE 7-17. Cone-beam images (Prexion). **A,** Three-dimensional soft tissue image. **B,** Lateral cephalometric image. **C,** Three-dimensional osseous image. **D,** Coronal image. **E,** Lateral osseous image. **F,** Panoramic image.

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Field of View

Cone-beam computed tomography units vary on the area of interest or what is commonly termed the *field of view* in radiology. The FOV describes the scan volume, which is dependent on many factors including the detector size and shape, beam projection geometry, and beam collimation. Beam collimation is paramount in decreasing radiation exposure to the patient and ensuring only the area of interest to be radiated. Usually, smaller scan volumes produce higher resolution images. Currently, CBCT units are classified as small, mid, or large FOVs (Figure 7-19).

Effective Dose Range of Cone-Beam Computed Tomography Scanners. Because of the increasing number of CBCT units being developed and released on the market, it is very difficult to generalize radiation dose of CBCT. These units exhibit a wide variation of exposure parameters such as x-ray spectrum (voltage peak and filtration), x-ray exposure (mA and number of projections), and FOV. Thus, the range of units and imaging protocols will result in different absorbed radiation doses.

To determine radiation risk for the patients, the effective dose measured in microsieverts is still the most accepted. A number of studies have measured the effective dose on dental CBCT units using thermoluminescent dosimeters (TLDs) with dosimetry phantoms. The phantoms are placed into multiple layers along the axial plane to allow for access to internal anatomy. The TLDs are placed on the radiosensitive area to be tested (i.e., ramus, symphysis, thyroid, salivary glands). The operator may control the FOV, kVp, mA, and scanning times to reduce the effective dose. However, these reductions result in a decreased signal and poorer image quality (Figure 7-20).

Interactive Diagnostic Imaging

One of the most significant advances in CT is ICT or interactive diagnostic imaging, which addresses many of the limitations of

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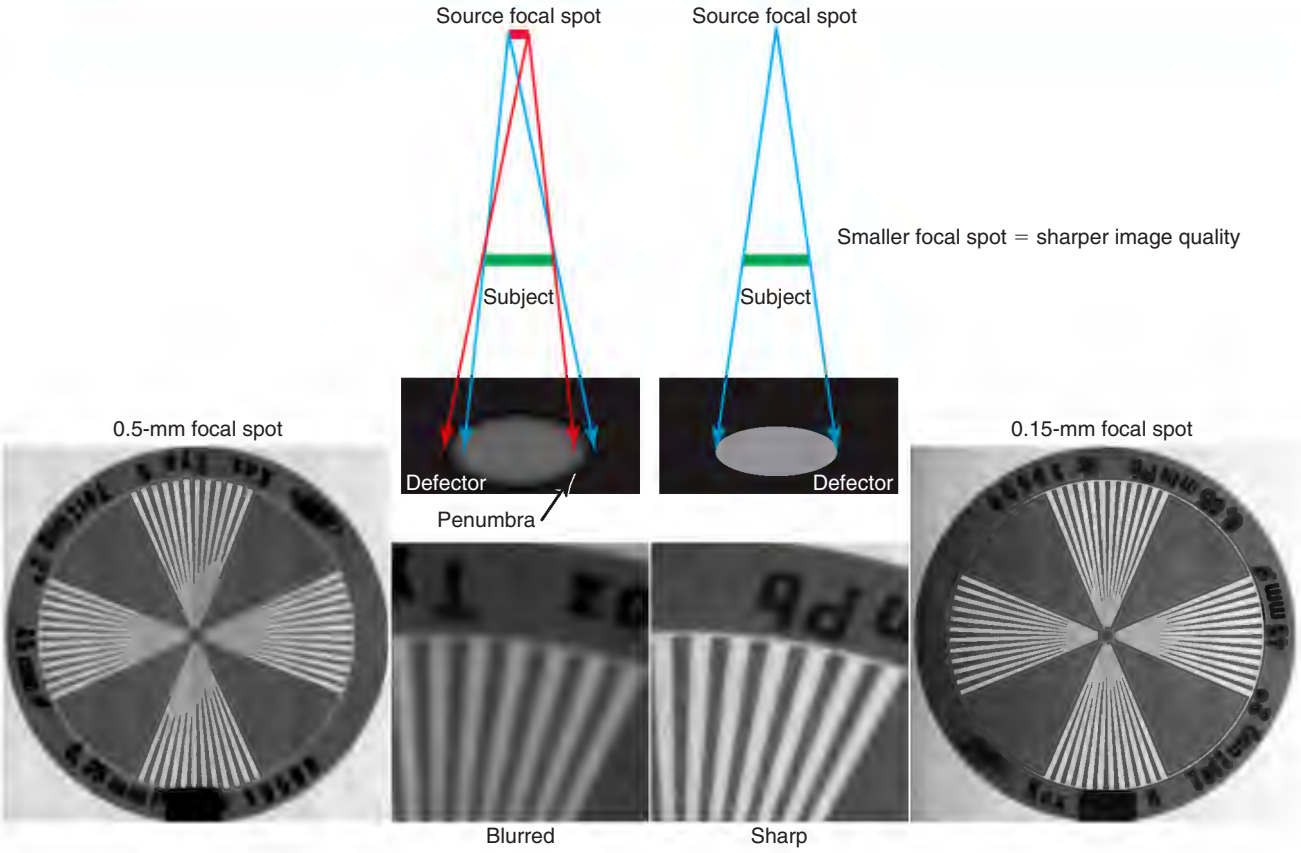


FIGURE 7-18. A smaller focal spot will result in a sharper image.

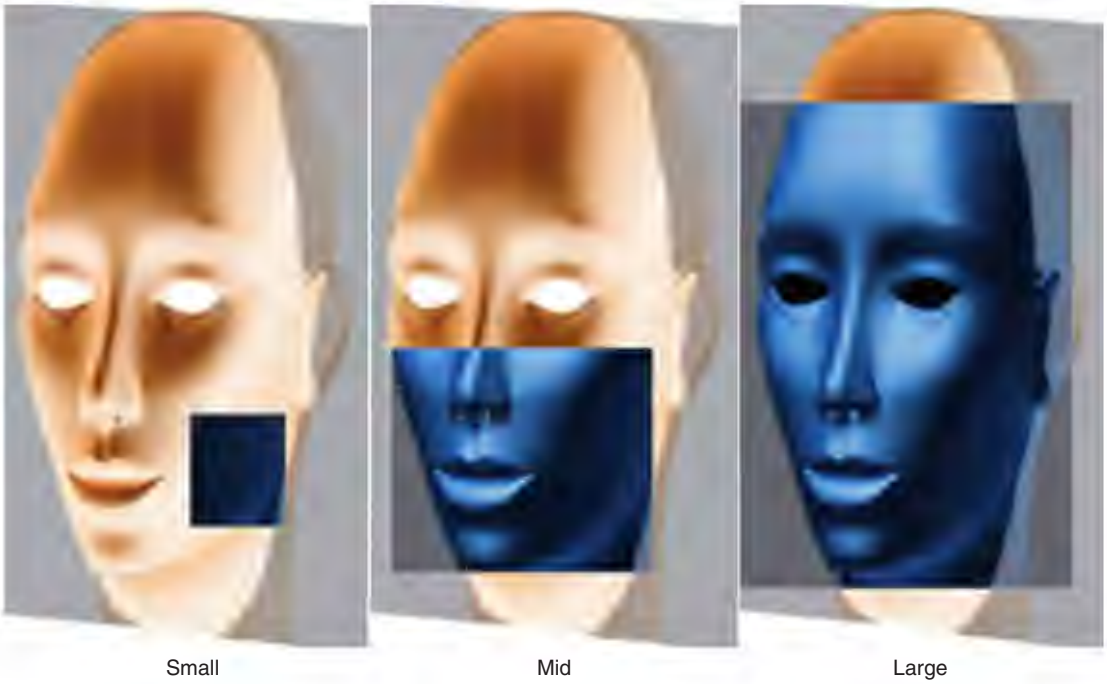


FIGURE 7-19. The field of view of cone-beam computed tomography units: small (**A**), mid (**B**), and large (**C**).

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CT.[57–60] ICT is a technique that was developed to bridge the gap in information transfer from the CT data obtained to its use in the formulation of diagnosis and treatment planning for implant dentistry. Implant dentists are now able to view and interact with the imaging study on a personal computer (Figure 7-21).

Effective dose	12" FOV	9" FOV
NewTom 3G	44.7 μSv	36.9 μSv
i-CAT	134.8 μSv	68.7 μSv
Hitachi	476.6 μSv	288.9 μSv

Panoramic radiograph:	6.3 μSv
Full-mouth intraoral:	150 μSv
Medical CT, both jaws:	2100 μSv
Medical CT, upper jaw:	1400 μSv

*Average natural background radiation (cosmic radiation, radon, etc.) 3000 μSv per year

FIGURE 7-20. The radiation exposure is measured in microsieverts. A comparison of cone-beam computed tomography (CT) exposure is approximately one third of a full-mouth film radiograph. *FOV,* Field of view. (Data from Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB: Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: NewTom 3G and i-CAT, *Dentomaxillofac Radiol* 35:219-226, 2006.)

Image Formation

The CT data are exported to a universal format called DICOM (Digital Image and Communications in Medicine), which was introduced by the American College of Radiology—National. From these files, reformatted images using a part or all the data are generated and displayed in many different views. The standard display consists of planar imaging, which consists of a sequence of slices in different planes such as axial, coronal, sagittal, and cross-sectional. If a panoramic image is desired, the user may select an uninterrupted sequence of voxels along a curve plane in the maxilla or mandible to display a panoramic image in any plane desired. If surface-only voxels are selected, a three-dimensional image is produced.

Preimplant Evaluation: Diagnosis and Treatment Planning

The first part of the preimplant evaluation is the assessment of the edentulous area in question for bone quantity and quality. Most proprietary software available today allows the implant dentist to evaluate the area of interest in multiple reconstructions in many different planes, including cross-section, axial, panoramic, sagittal, and three dimensional (Figure 7-22). From these reconstructions, a series of interactive tools is available, including measurement tools, bone density, angulation (restorative spaces), virtual teeth, and vital structure outlining (inferior alveolar nerve) (Figure 7-23).

Preimplant Evaluation: Site Evaluation with Implants

After the quantity and quality of bone are evaluated, special software programs allow the implant dentist to actively place

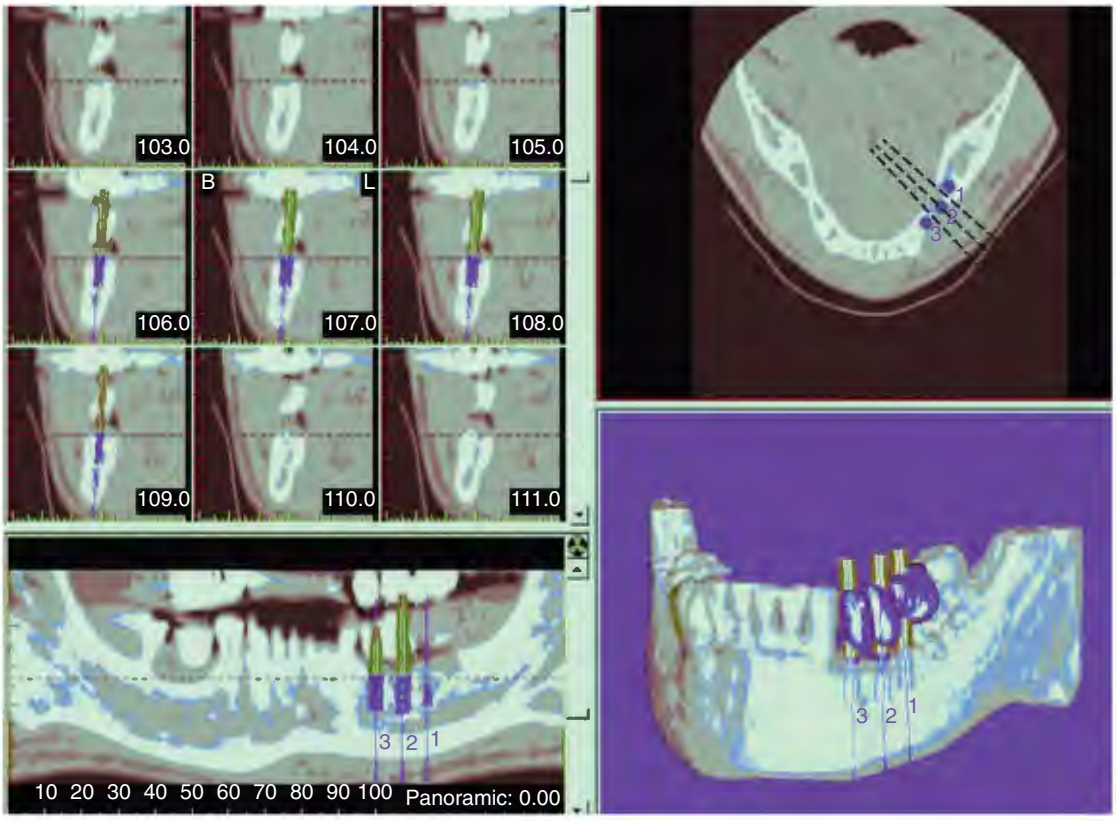


FIGURE 7-21. Reformatted computed tomography scan showing the interactive placement of implants in relation to the diagnostic wax-up fabricated radiopaque template. Note that each position is cross-referenced according to the tick marks.

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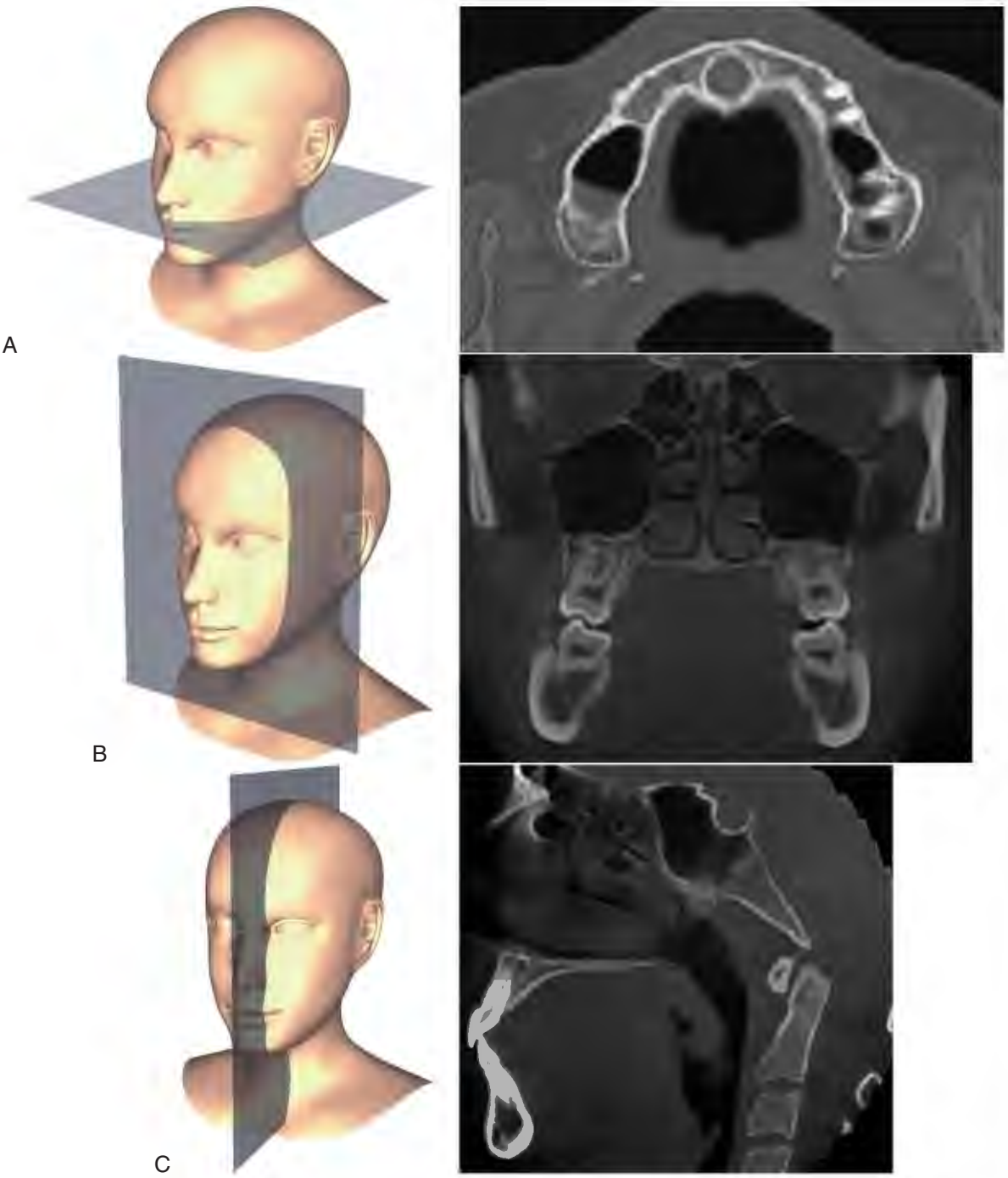


FIGURE 7-22. Cone-beam computed tomography reformatted images. **A,** Axial. **B,** Coronal. **C,** Sagittal.

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FIGURE 7-22, cont'd. **D,** Three dimensional. **E,** Cross-sectional.

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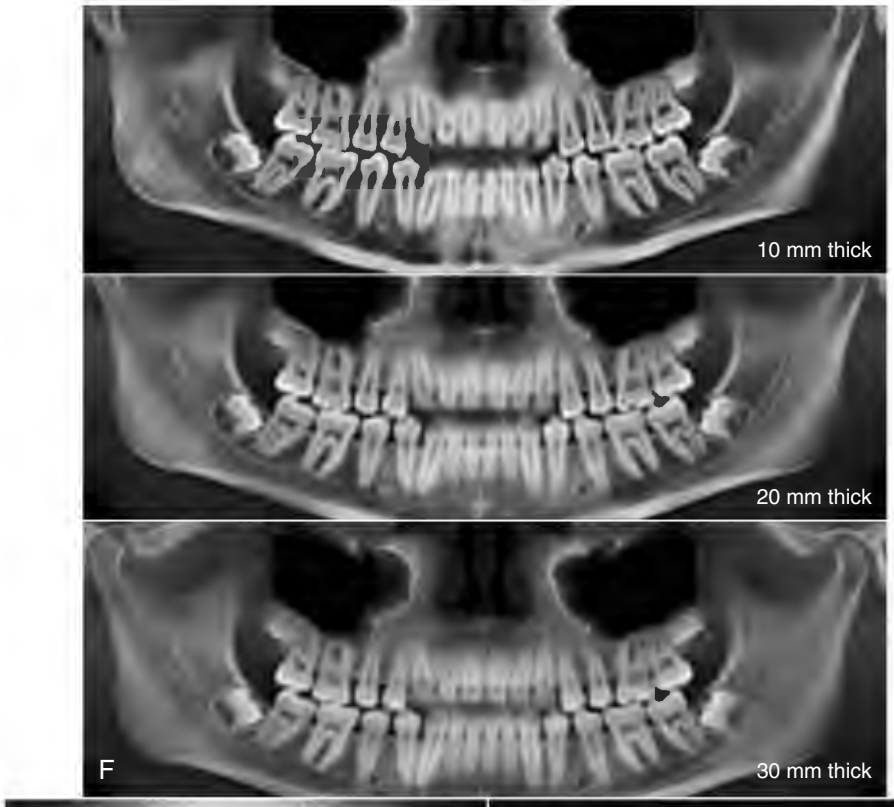




FIGURE 7-22, cont'd. **F,** Panoramic. **G,** Soft tissue.

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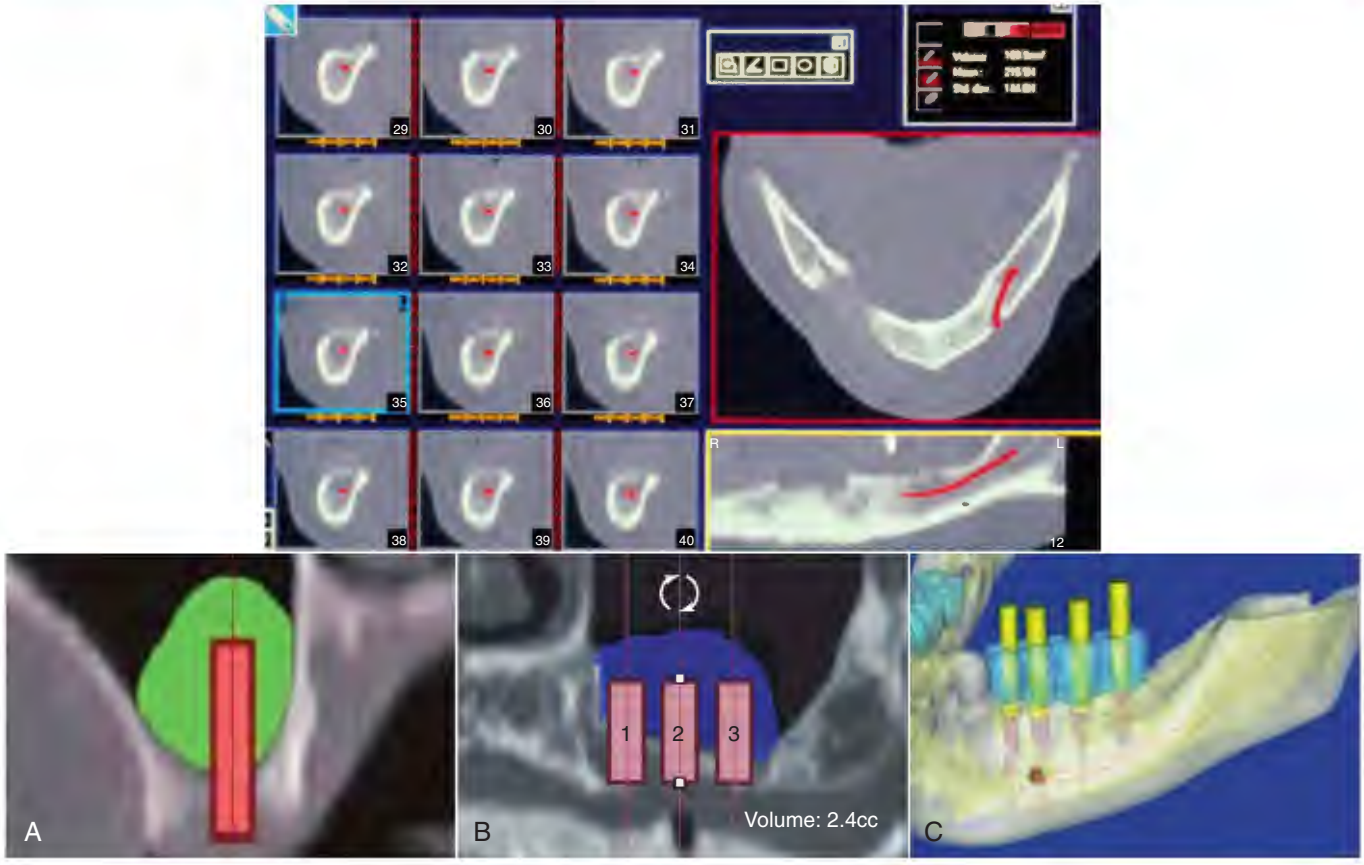


FIGURE 7-23. **A,** The inferior alveolar canal and mental foramen may be drawn, and the position is transferred to various views. **B,** In areas where there is insufficient available bone such as the maxillary sinus, the amount of bone grafting needed may be determined. **C,** Implant placement in relation to the mandibular canal and mental foramen; all images are cross-referenced with each other. Three-dimensional analysis for the evaluation of proximity to vital structures may be generated from the same computed tomography images.

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implants in areas of interest. These special programs allow for the selection of implant brand, type, and dimensions along with prosthetic abutments that are selected from special libraries. These features allow for the placement of multiple implants that are precisely parallel, thus allowing for fabrication of a surgical template to be used for the surgical placement of the implants. If the implant needs to be placed at an angle, the angle can easily be determined and the final abutment selected even before the surgery (Figure 7-24).

Most of the current proprietary software programs use similar restorative and surgical protocols. The first step includes a diagnostic wax-up for positioning for partially edentulous patients. For fully edentulous patients, duplication of their existing prosthesis or fabrication of a new prosthesis is indicated. The implant team then creates an ideal restorative treatment plan, including the placement of the proposed teeth in the ideal esthetic and functional position.

Preimplant Evaluation: Scanning Prosthesis

The first step in the interactive CT process is the impressions for diagnostic casts. For partially edentulous patients, a diagnostic wax-up is completed according to the ideal position of missing teeth in question with emphasis on the final prosthesis. For edentulous patients, duplication of an existing complete denture can be used if no changes are needed for esthetics and function. If changes are indicated, fabrication of new dentures is required. From the diagnostic wax-up or denture, a radiopaque template is fabricated that the patient will wear during the scan. This diagnostic template will allow the transfer of the ideal positioning of the teeth that will be transferred into the radiographic examination[60,61] (Figure 7-25).

The delineation of the positioning of the teeth and contours of the final prosthesis can be integrated into a scanning template with the use of various radiopaque materials. This can be accomplished by way of an acrylic template coated with barium sulfate, gutta-percha markers, or radiopaque denture teeth.[62,63] Caution should be noted that the prosthesis must be completely stable during the scanning process. If there exists any retention issues, denture adhesive should be used because an unstable radiopaque template will transfer incorrect information (Figure 7-26).

Computed tomography uses voxels that are isotropic (equal in all dimensions), and as a result, measurements are completely accurate and considered 1:1; therefore, study models and stereolithographic surgical guides can be fabricated with accuracy. These radiopaque templates may then be modified for use as surgical templates (Figure 7-27).

Preimplant Evaluation: Computer-Assisted Planning Surgical Guides

The need for ideal implant placement is crucial to the functional and esthetic result. To help fulfill this ideal placement, implant

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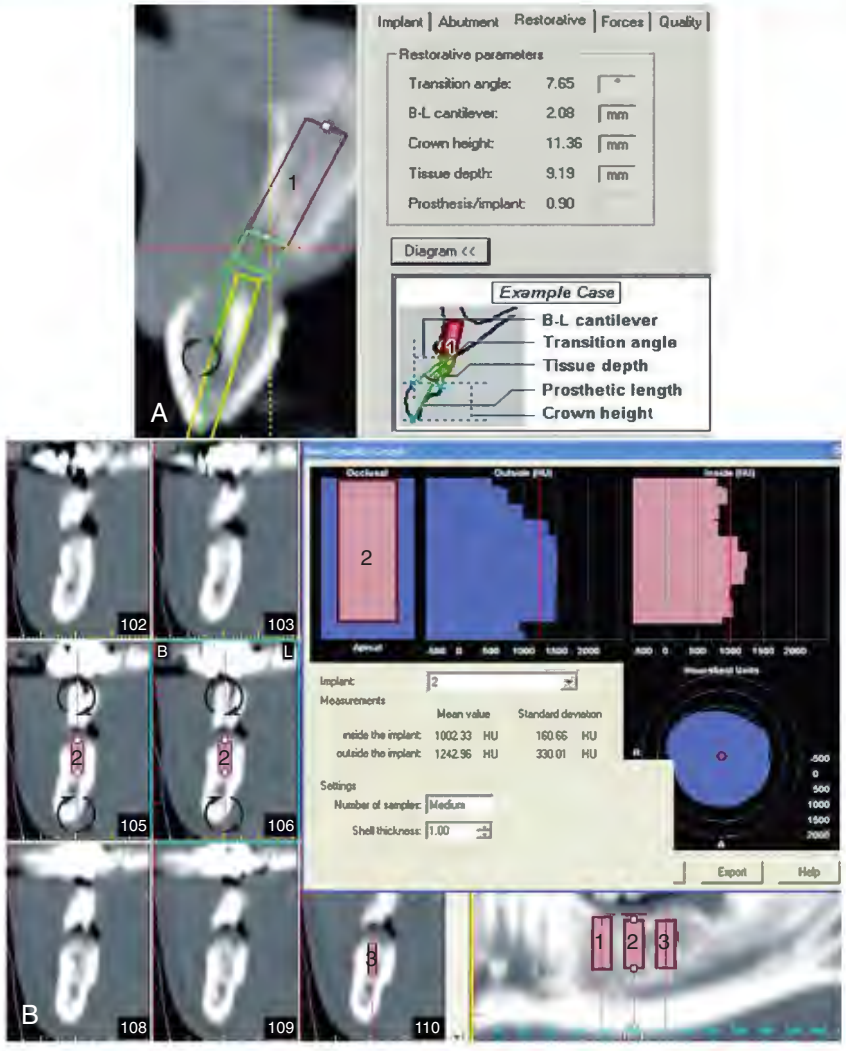


FIGURE 7-24. **A,** Valuable prosthetic information may be obtained from the positioning of the implants on interactive computed tomography. **B,** Determination of bone density values is calculated inside and outside of the implant and can be correlated to various densities of bone.

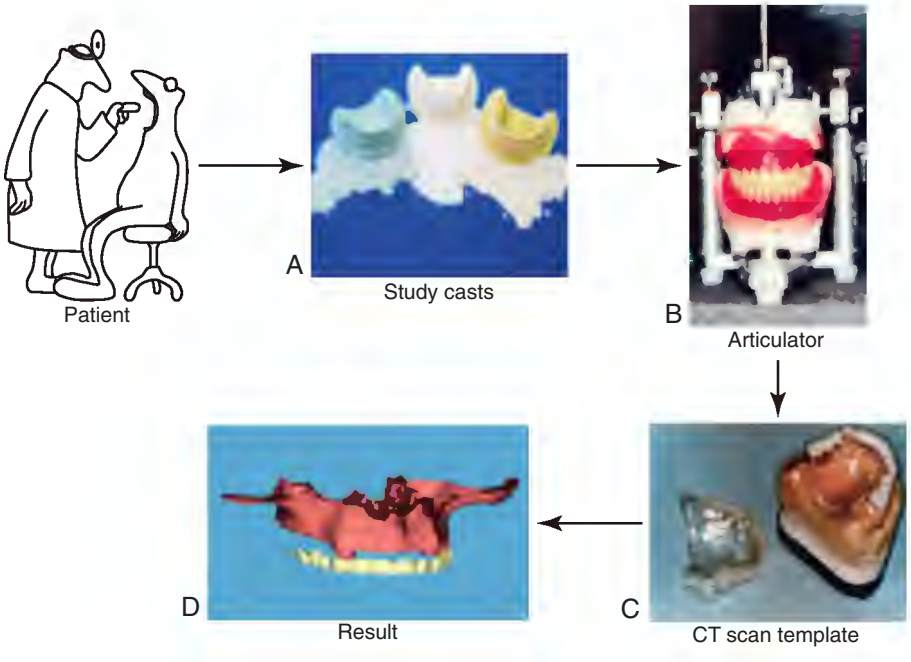


FIGURE 7-25. Prosthetic steps in obtaining a radiopaque template. **A,** Study casts. **B,** Articulated setup. **C,** Laboratory fabrication of a template. **D,** The patient wears the template during a scan. *CT,* Computed tomography.

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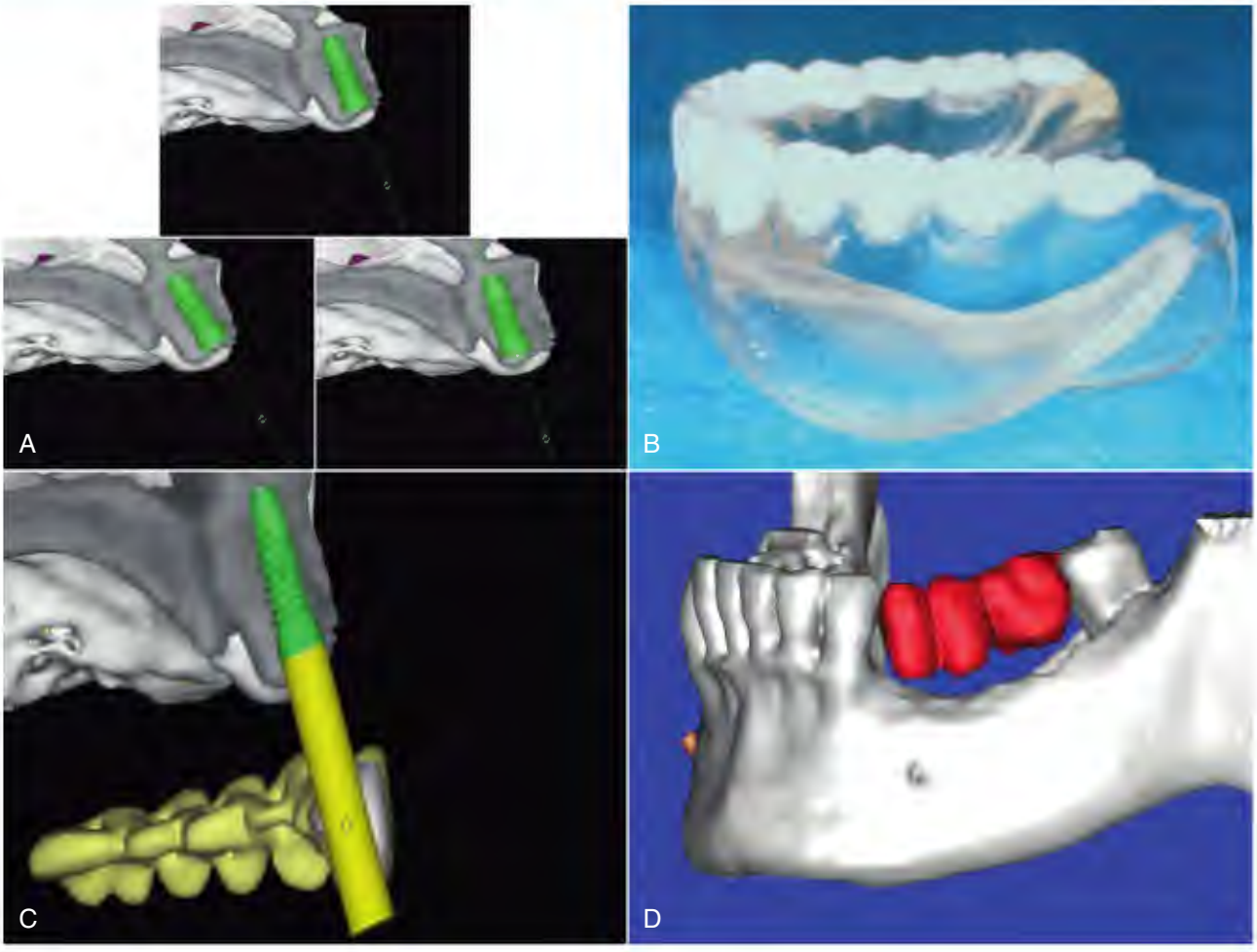


FIGURE 7-26. **A,** Without a radiopaque template, the correct angulation for placement cannot be determined. **B,** With a radiopaque template made from diagnostic casts. **C** and **D,** The reformatted images show the exact location for ideal placement.



FIGURE 7-27. The radiopaque template can be modified to be used as a surgical template.

surgeons sometimes require a surgical guide to be fabricated from the treatment plan on the software programs. These computer-generated drilling guides are fabricated through the process of stereolithography and are used during surgery to replicate the computer-planned procedure. These guides allow for the ability to avoid vital structures (nerves, sinus cavity) and allow for precise placement of the implants. Third-party companies fabricate SurgiGuides (e.g., Materialise NV; Glen Burnie, MD and Virtual Implant Placement [VIP]; BioHorizons Implant System, Birmingham, AL), which are based on the presurgical treatment planning using software for ideal implant positioning. The surgical guides use drilling tubes with successive-diameter surgical osteotomy drill guides, which may be bone, teeth, or mucosa borne. SurgiGuides have metal cylindric tubes that correspond to the number of desired osteotomy preparations and specific drill diameters. The diameter of the drilling tube is usually 0.2 mm larger than the corresponding drill, thus making angle deviation highly unlikely.

Clinical data and studies have shown that these computer-aided stereolithographic surgical guides have shown that implant placement is improved and these guides allow precise translation of a predetermined treatment plan directly to the surgical field[64,65] (Figures 7-28 to 7-30).

Indications for Computed Tomography–Guided Surgical Guides

Surgical guides are very helpful in the precision and accuracy of implant placement. However, each case should be evaluated on its complexity and a cost, time, and benefit determination made by the clinicians on the use of a surgical template. With surgical

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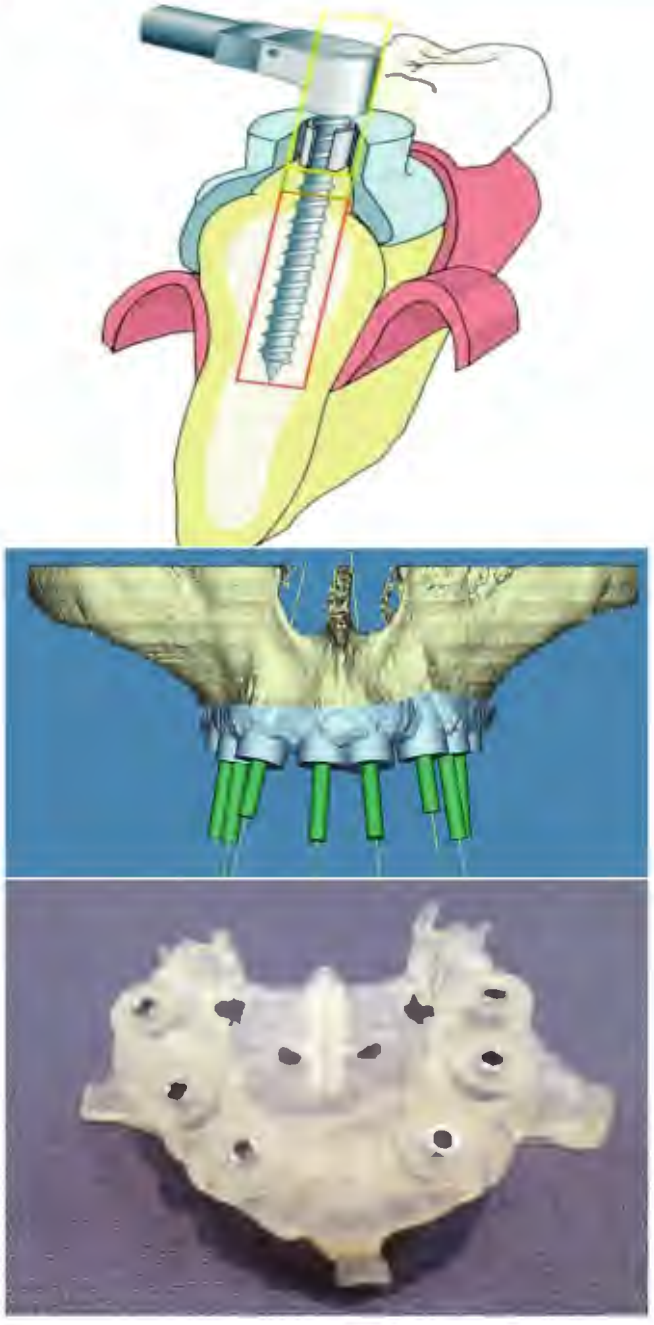


FIGURE 7-28. Bone-supported surgical template.

guides, there exist increased patient and treatment planning time and additional expense along with radiation exposure, which may outweigh the clinical benefits in certain cases. Some of the most common indications include the clinician's early learning curve, proximity to vital anatomic structures, implant position that is crucial to the planned restoration, and multiple implants in an esthetic region.

Immediate Loading Prostheses

The newest technological advancement in CT-guided surgery is the fabrication of a provisional prosthesis that is immediately inserted at the time of surgery. After the virtual treatment plan is created by the implant team, computer-generated stereolithographic surgical guides are fabricated by the manufacturer from the virtual treatment plan. A dental laboratory then uses the fabricated surgical guides and mounted study casts to interim or final prostheses to be inserted after implant placement. Some proprietary software companies have allowed for the fabrication of provisional and final restorations to be completed from the presurgical workup (Figure 7-31).

Computed tomography images are inherently three dimensional. Contiguous CT images describe a three-dimensional structure of voxels. The original imaging computer can create secondary images from almost any perspective by projecting or reformatting the original three-dimensional voxel data. When a secondary computer is used to perform reformatting or image processing of the original CT data, the system is referred to as a *workstation*.

The power and usefulness of CT for maxillofacial imaging and diagnosis were apparent as soon as high-resolution CT was introduced in the early 1980s. CT was used for imaging the temporomandibular joint, evaluating dental bone lesions, assessing maxillofacial deformities, and preoperative and postoperative evaluation of the maxillofacial region.[66] CT provides a unique means of postimaging analysis of proposed surgery or implant sites by reformatting the image data to create tangential and cross-sectional tomographic images of the implant site. With current-generation CT scanners, reformatted images are characterized by a section thickness of 1 pixel (0.25 mm) and an in-plane resolution of 1 pixel by the scan spacing (0.5–1.5 mm), producing a geometric resolution similar to that of planar imaging. The density of structures within the image is absolute and quantitative and can be used to differentiate tissues in the region and characterize bone quality.[10,11,57,58,67–70]

Computed tomography enables the evaluation of proposed implant sites and provides diagnostic information that other imaging or combinations of imaging techniques cannot provide. The utility of CT for dental implant treatment planning[47,71–76] was evident, but the access to these imaging techniques was limited. Access to this diagnostic information required a radiologist to communicate with the referring doctors in detail about prospective surgery and then to sit at the imaging computer or a workstation for a considerable length of time to reformat the study, interpret the resulting images, and produce hard-copy images to send to the referring doctor.

The advantages of this type of imaging were evident and the limitations of delivery clear, which spawned the development of a number of techniques referred to generically as CBVT. CVBT avoids the errors in medical scanners by accumulating data from one 360-degree rotation around the patient's head. The algorithms on CBVT scanners are very predictable because they are void of any "gaps," thus eliminating distortion and magnification. Margins of error for CBVT are less than 0.1 mm. Numerous studies have shown cone-beam technology to be more accurate than conventional medical CT.[77]

Magnetic Resonance Imaging

Magnetic resonance imaging is a CT imaging technique that produces images of thin slices of tissue with excellent spatial resolution. This imaging modality, developed by Lauterbur in 1972,[78] uses a combination of magnetic fields that generate images of tissues in the body without the use of ionizing radiation.[79] MRI allows complete flexibility in the positioning and angulation of image sections and can reproduce multiple slices simultaneously. Digital MR images are characterized by voxels with an in-plane resolution measured in pixels (512 × 512) and millimeters and a section thickness measured in millimeters (2

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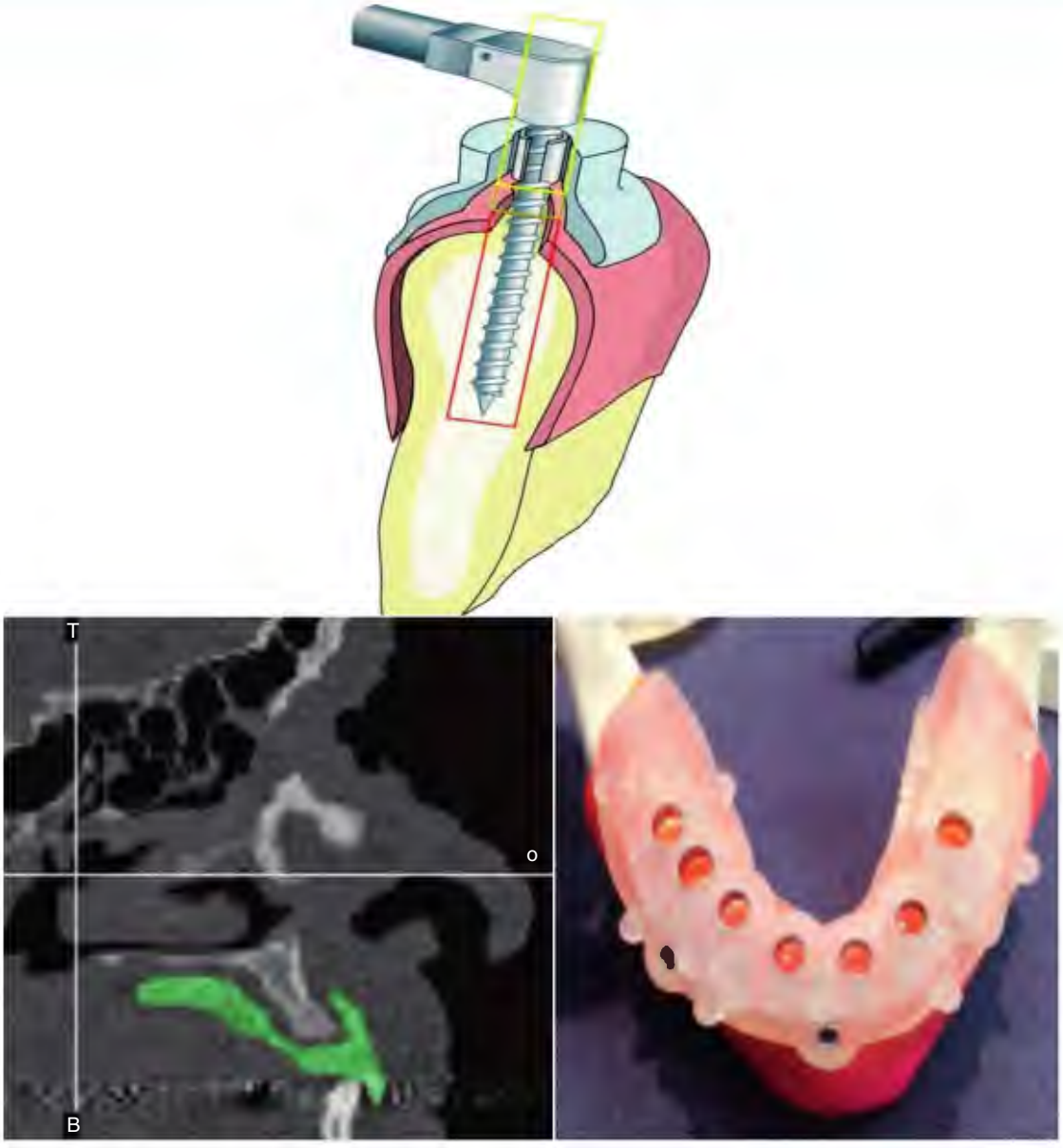


FIGURE 7-29. Soft tissue–supported surgical template.

to 3 mm) for high-resolution imaging acquisitions. The image sequences used to obtain magnetic resonance images can be varied to obtain fat, water, or balanced imaging of the patient's anatomy. The images created by MRI are the result of signals generated by hydrogen protons in water or fat such that cortical bone appears black (radiolucent) or as having no signal. Cancellous bone generates a signal and appears white because it contains fatty marrow. Metal restorations do not produce scattering and thus appear as black images. Therefore, MRI has been shown to be less prone to artifacts from dental restorations, prostheses, and dental implants than CT scans.[80] As with CT, MRI is a quantitatively accurate technique with exact tomographic sections and no distortion.[81]

Numerous authors have suggested the use of MRI for dental implant evaluation and treatment planning.[82,83] Additionally, vital structures are easily viewed, such as the inferior alveolar canal and the maxillary sinus. When the inferior alveolar canal cannot be differentiated by conventional or CT, MRI would be a viable alternative because the trabecular bone is easily differentiated with the inferior alveolar canal. In cases of nerve impairment or infection (osteomyelitis), MRI may be used because of added advantages, including differentiation of soft tissue with respect to CT. Studies have shown that the geometric accuracy of the mandibular nerve with MRI is comparable to CT and is an accurate imaging method for dental implant treatment planning.[84]

Magnetic resonance imaging may be used in implant imaging as a secondary imaging technique when primary imaging techniques such as complex tomography, CT, or ICT fail (Box 7-10).[83,85] Complex tomography fails to differentiate the inferior alveolar canal in 60% of implant cases, and CT fails to differentiate the inferior alveolar canal in about 2% of implant cases. Failure to differentiate the inferior alveolar canal may be caused by osteoporotic trabecular bone and poorly corticated inferior alveolar canal. MRI visualizes the fat in trabecular bone and differentiates the inferior alveolar canal and neurovascular

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FIGURE 7-30. Teeth-supported surgical template.

BOX 7-10 Recommended Imaging for Implant Treatment Planning

1. Division A: available bone with no approximate vital structures
   Panoramic radiograph
   Supplemental periapical radiographs if needed
2. Division A: available bone with approximate vital structures
3. Division B: available bone
4. Division C: available bone
5. Division D: available bone (allografts, autographs, sinus grafts)
   Panoramic radiograph
   Conventional or computed tomography
   Supplemental periapical radiographs
6. Division A, B, C, D: available bone in which computed tomography does not clearly distinguish exact location of mandibular canal or mental foramen
7. Infection (osteomyelitis)
   Magnetic resonance imaging

BOX 7-11 Magnetic Resonance Imaging

Advantages
- No radiation
- Vital structures are easily seen (inferior alveolar canal, maxillary sinus)

Limitations
- Cost
- Technique sensitive
- No reformatting software
- Availability
- Nonsignal for cortical bone

Uses
- Evaluation of vital structures when computed tomography is not conclusive
- Evaluation of infection (osteomyelitis)

bundle from the adjacent trabecular bone. Double-scout MRI protocols[81] with volume and oriented cross-sectional imaging of the mandible produce orthogonal quantitative contiguous images of the proposed implant sites. Oriented MRI of the posterior mandible is dimensionally quantitative and enables spatial differentiation between critical structures and the proposed implant site. However, there exist numerous disadvantages for the use of MRI for implant dentistry. MRI is not useful in characterizing bone mineralization or as a high-yield technique for identifying bone or dental disease. No commercially available reformatting programs are available to use as reference points. Additional disadvantages are listed in Box 7-11.

Radiographic Imaging of Vital Structures in Oral Implantology

Mental Foramen and Mandibular Canal

When evaluating the posterior mandible for implants, the position of the mandibular canal and mental foramen must be identified to avoid trauma to the inferior alveolar nerve. In implant dentistry, two-dimensional radiographs such as periapical and panoramic images are still used routinely as the sole determinate of osseous measurements with respect to these vital structures. However, these imaging views have numerous disadvantages with the lack of buccolingual identification as the most significant. When evaluating distances around these anatomical structures with two-dimensional radiographs, positioning has a significant impact on the intraoral imaging of vital structures.[86] Because of the curvature of the mandible, great care must be

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FIGURE 7-31. Immediate smile technique.

given to the angulation of the x-ray beam for intraoral radiography. The x-ray beam must be perpendicular to the tangent of the area in question between the foramen and the most anterior tooth. If the image is taken from a mesio-oblique orientation, measurements will be foreshortened, and if the orientation is from a distal-oblique, measurements will appear to be elongated (Figure 7-32).

When evaluating the correct position of the mental foramen using two-dimensional radiographs, care must be taken to evaluate the position of the actual foramen. Studies have shown that on some two-dimensional radiographs, there exists lack of identification because of too large of a radiographic density.[44] This study states that mental foramina are easily seen on light radiographs; however, as the density increases above 2.8, the foramina area becomes less apparent. Other studies show lack of identification because of a lack of cortical bone around the mandibular canal. When evaluating the mental foramen on periapical radiographs, studies have shown that on 50% of periapical radiographs, the mental foramen is not visible.[87] Many studies including dry skull evaluations conclude that the mental foramen is absent in approximately 12% of panoramic radiographs.[44]

In summary, the location of the mental foramen on periapical and panoramic radiographs is inaccurate. It has been shown that even though the mental foramen can be seen on Panorex more consistently than periapical radiographs, the radiograph position of this structure is dependent on the mandibular positioning in the panoramic unit. Additionally, the radiograph landmark depicted on these panoramic radiographs as the mental foramen is not the true foramen but instead represents

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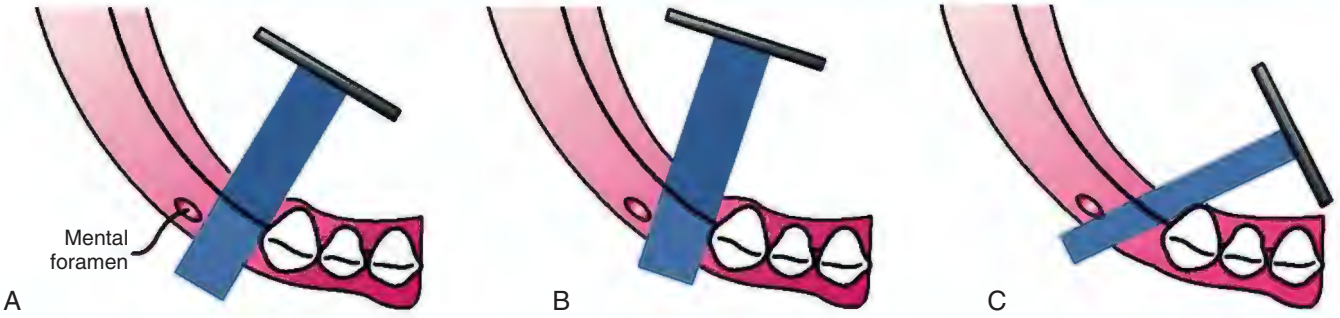


FIGURE 7-32. To have an accurate measurement between a tooth and a vital structure (mental foramen), a correct horizontal angulation of the x-ray beam is essential. Correct (**A**) and improper positioning (**B**) result in too large of a distance, and improper positioning (**C**) results in too small of a distance.

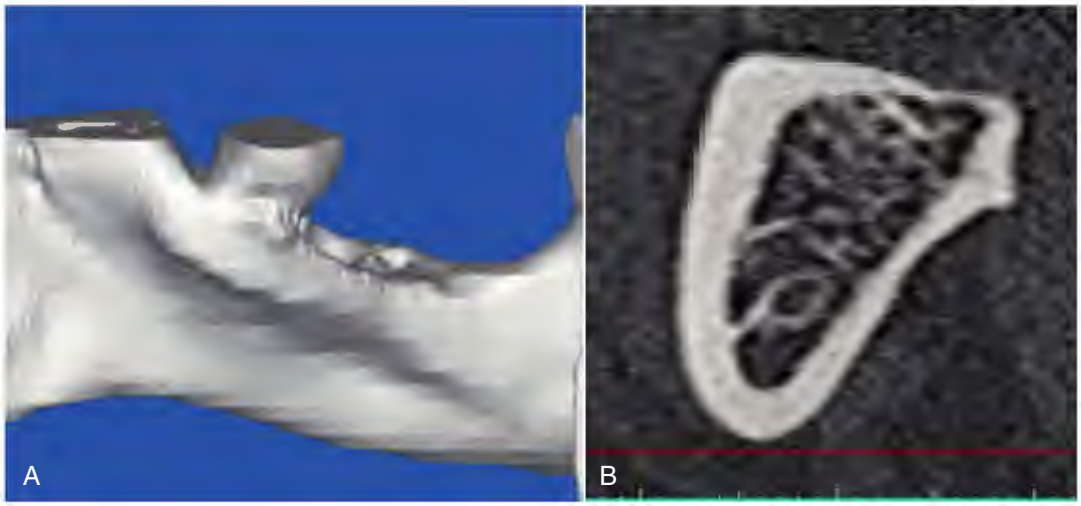


FIGURE 7-33. **A** and **B,** Images depicting sublingual undercuts.

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a portion of the mental canal as it leaves the mandibular canal. In edentulous mandibles, the risk of error increases considerably where there is increased resorption of the alveolar crest.

Numerous studies have shown that the most accurate means of identification is with CT. The most accurate means of viewing the mandibular canal and mental foramen is with three-dimensional radiography. These images may be altered in contrast, brightness, and gray scale to help depict these structures. Therefore, CT has been shown to be the most accurate and is highly recommended when exact location and measurements are needed for the inferior alveolar canal and mental foramen.[14,76,80]

When the inferior alveolar canal or mental foramen is not seen on a radiograph, usually superimposition of structures on the contralateral side or lack of cortical bone around the canal is the cause.[88] Studies have shown that in cases in which the canal or foramen cannot be seen, tilting the patient's head approximately 5 degrees downward in reference to the Frankfort horizontal plane allows these anatomical structures to be seen in 91% of radiographs.[89]

Mandibular Lingual Concavities

When relying on two-dimensional radiographs for evaluation of the amount of bone for implant placement, significant complications may occur because of overestimation of bone. When advanced atrophy in the posterior mandible is present, lingual concavities may be present (Figure 7-33). Even though adequate bone exists on two-dimensional radiographs, this may be misleading. A study by Quirynen et al.[90] showed a 2.4% prevalence of concavities with average depths of 6 mm (±2.6 mm). Within these concavities or submandibular gland fossa, branches of the facial artery may be present. Overestimation of the amount of bone may lead to perforation of the lingual plate when drilling the osteotomy. This may result in lingual bleeding problems that may even be life threatening.[91–94] When assessment of the posterior mandible is needed, cross-sectional tomography is recommended.

Mandibular Ramus (Donor Site for Autogenous Grafting)

The mandibular ramus area has become a very popular donor site for autogenous onlay bone grafting. This area of the mandibular jaw is extremely variable in the amount of bone present. Standard radiographs for preassessment include panoramic images in which the location of the external oblique and the mandibular canal should be noted. However, two-dimensional evaluation of this area can be very difficult to use for adequate assessment of the amount of host bone present. A more accurate representation is the use of tomography, preferably CT. Accurate measurements may be made along with the use of

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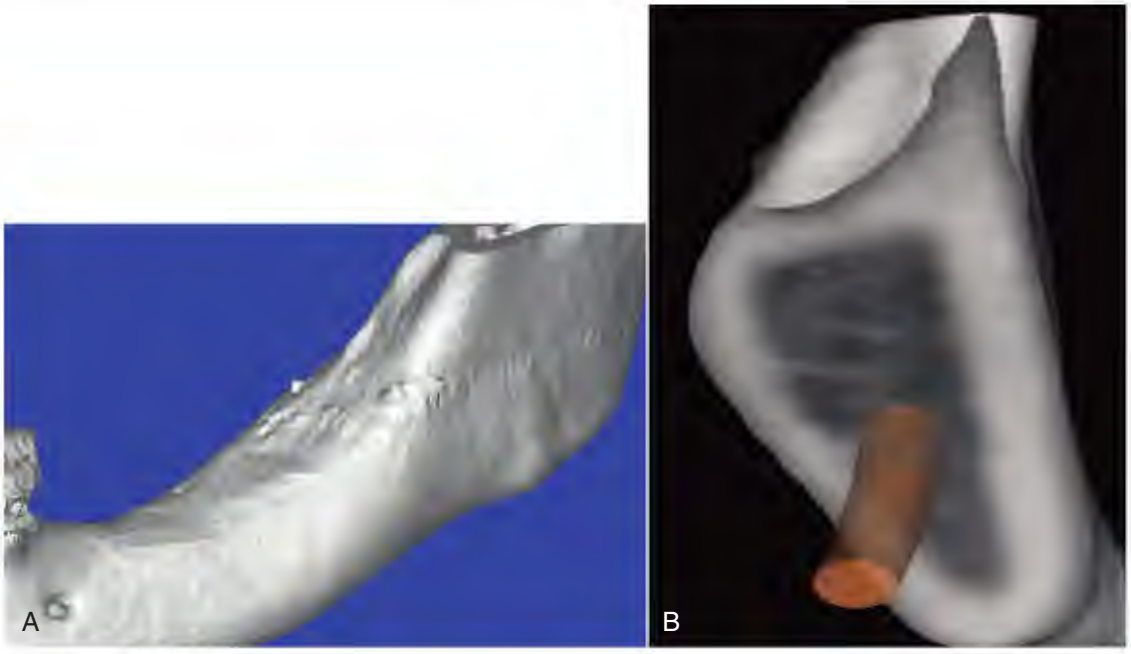


FIGURE 7-34. The more prominent the external oblique ridge, the better candidate for the ramus as a donor site. This can be best illustrated on a three-dimensional reformatted computed tomography image allowing 360-degree evaluation of the ramus area.

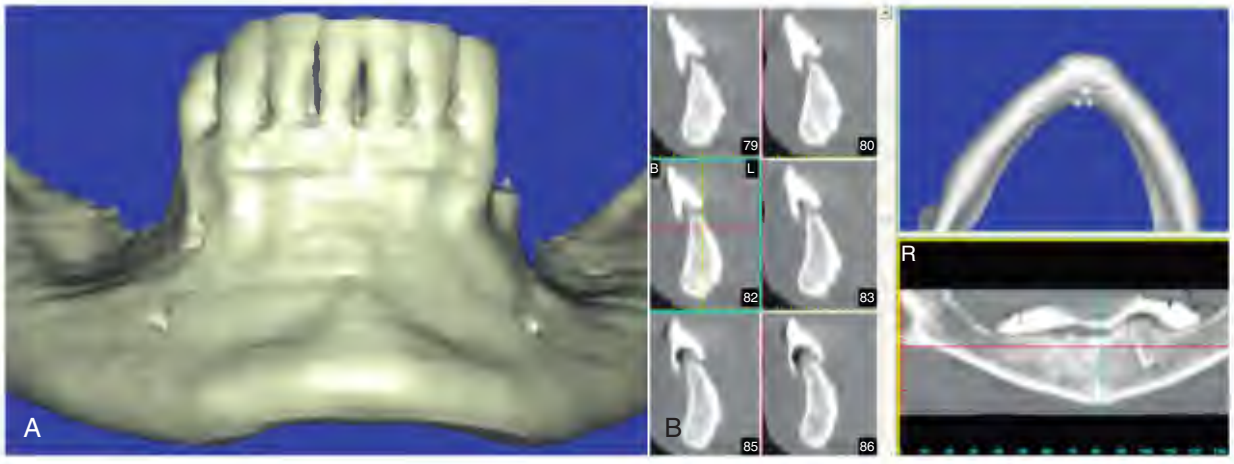


FIGURE 7-35. Mandibular symphysis. **A,** Computed tomography images illustrate various views of the mandibular anterior region. **B,** A lateral cephalometric image yields only midline osseous information.

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three-dimensional bone models depicting the exact anatomy present (Figure 7-34).

Mandibular Symphysis

The mandibular symphysis area is a very critical anatomical area for oral implantology. Not only is this region a common position for implants in mandibular edentulous patients, but it is also used as a donor site for autogenous grafting. When two-dimensional images are used, inherent errors may occur because of lingual concavities. It is common to overestimate the height of available bone in the anterior region on panoramic radiographs. For this reason, an imaging technique that will depict the true buccolingual amount of bone is recommended. Radiographs including lateral cephalometric and conventional CT may be used (Figure 7-35).

Maxillary Sinus

Today, no radiographic modality gives more information of the paranasal sinuses than CT, which is the gold standard for viewing the osseous structures and evaluating pathology in the sinuses. This type of radiography provides much more detailed information regarding prevalence and position of septa,[95] maxillary sinus anatomy, and detection of sinus pathology in comparison with plain film imaging (Figures 7-36 and 7-37).

Recommended Presurgical Treatment Planning

In the past, panoramic radiology was the gold standard for dental implant treatment planning. Along with periapical radiographs, these imaging techniques have many shortcomings that

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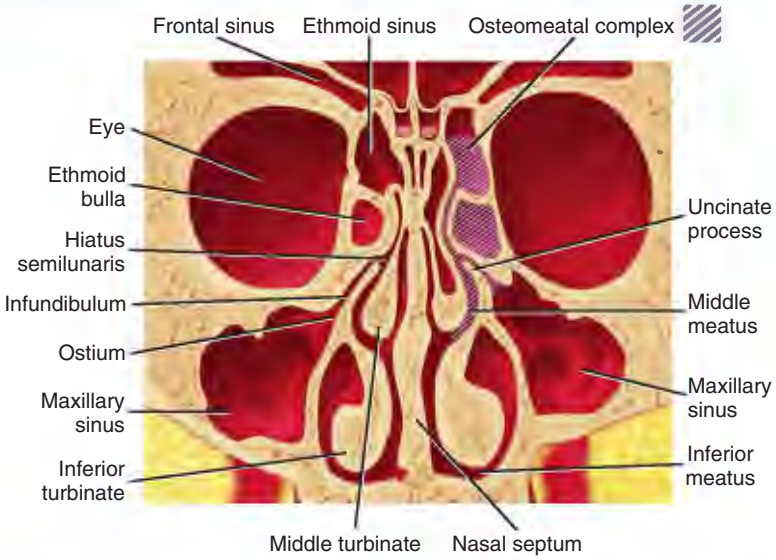


FIGURE 7-36. Maxillary sinus, normal anatomy.

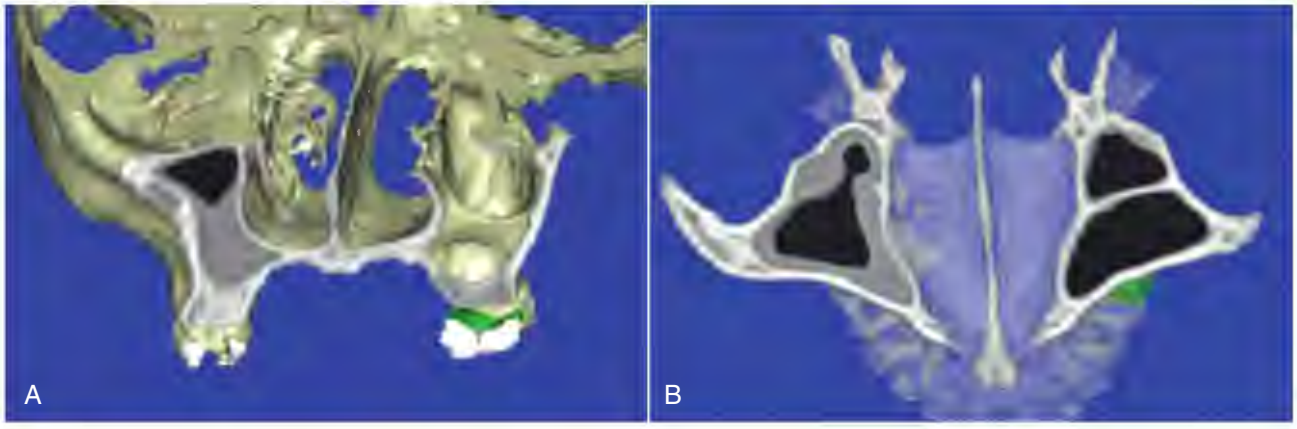


FIGURE 7-37. The left maxillary sinus has thickened mucosa and is a contraindication for a sinus graft without resolution of the sinus pathology. The right maxillary sinus has an unusual septum in the mid region.

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have previously been discussed. The most significant drawback to these radiographs is that they are two dimensional. For more complex cases or when accurate representation and location of vital structures is needed, CT should be integrated into the pretreatment imaging process.

With CT technology and interactive software, treatment planning has become a very accurate modality for dental implant surgery. Because optimal placement of dental implants can be challenging, special interactive software along with computer-generated templates have been developed to assist implant surgeons in accurate positioning. From this information and evaluation of all imaging modalities available in implant dentistry, pretreatment imaging evaluation is recommended, as illustrated in Box 7-10.

Computed Tomography

Two-dimensional radiographs (periapical, panoramic) have limitations in that they give no buccolingual information about the present condition of alveolar bone. CT does allow three-dimensional information about the osseous status around an implant. Resolution and scattering have always been problems in evaluation of implants; however, with the advent of cone-beam technology, this is greatly improved.

Computed tomography can be of great benefit in the evaluation of sinus augmentation graft prognosis. With the advantage of bone density evaluation using Hounsfield units, important information on bone maturation may be determined. Also, this radiographic modality is the image of choice for evaluation of sinus infection or postsurgical sinusitis complications (Figure 7-38).

Fabrication of Diagnostic Templates

The purpose of diagnostic radiographic templates is to incorporate the patient's proposed treatment plan into the radiographic examination.[60–63] This practice requires the development of a tentative treatment plan before the imaging procedure. Ideally, mounted diagnostic casts, a diagnostic wax-up, agreement between the practitioners on the number and location of proposed dental implants, and prior authorization of the proposed treatment by the patient make the diagnostic template a useful tool and many times the determining factor in the final treatment plan of the patient. The preprosthetic imaging procedure enables evaluation of the proposed implant site at the ideal position and orientation identified by radiographic markers incorporated into the template.

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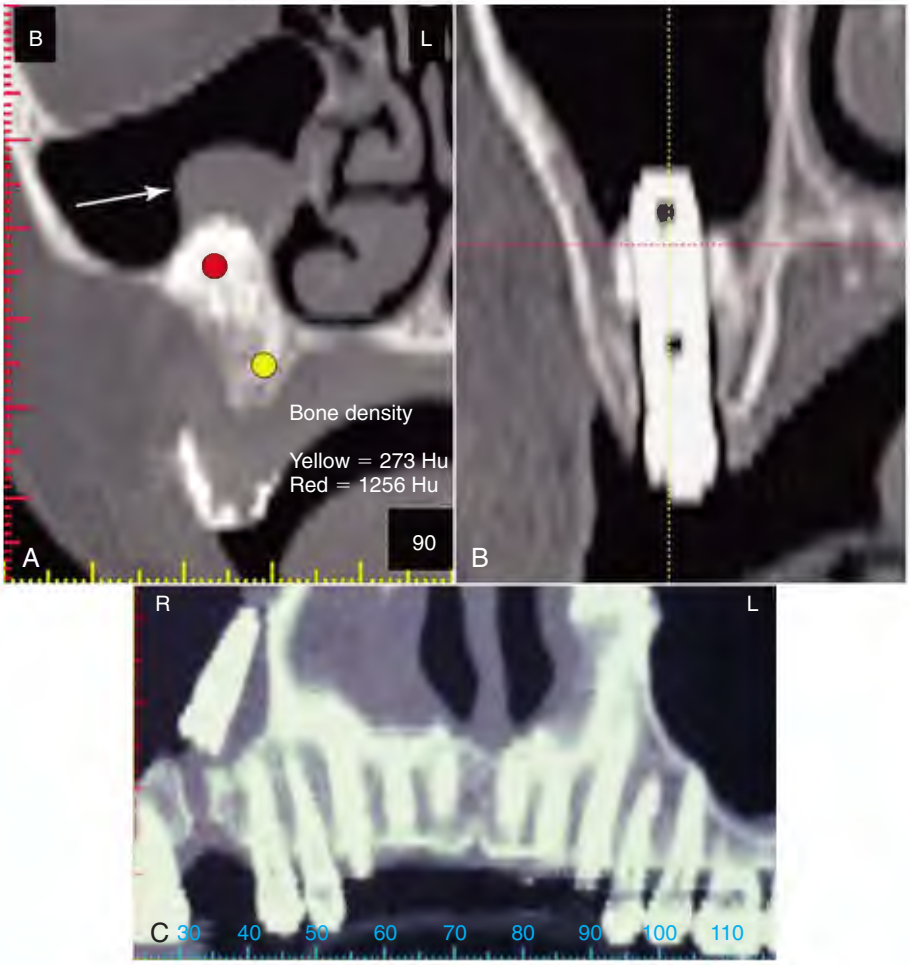


FIGURE 7-38. **A,** Post–sinus graft computed tomography (CT) scan showing differences in bone density of graft material (red = 1256 Hounsfield units; yellow = 273 Hounsfield units) and illustrating a post–sinus graft cyst blocking the ostium. **B,** CT image of failing implant with a lack of bone at implant interface. **C,** CT image of implant migration in the maxillary sinus.

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Computed Tomography

The precision of CT enables use of a complex and precise diagnostic template. Although CT can identify the available bone height and width accurately for a dental implant at a proposed implant site, the exact position and orientation of the implant, which many times determine the actual length and diameter of the implant, often are dictated by the prosthesis. As such, a diagnostic template used during imaging is most beneficial. The surfaces of the proposed restorations and the exact position and orientation of each dental implant should be incorporated into the diagnostic CT template. Designs for diagnostic CT templates have evolved from a simple VacuForm reproduction of the wax-up to one produced from a processed acrylic reproduction of the diagnostic wax-up and to more sophisticated types fabricated with specifically designed radiopaque denture teeth.[62,63] The processed acrylic template may be modified by coating the proposed restorations with a thin film of barium sulfate and filling a hole drilled through the occlusal surface of the restoration with gutta-percha. The surfaces of the proposed restoration then become radiopaque in the CT examination, and the position and orientation of the proposed implant may be identified by the radiopaque plug of gutta-percha within the proposed restoration.

The VacuForm template has a number of variations. Another design involves coating the proposed restorations with a thin film of barium sulfate. Although the proposed restoration becomes evident in the CT examination, the ideal position and orientation of the proposed implant are not identified by this design. Another design involves filling the proposed restoration sites in the VacuForm of the diagnostic wax-up with a blend of 10% barium sulfate and 90% cold-cure acrylic. This results in a radiopaque tooth appearance of the proposed restorations in the CT examination, which matches the density of enamel and dentin of natural teeth but does not identify the exact position and orientation of the proposed implant sites. The next design modifies the previous design by drilling a 2-mm hole through the occlusal surface of the proposed restoration at the ideal position and orientation of the proposed implant site with a twist drill. This procedure results in a natural tooth–like appearance to the proposed restoration in the CT examination in which all the surfaces of the restoration are evident along with a 2-mm radiolucent channel through the restoration, which precisely identifies the position and orientation of the proposed implant.[62]

Recently, radiopaque teeth specifically designed for the fabrication of diagnostic templates for fixed and removable implant-supported restorations have been introduced. The radiopaque material (barium sulfate) is an integral component of the CT scan tooth (66%–67%) The advantages of prefabricated teeth are that they are time saving, are placed easily, provide consistently high radiopacity, have molds corresponding to prosthetic teeth used in the final restoration, and are bonded easily with the template-based material. The diagnostic template then can be modified into a surgical template.[74]

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Implant Imaging in Perspective

The purpose of implant imaging is to assist the implant team in restoring the patient's occlusion and function by providing accurate and reliable diagnostic information on the patient's anatomy at the proposed implant sites. The use of CT, especially with the rapid emergence of CBCT, has changed the treatment planning and diagnostic procedures available to implant clinicians. CBCT provides reliable and accurate images that allow for three-dimensional visualization of the maxillofacial regions. With the progressive nature of this technology, future enhancements will surely reduce scan times and radiation exposure along with improving resolution. This technology has provided clinicians with a modality extending maxillofacial imaging from diagnosis to guidance of prosthetic and surgical procedures.

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CHAPTER 8

Stress Treatment Theorem for Implant Dentistry: The Key to Implant Treatment Plans

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Dentistry is a unique aspect of medicine, blending science and art form. Some aspects of the dental field emphasize the art form, as in dental esthetics, which deals with tooth color and shape to enhance a patient's smile and overall appearance. In partially or completely edentulous patients, dental prostheses are responsible for dental esthetics (Figures 8-1 to 8-3). However, dental laboratory technicians are largely responsible for the final esthetic result, and they do not have the title of doctor. The primary reason the term *doctor* is applied to the dental profession is not a result of the art form; it is because of the dental sciences.

The dental sciences may be separated into a biological component and a biomechanical component. For dentists in general, the biological aspects of oral health are emphasized in our education. This makes sense because the most common complications related to the natural dentition are primarily of biological origins, with periodontal diseases, caries, and endodontic problems as examples.[1–3] In fact, the doctorate we receive in dentistry is really a doctorate of biological sciences.

A combination of biological and biomechanical factors is responsible for the failure of tooth-supported fixed prostheses. For example, the four most common complications for three-unit fixed prostheses are (1) caries, (2) endodontic problems, (3) an unretained prosthesis, and (4) porcelain fracture.[4,5] The biological complications occur with greater frequency (11%–22%) compared with the biomechanical (7%–10%), but both aspects should be understood by clinicians. Yet most often as dentists, we have few lectures on the biomechanics of dentistry, with the exception of orthodontics related to tooth movement.

Implant dentistry primarily involves the replacement of teeth. When implant complications are reported, the vast majority of problems are related to the implant sciences.[6] But unlike natural teeth, the biological aspects of implant dentistry have



FIGURE 8-1. The art form of dentistry is used to fabricate a prosthesis that appears as natural teeth.



FIGURE 8-2. Many guidelines to restore a partial or complete edentulous patient are similar, whether the prosthesis is made on natural teeth or dental implants.



FIGURE 8-3. One goal for the edentulous patient is to provide a restoration that appears as natural teeth. This requires a skilled laboratory technician because the soft tissue drape is often replaced in addition to the teeth.

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fewer complications. For example, the development of a direct bone–implant interface is very predictable and largely biological. Most recent reports indicate the surgical phase of implants form a successful interface more than 95% of the time regardless of the implant system used.[7–10] However, biomechanical-related problems may affect more than 30% of the implant restorations.[6]

Natural Tooth versus Implant Support Systems

Compared with an implant, the support system of a natural tooth is better designed to reduce the biomechanical forces distributed to the tooth and restoration and the crestal bone region. The periodontal membrane, biomechanical design, nerve and blood vessel complex, occlusal material, and surrounding type of bone blend to decrease the risk of occlusal overload to the tooth system[11] (Table 8-1).

Periodontal Complex versus Direct Bone Interface

The presence of a periodontal membrane around natural teeth significantly reduces the amount of stress transmitted to the bone, especially at the crestal region.[12] The displacement of the periodontal membrane dissipates the energy to the fibrous tissue interface (periodontal ligament) surrounding natural teeth and acts as a viscoelastic shock absorber, serving to decrease the magnitude of stress to the bone at the crest and to extend the time during which the load is dissipated (thereby decreasing the impulse of the force).[13] The force transmission is so efficient and within ideal strain conditions for bone that a thin layer of cortical-like bone (cribriform plate) forms around the tooth. When the tooth is lost, the cortical plate lining disappears, demonstrating this is not an anatomic structure but is a result of an ideal strain interface to the bone.

Compared with a tooth, the direct bone interface with an implant is not as resilient. No cortical lining is present around the implant, which indicates that the forces are not dissipated ideally around the interface. Instead, the energy imparted by an occlusal force is not dissipated away from the crestal region but rather transmits a higher intensity force to the crestal contiguous bone interface.

The mobility of a natural tooth can increase with occlusal trauma. This movement dissipates stresses and strains otherwise imposed on the adjacent bone interface or the prosthetic components. After the occlusal trauma is eliminated, the tooth can return to its original condition with respect to the magnitude of movement.[14] Mobility of an implant also can develop under occlusal trauma. However, after the offending element is eliminated, an implant does not return to its original rigid condition. Instead, its health is compromised, and failure of the entire implant system is usually imminent.

A lateral force on a natural tooth is dissipated rapidly away from the crest of bone toward the apex of the tooth. The healthy, natural tooth moves almost immediately 56 to 108 microns (primary tooth movement) and pivots two thirds down toward the tapered apex with a lateral load[13,15] (Figure 8-4). This action minimizes crestal loads to the bone. An implant does not exhibit a primary immediate movement with a lateral load. Instead, a more delayed movement of 10 to 50 microns occurs, which is related to the viscoelastic bone movement[16] (Figure 8-5). In addition, this action does not pivot (as a tooth) toward the apex but instead concentrates greater forces at the crest of surrounding bone. Therefore, if an initial lateral or angled load (e.g., premature contact) of equal magnitude and direction is placed on an implant crown and a natural tooth, the implant system (crown, cement or screw retention, abutment screw, marginal bone, implant–bone interface) sustains a higher

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TABLE 8-1
Tooth versus Implant Support Systems

Tooth	Implant
1. Periodontal membrane	1. Direct bone implant
a. Shock absorber	a. Higher impact force
b. Distribution of force around tooth	b. Force primarily to crest
c. Tooth mobility can be related to force	c. Implant is always rigid (mobility is failure)
d. Mobility dissipates lateral force	d. Lateral force increases strain to bone
e. Fremitus related to force	e. No fremitus
f. Radiographic changes related to force (reversible)	f. Radiographic changes at crest (bone loss; not reversible)
2. Biomechanical design	2. Implant design
a. Longer force duration (decreases impulse of force)	a. Short force duration (increased force impulse)
b. Cross-section related to direction and amount of stress	b. Round cross-section and designed for surgery
c. Elastic modulus similar to bone	c. Elastic modulus five to 10 times that of cortical bone
d. Diameter related to force magnitude	d. Diameter related to existing bone
3. Sensory nerve complex in and around tooth	3. No sensory nerves
a. Occlusal trauma induces hyperemia and leads to cold sensitivity	a. No precursor sign of slight occlusal trauma
b. Proprioception (reduced maximum bite force)	b. Occlusal awareness of two to five times less (higher maximum bite force functional)
	c. Functional bite force four times higher
4. Occlusal material: enamel	4. Occlusal material porcelain (metal crown)
a. Enamel wear, stress lines, abfraction, and pits	a. No early signs of force
5. Surrounding bone is cortical	5. Surrounding bone is trabecular (may be fine)
a. Resistant to change	a. Conducive to change
b. Strong	b. Reduced strength

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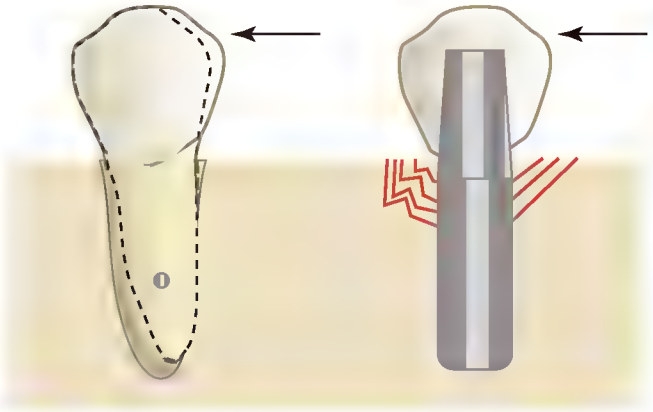


FIGURE 8-4. A lateral force on a tooth causes the tooth to rotate from the force, two thirds toward the apex. A lateral force on an implant crown captures the force at the marginal bone at the crest of the ridge around the implant.

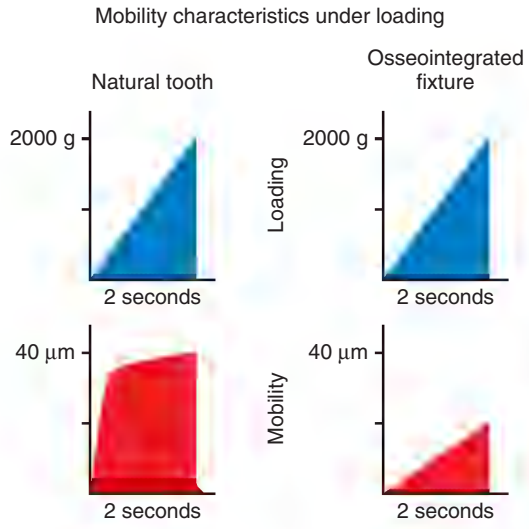


FIGURE 8-5. When a natural tooth has a gradual increase in load applied *(upper left)*, the tooth moves its full range of physiologic movement with very little load *(bottom left)*. When an implant is loaded in similar fashion *(upper right)*, the implant has almost no movement with the light force *(bottom right)*.

proportion of the load that is not dissipated to the surrounding structures.

The dentist uses mobility ratings to evaluate the quality of a natural abutment. A tooth with a Miller index mobility of 0 is considered "stronger" than a tooth with mobility of 2. Implants exhibit no clinical mobility compared with teeth. Phrases such as "solid as a rock" were used originally to describe their rigid fixation. As a result, the dentist may consider the implant a stronger abutment than a tooth, especially when the literature has implied that distal cantilevers off four anterior implants can be used to restore an entire arch.[17] However, when considering stress factors, mobility is an advantage. The natural tooth, with its periodontal ligament, constitutes a near perfect optimization system to handle biomechanical stress. In fact, the stress is handled so well that bacteria-related disease is the weak link. An implant system handles stress poorly (capturing the stress at the crest of the ridge) and is unable to increase mobility without failure, so biomechanical stress is the weakest link in the system.

BOX 8-1 Components of an Implant System

- Occlusal porcelain on the crown
- The cement or screw that retains the prosthesis
- The abutment screw that contains the components
- The crestal marginal bone
- The complete implant–bone interface
- The implant and prosthetic components

The natural teeth may have an occlusal adjustment by using fremitus, the act of lightly placing the fingers against the buccal of the teeth as they are lightly tapped together. The implant crowns do not have fremitus as they occlude together, which makes it more difficult to adjust the occlusal contact intensity.

A radiograph of a natural tooth that has occlusal trauma will have a widened periodontal space and a thicker lamina dura (cribriform plate). A radiograph of an implant crown with occlusal trauma has no changes in the bone around the implant. However, crestal bone loss may be a consequence of the excessive load because the forces are concentrated on the marginal bone. The complete bone–implant interface may also break down, and the implant may become mobile and surrounded by fibrous tissue.

Biomechanical Design

When two bodies collide in a small interval of time (fractions of a second), large reaction forces develop. Such a collision is described as *impact*. When the collision is between a weight and a platform supported by a spring, the spring absorbs some of the intensity of the force (because of the deformation of the spring), and the impact force is reduced. This is similar to the collision with teeth, which are supported by a periodontal complex. When a similar force (mass and velocity) collides with a rigid platform, the intensity of the force (implant force) is greater. This is similar to a collision with an implant system, which has a direct implant–bone interface[11] (Figure 8-6).

An implant system receives a greater impact force than a natural tooth because it is not surrounded by a periodontal complex. The fact that the implant is more rigid actually means that the implant system receives greater force and is more at biomechanical risk than a natural tooth. The implant system includes the occlusal porcelain on the crown (which may fracture), the cement or screw that retains the prosthesis (which may debond or loosen), the abutment screw that contains the components (which may loosen), the crestal marginal bone (which may be lost from pathologic overload), the complete implant–bone interface (which may result in mobility and failure), and the implant and prosthetic components (which may result in fracture) (Box 8-1).

An analogy of the difference in impact force between an implant and a tooth is hitting a nail with a steel hammer (a rigid structure) compared with a rubber hammer (a mobile structure). The more rigid hammer transmits a higher intensity force and drives the nail farther into the wood rather than having the energy partially dissipated through deflection of the rubber hammer.

The width of almost every natural tooth is greater than the width of the implant used to replace the tooth. The greater the width of a transosteal structure (tooth or implant), the lesser the magnitude of stress transmitted to the surrounding bone.[11] The anterior teeth are narrower than the posterior teeth because

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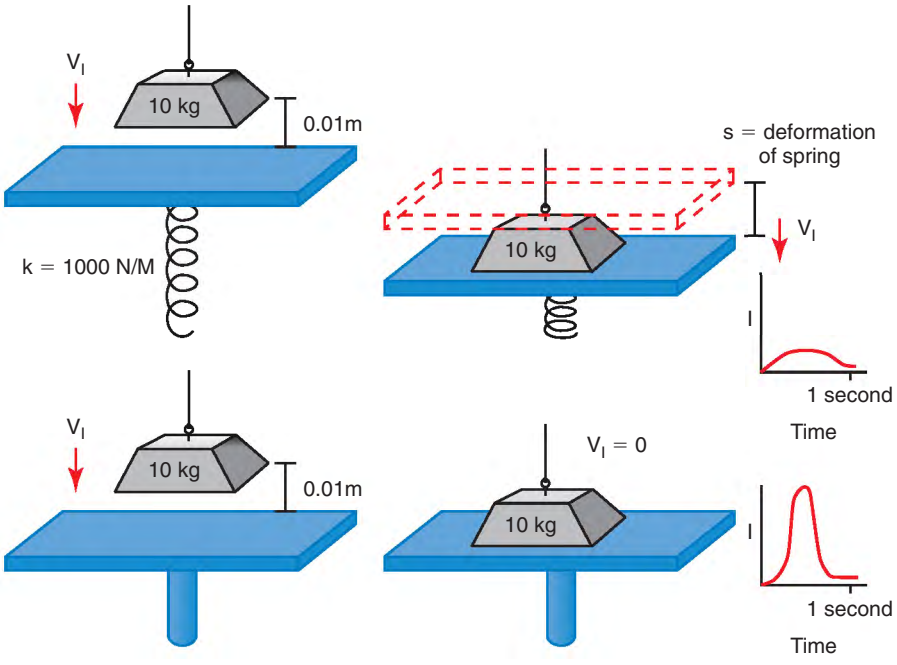


FIGURE 8-6. When a weight is dropped onto a platform and a spring, the spring deforms and absorbs some of the intensity of the stress and the impact force is reduced *(top picture sequence)*. When a similar weight is dropped onto a rigid platform, the intensity of the force is greater *(bottom sequence)*.

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the forces are greater in the posterior regions. An implant width is most often decided by the available bone width and is more narrow than a natural tooth in the region. In addition, the implant width is most often the same in all regions of the mouth.

The cross-sectional shape of the natural tooth at the crest is biomechanically optimized to resist lateral (buccolingual) loads because of the bending fracture resistance (moment of inertia) of the tooth and the direction of occlusal forces. Hence, mandibular anterior teeth are greater in size in the faciolingual directions (to resist protrusive forces), and canines have different cross-sections than other anterior teeth and sustain lateral loads in more directions. In contrast, implants are round in cross-section, which is less effective in resisting lateral bending loads and consequently increase stress concentration in the crestal region of the jaws.

The design of the natural tooth root and surface area is related to amount of biomechanical stress. Molars have greater dimensions than premolars (greatest bite forces in molar region), and the maxillary molars have greater surface area than the mandibular counterparts to compensate for the difference in surrounding bone. The length and design of the implant often is decided by the existing bone volume rather than the amount and direction of force. Hence, the greatest-sized (surface area) implants are often inserted into the anterior mandible followed by the anterior maxilla and the posterior mandible, and the smallest-length implants are often inserted into the posterior maxilla. The design of the implant is most often the same regardless of its length or width.

The elastic modulus of a tooth is closer to bone than any of the currently available dental implant biomaterials. Titanium is more than 10 to 20 times more stiff than cortical or trabecular bone. The greater the flexibility (modulus) difference between two materials (metal and bone or tooth and bone), the greater the potential relative motion generated between the two surfaces upon loading.[11] In addition, the greater the elastic modulus difference, the greater the stress concentrations where they first meet (the crest of the ridge). Hence, under similar mechanical loading conditions, implants generate greater stresses and strains to the overall bone and at the crest of bone compared with a natural tooth.[18]

Sensory Nerve Complex versus Direct Bone Interface

The precursor signs of a premature contact or occlusal trauma on natural teeth are usually reversible and include hyperemia and occlusal or cold sensitivity.[14] This condition often results in the patient's seeking professional treatment to reduce the sensitivity, and usually this condition is treated by an occlusal adjustment and a reduction in force magnitude, which concomitantly decreases stress magnitude. This treatment most often reduces the hyperemia and the symptoms associated with this condition. If the patient does not have an occlusal adjustment, the tooth often further increases in mobility to dissipate the occlusal forces. If the patient still fails to seek professional treatment for the increased mobility, the tooth may migrate orthodontically away from the cause of the occlusal stress. Hence, the early warning signs and symptoms of excessive biomechanical load on natural teeth are often reversible or decreased as a result of mobility and tooth movement.

The initial reversible signs and symptoms of trauma on natural teeth do not occur with endosteal implants. An absence of soft tissue interface between the implant body and bone results in the greatest portion of the force being concentrated around the transosteal implant–bone region.[11] The magnitude of stress may cause bone microfractures; place the surrounding bone in the pathologic loading zone, causing bone loss[19]; or cause mechanical failure of prosthetic or implant components (e.g., porcelain fracture, abutment screw loosening).[6]

Unlike the reversible signs and symptoms exhibited by natural teeth, implant bone loss or unsecured restorations most often occur without any warning signs. Abutment screw loosening most often is a symptom of biomechanical stress beyond limits of the system. Marginal bone loss around the implant occurs without symptoms. The loss of crestal bone around the implant is not reversible without surgical intervention and results in a decreased implant support and increased sulcus depth around the abutment. As a result, unless the density of

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bone increases after loading or the amount or duration of force decreases, the bone loss condition may progress until implant loss because the implants cannot move orthodontically away from the offending force.

The natural teeth and their periodontal ligament provide proprioception and early detection of occlusal loads and interferences. As a result, an occlusal premature contact greater than 20 microns may alter the path of mandibular closure to decrease the noxious elements of the premature, angled force.[20] In addition, the jaw of a dentate patient almost stops before the food is penetrated and the maximum chewing force is applied. This is why a piece of bone in meat may shear off a cusp tip because the jaws did not reduce their velocity before the contact with the piece of bone. Implant prostheses do not have as much occlusal awareness as teeth during function. As a result, the bite forces used in mastication or parafunction can be of greater magnitude, and the path of closure is not altered with a premature contact.

Several studies confirm that implant prostheses have less occlusal awareness and higher bite forces than natural teeth. Trulsson and Gunne compared three patient groups holding a peanut between the teeth for 3 seconds and then biting through the peanut.[21] The natural teeth group had no problem holding the peanut or biting through it afterward. The denture group of patients experienced greater problems holding the peanut without its falling or becoming dislodged. The implant group had no problem holding the peanut in place, but they bit through the peanut with a force fourfold greater than the natural dentition group. The four times higher force in the implant patients is generated to the implant system, not the soft tissue of the denture group or the periodontal complex of the natural dentition. Hence, the decrease in proprioception of implant patients can lead to a higher bite force during functional loading.

Other studies confirm that teeth have more occlusal awareness than implant prostheses. Jacobs and van Steenberghe[22,23] evaluated occlusal awareness by the perception of an interference. When teeth oppose each other, an interference is perceived at approximately 20 microns. An implant opposing a natural tooth detects an interference at 48 microns, which is therefore more than twice as poor. An implant crown opposing an implant crown perceives the interference at 64 microns, and when a tooth opposes an implant overdenture, the awareness is 108 microns (five times poorer than teeth opposing each other). Mericke-Stern et al. measured oral tactile sensitivity with steel foils.[24] The detection threshold of minimal pressure was significantly higher on implants than on natural teeth (3.2 vs. 2.6 foils). Similar findings also were reported by Hammerle et al. in which the mean threshold value for implants (100.6 g) was 8.75 times higher than that of natural teeth (11.5 g).[25] As a consequence of decreased quantity and quality of occlusal awareness, a premature contact does not trigger an adaptation response (Figure 8-7).

The proprioceptive information relayed by teeth and implants also differs in quality awareness. Teeth deliver a rapid, sharp pain sensation under high pressure that triggers a protective mechanism. However, implants deliver a slow, dull pain that triggers a delayed reaction, if any.[26] Implant occlusal sensitivity is uncommon and signifies more advanced complications.

Occlusal Material

The natural tooth can show clinical signs of increased stress such as enamel wear facets, stress lines, lines of Luder (in amalgam fillings), cervical abfraction, and pits on the cusps of teeth.[20] An implant crown rarely shows clinical signs other than fatigue fracture. As a result, fewer diagnostic signs are present to warn the practitioner to reduce the stress on the support system. The enamel on a tooth will wear when repeated lateral forces or premature contacts are introduced on the system and may reduce the angle of force for the premature contact. A porcelain occlusal implant crown does not wear and reduce the noxious force when a lateral premature contact is present.



FIGURE 8-7. An implant crown with premature occlusal contact (first molar) has less occlusal awareness than a natural tooth.

Surrounding Bone

The tooth slowly erupts into occlusion and is present in the mouth from childhood. The surrounding bone has developed in response to the biomechanical loads. Note that there is no organized cribriform plate around the deciduous or permanent tooth until it is loaded. The permanent teeth are gradually introduced a few at a time while other teeth are present and bear the load. Hence, periodontal tissues organize gradually to sustain increasing loads, including those brought to bear by an attached prosthesis. The only progressive bone loading around an implant is performed by the restoring dentist in a much more rapid time frame and intense magnitude of load.

When implants or teeth are subjected to repeated occlusal loads, microscopic stress fractures, work hardening, and fatigue may result. Fatigue fractures are related to the amount of stress and the number of cycles of load.[11] Unlike the natural tooth system, the implant components, coping screws, or cement cannot adjust or repair to these conditions and ultimately fracture. The implant needs to perform its service for scores of years, increasing the cycles in the fatigue curve and the risk of long-term complications. As a result, forces from occlusion may result in subtle changes but may cause more serious long-term problems for survival as a result of bone or implant component complications compared with natural teeth (Table 8-2).

Biomechanical parameters are excellent indicators of the increased risk because they are objective and can be measured. As a result, ways to decrease biomechanical stress are a constant concern to minimize the risk of implant system complications.[18] The dentist can determine which condition presents greater risk and by how much the risk is increased. In other words, if a clinical condition creates an increased biomechanical stress to the implant–prosthetic system, the dentist should implement mechanisms to decrease the stress. Remember, the implant system is composed of the occlusal porcelain, the cement or

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TABLE 8-2
Natural Tooth versus Implant Characteristics Under Load

Criterion	Tooth	Implant
Connection	PDL	Functional ankylosis
Impact force	Decreased	Increased
Mobility	Variable Anterior teeth more than posterior teeth	None
Movement	Shock breaker effect of PDL	Stress captured at crest
Apical	Intrude quickly 28 μm	No initial movement (3 μm)
Lateral	56–108 μm	No initial movement
Diameter	Large	Small
Cross-section	Not round	Round
Modulus of elasticity	Similar to cortical bone	10–20 times greater than trabecular bone
Signs of hyperemia	Yes	No
Orthodontic movement	Yes	No
Fremitus	Yes	No
Radiographic changes	PDL and cortical bone thickening	Crestal bone loss
Progressive loading	Eruption sequence (crestal bone loss)	Shorter loading period
Wear	Enamel wear facets, localized fatigue and stress fracture, cervical abfraction, and pitting on occlusal cusps	Minimal wear
Tactile sensitivity	High	Low
Occlusal awareness (proprioception)	High detection of premature contacts	Low; higher loads to premature occlusal

PDL, Periodontal ligament.

BOX 8-2 Complications of Biomechanical Stress

1. Porcelain fracture
2. Acrylic resin veneer fracture
3. Unretained cemented restoration
4. Prosthetic screw loosening
5. Abutment screw loosening
6. Prosthetic framework fracture
7. Overdenture attachment adjustments
8. Overdenture attachment fracture
9. Acrylic base fracture of overdentures
10. Abutment screw fracture
11. Crestal bone loss may have an occlusal stress component
    a. Esthetic complications
    b. Periimplant disease
12. Early implant failure (especially in soft bone or short implants)
13. Implant body fracture

BOX 8-3 Stress Treatment Theorem: Biological versus Biomechanical

BIOLOGICAL	BIOMECHANICAL
Implant Failure	
Surgical failure	Early loading failure
Initial healing	Micromovement
Prosthetic Complications	
	Attachment wear
	Denture tooth fracture
	Attachment fracture
	Opposing prosthesis fracture
	Screw loosening fracture
	Component fracture
	Implant body fracture
	Acrylic veneer or porcelain
	Acrylic base fracture
	Framework fracture
Crestal Bone Loss	
Periosteal reflection	Cellular biomechanics
Autoimmune (bacteria)	Bone mechanics
Biological microgap	Engineering principles
Osteotomy	

screw that retains the restoration, the abutment screw that retains the implant components, the crestal marginal bone around the implant, the complete bone–implant interface, and the implant bodies themselves. Higher stresses may lead to complications in any aspect of this system[18] (Box 8-2).

Any complex engineering structure will fail at its "weakest link," and dental implant structures are no exception. A general concept in engineering is to determine the causes of complications and develop a system to reduce the conditions that cause the problems. Natural teeth most often have biological complications. Implants may also have biological problems. However, unlike natural teeth, the most common causes of implant-related complications are centered around biomechanical stress (Box 8-3). Thus, the overall treatment plan should (1) assess the greatest force factors in the system and (2) establish mechanisms to protect the overall implant–bone–prosthetic system.

Failure of Natural Tooth–Supported Prostheses

The most common failures of a fixed prosthesis supported by natural teeth are intermediate- to long-term failure and are often related to biological factors. For example, a three-unit fixed partial denture replacing one posterior tooth has a 5-year survival rate above 95%. The 10-year failure rate is

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approximately 30%, and the 15-year failure rate is almost 50%. The primary cause of natural tooth–supported prostheses is caries of the abutment teeth. Hence, failures are after many years and primarily related to bacteria plaque as a result of inadequate patient oral hygiene (biological related failure).

Early Loading Failure

The surgical and initial healing phase for implants is primarily related to the biological aspects of healing and is very predictable. The implant prosthesis may have a higher intermediate- to long-term survival rate compared with natural teeth because implants do not decay and do not require endodontic treatment[7–10] (Figure 8-8). Although the initial healing of the implant has very high success rates, an implant may fail shortly after it is loaded with the prosthesis. Before failure, the implant appears to have rigid fixation, and all clinical indicators are within normal limits. However, after the implant is loaded, the implant becomes mobile, most often within the first 18 months (Figure 8-9). This has been called *early loading failure.*[27] Hence, the implant and prostheses may fail early, but a natural tooth restoration has more of a long-term failure rate. The primary cause of early loading failure is related to biomechanical factors for the bone–implant interface, and this failure may approach rates more than five times greater than initial healing rates. The causes of early loading failure are important to understand, so a method may be established to limit this complication (Figure 8-10).



FIGURE 8-8. An implant prosthesis may have greater intermediate- to long-term survival rates because they do not decay and do not require endodontic procedures. Note that the bone is above the implant abutment connection.



FIGURE 8-9. The most common time period an implant fails is after prosthetic loading.

Cellular Biomechanics

Bone remodeling at the cellular level is controlled by the mechanical environment of strain.[28] *Strain* is defined as the change in length divided by the original length, and the units of strain are given in percentages. The amount of strain in a material is directly related to the amount of stress applied.[11] Occlusal stress applied through the implant prosthesis and components can transmit stress to the bone–implant interface.[18] The amount of bone strain at the bone–implant interface is directly related to the amount of stress applied through the implant prosthesis (the greater the stress, the greater the strain). Mechanosensors in bone respond to minimal amounts of strain, and microstrain levels 100 times less than the ultimate strength of bone may trigger bone remodeling, which may result in bone loss[29] (Figure 8-11).

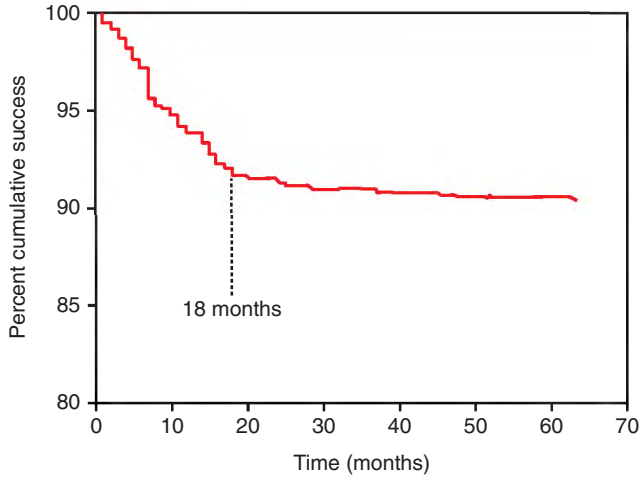


FIGURE 8-10. The majority of implant failures occur within 18 months after prosthetic loading and are primarily related to biomechanical factors (e.g., short implants or implants placed in poor-quality bone).

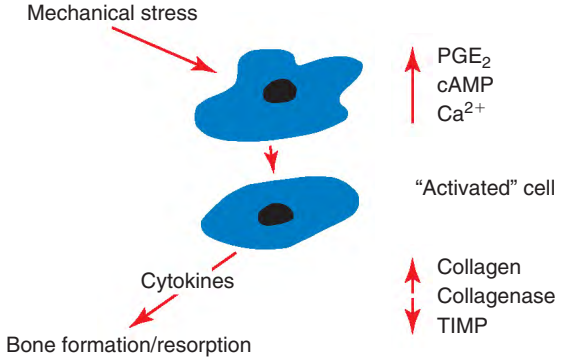


FIGURE 8-11. A bone cell acts as a mechanosensor, and a change in shape (strain) triggers cellular events, which may include bone loss when the stress–strain is in a pathologic overload condition. *cAMP,* Cyclic adenosine monophosphate; *PGE_2,* prostaglandin E_2; *TIMP,* tissue inhibitor of metalloproteinase.

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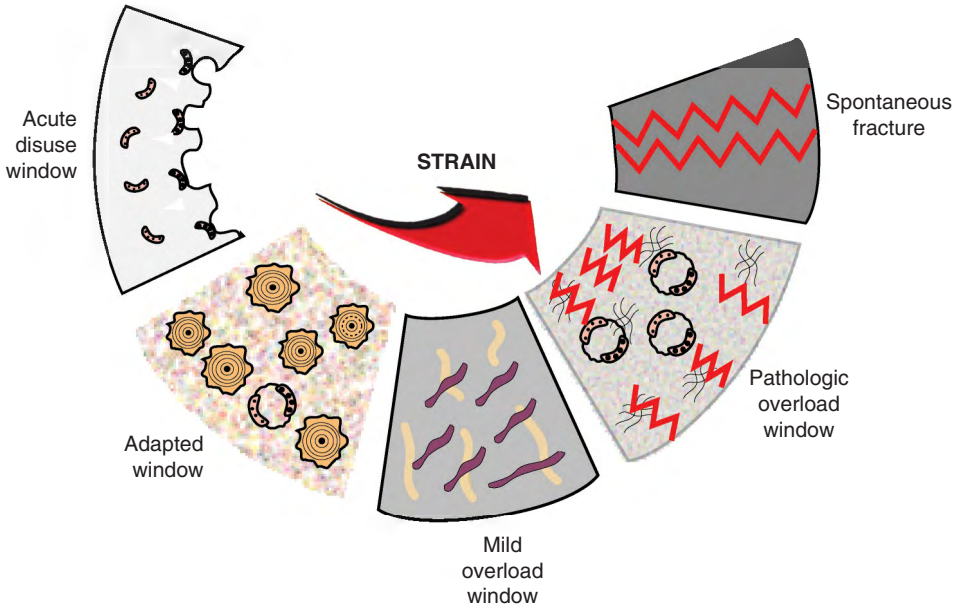


FIGURE 8-12. When bone is not loaded, it may resorb (acute disuse window). When bone is ideally loaded and strained, it is in the adapted window. Bone may have so much strain that it may fracture. Strain conditions less than 20% to 40% of the fracture zone may cause bone loss and resorption (pathologic overload zone).

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One of the earliest remodeling theories for a direct relationship between stress and the magnitude of bone remodeling (including loss) was proposed by Kummer in 1972.[30] More recently, Frost reported on the cellular reaction of bone to different microstrain levels.[19,31] When bone does not have enough strain, it resorbs (acute disuse window). When bone has an ideal strain, it remains organized, mineralized, and the ideal load-bearing bone (adapted window). Bone fractures at 10,000 to 20,000 microstrain units (1%–2% deformation). However, at levels 20% to 40% of this value (4000 units), bone cells may trigger cytokines to begin a bone resorption response (pathologic overload window) (Figure 8-12). It is interesting to note that cytokines in the bone–implant interface tissue obtained from failed hip replacement devices leading to bone loss have been reported in humans.[32] It is logical that a similar condition may exist around a dental implant. In other words, excessive bone strain may not only result in physical fracture but may also cause bone cellular resorption.

Strain determines the cellular reaction of bone. When bone has ideal strain, the bone remains organized and load bearing. When the strain is greater, it may be in a pathologic overload zone, which causes bone loss. Therefore, the hypothesis that occlusal stresses beyond the physiologic limits of bone may result in strain in the bone significant enough to cause bone resorption is supported from a cellular biomechanics standpoint.

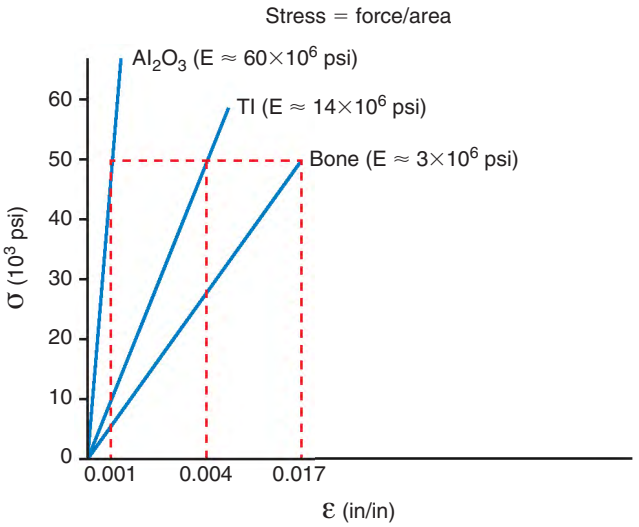


FIGURE 8-13. The modulus of elasticity is greater for titanium (Ti) compared with bone. When stress is plotted on the *y*-axis and strain on the *x*-axis, the modulus of elasticity can be obtained. Titanium is 5 to 20 times more rigid than the surrounding bone. When 50 units of stress is applied to titanium and bone, the microstrain difference between titanium and surrounding bone may be in the pathologic overload zone.

Engineering Principles

The relationship between stress and strain determines the modulus of elasticity (stiffness) of a material.[11] The modulus conveys the amount of dimensional change in a material for a given stress level. The modulus of elasticity of a tooth is similar to cortical bone. Dental implants are typically fabricated from titanium or its alloy. The modulus of elasticity of titanium is five to 10 times greater than that of cortical bone and may be 20 times greater for trabecular bone. Hence, when 50 units of stress is applied to titanium, the strain (change in shape) of the material is less than when applied to bone (Figure 8-13). The biomechanical strain difference between titanium and bone with a direct implant–bone interface may be in the pathologic overload zone for bone with greater stress magnitudes. When the stress magnitude is reduced, the biomechanical difference between titanium and bone is less and more likely in the adapted window zone for bone (Figure 8-14).

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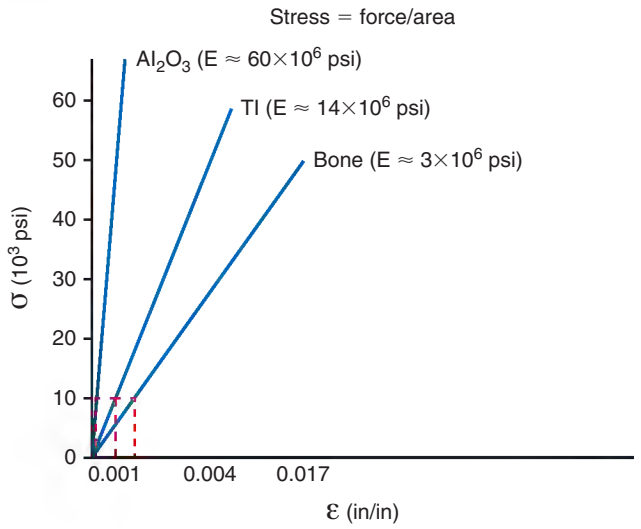


FIGURE 8-14. When 10 units of stress is applied to titanium and bone, the microstrain difference may be in the adapted window zone for bone, and a direct bone–implant interface is maintained.



FIGURE 8-15. Bone may continue to be integrated to an implant after initial healing when the prosthetic loads are within physiologic limits of bone and remain in the adapted window zone.

When the microstrain of the bone is more ideal, the adapted window strain zone may allow the bone to remain integrated to the implant (Figure 8-15). Isidor allowed eight implants to integrate in monkey jaws.[33,34] Crowns were attached to eight of the integrated implants with excessive premature occlusal contacts. Over a 14-month period, six of eight implants failed (Figure 8-16). In these same animals, eight integrated implants with no occlusal loads had strings placed in the marginal gingiva to increase the amount of plaque retention. None of these implants failed over the following 18 months. In this animal model, biomechanical occlusal stress was a greater risk factor for early implant failure than the biological component of bacterial plaque (Figure 8-17).

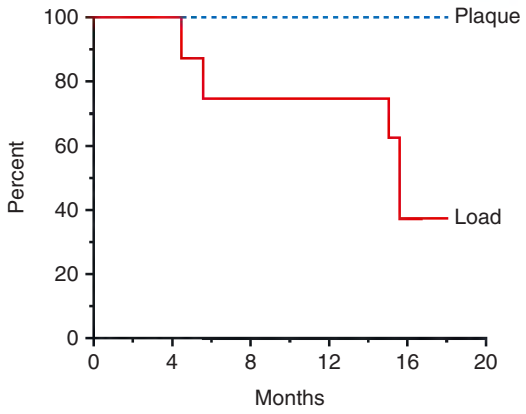


FIGURE 8-16. Excessive premature occlusal contacts caused six of eight integrated implants to fail within 14 months. Strings in the sulcus and excessive plaque accumulation caused no failure over 18 months.



FIGURE 8-17. Six of eight implants with an excessive premature occlusal contact became mobile and surrounded by fibrosis tissue within 14 months. (From Isidor F: Loss of osseointegration caused by occlusal load of oral implants: a clinical and radiographic study in monkeys, *Clin Oral Implants Res* 7:143–152, 1996.)

Early loading failure is most often related to the amount of force applied to the prosthesis[35] or the density of the bone around the implants, both biomechanical factors.[36,37] For example, a literature review found these early implant loading failures may occur 16% of the time in the softest bone types or at similar rates when the implants are less than 10 mm long.[6] These two failure groups are typically caused by biomechanical factors. Soft bone is too weak for the occlusal forces applied to the implants, and short implants have less surface area and higher stresses at the bone–implant interface.[38,39] No reports in the literature correlate such high incidence extreme with early implant failure rates related to biological complications. It should be noted that biomechanical-related causes of failure are more often influenced by the dentist than biological causes of failure (Figure 8-18).

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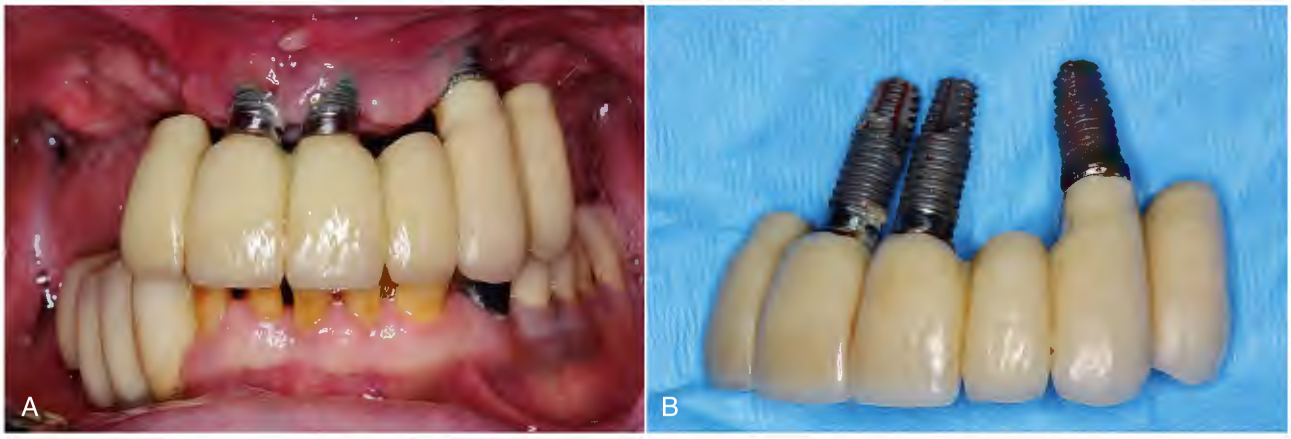


FIGURE 8-18. **A,** Biomechanical causes of implant bone loss and failure outnumber biological causes of failure. **B,** Biomechanical-related failure is more in the control of the dentist than biological-related failure.

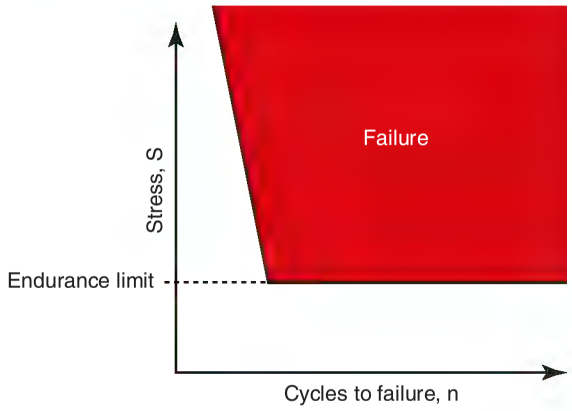


FIGURE 8-19. When stress is plotted on the y-axis and cycles to failure are plotted on the x-axis, the fatigue curve of a material may be established. Any stress condition above the endurance limit will eventually cause fracture when enough cycles are applied.



FIGURE 8-20. Porcelain fracture on an implant prosthesis occurs with greater incidence than on natural teeth and is directly related to the amount of stress in the system.

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Early loading failure is worse for the implant clinician than when a surgical failure occurs because the patient may blame the restoring dentist. Although this is bad enough, in addition, the restoring dentist spent two to five appointments restoring the implant and has a laboratory expense. The implant surgery may require a bone graft as a consequence of the failure. A bone graft is often less predictable than the integration of an implant in adequate bone. Hence, the overall treatment is often more difficult than the original reconstruction. This is not an ideal scenario because it occurs in a patient who already has experienced a failure.

Occlusal Overload on Prosthetic Components

Fatigue Fractures and Complications

The most common source of biomechanical stress to an implant system occurs during occlusal function. Most biomechanical complications do not occur as a result of a single force event, such as a car accident. Instead, they occur over time. Materials follow a fatigue curve, which is related to the number of cycles and the intensity of the force.[11] There is a force so great that one cycle causes a fracture (e.g., a hammer hitting a glass window). However, if a lower force magnitude repeatedly hits an object (and is greater than the endurance limit), it will still fracture (Figure 8-19). A wire coat hanger that is bent does not break the first time, but repeated bends will fracture the material—not because the last bend was more forceful but because of fatigue. Indeed, when a patient says he soaked his bread in coffee before he began to chew it and the porcelain–abutment screw–cement seal–cantilevered prostheses fractured, it may have been "the straw that broke the camel's back" that caused the problem. The most common complications of implants and prostheses are related to biomechanical conditions related to fatigue.[6]

Prostheses and Component Fractures

In a 2009 retrospective analysis by Kinsel and Lin of porcelain failures of metal ceramic crowns and fixed partial dentures supported by implants, porcelain fractures ranged from 0% to 53% of patients and were directly related to force factors[40] (Figure 8-20). For example, whereas 35% of patients with bruxism (and 19% of the implant crowns) experienced porcelain fracture with implant-supported prostheses, 17% of patients without bruxism had at least one porcelain fracture of porcelain units fractured. When implant prostheses opposed a denture, no fracture was observed. When implant prostheses opposed each other, 16% of the dental units experienced a fracture of porcelain. The higher forces in the implant system (including the occlusal porcelain) were related to a dramatic increase in biomechanical

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complications. Note that the incidence of porcelain fracture, even in patients without higher force conditions, are greater than observed with natural teeth.

Implant overdentures have problems of attachment fracture or complication (30%); removable prostheses may fracture (12%); and in implant-supported fixed prostheses, acrylic resin veneers may fracture (22%). Metal framework fractures also have been reported in an average of 3% of fixed complete prostheses and overdenture restorations may fracture with a range of 0% to 27%.[6]

Prosthesis screw fracture has also been noted in both fixed partial and complete fixed prostheses, with a mean incidence of 4% and a range of 0% to 19%.[6] Abutment screws are usually larger in diameter and therefore fracture less often, with a mean incidence of 2% and a range of 0.2% to 8% (Figure 8-21). Implant body fracture has the least incidence of this type of complication, with an occurrence of 1%. This condition is reported with more frequency in long-term fixed prostheses. For example, in a 15-year report, implant body fracture was the most common condition that led to failure of the implant system[41] (Figure 8-22).

Uncemented prostheses are the third most common cause of fixed prostheses failure on natural teeth.[4,5] This condition is more common with implant abutments because they are more rigid and higher forces are transmitted to the cement interface. Uncemented restorations (or worse, when one or more crowns become uncemented and some abutments are still retained) occur most likely when chronic loads are applied to the cement interface or when shear forces are present (as found with cantilevers). Cement strengths are weakest to shear loads. Zinc phosphate cement may resist a compressive force of 12,000 psi but can only resist a shear force of 500 psi. A shear load is applied to the cement when a cantilever is present.



FIGURE 8-21. Abutment screw fracture occurs less often than prosthetic screw fracture because they are larger in diameter. The cantilever on the implant crown in this case increased the force magnitude and decreased the cycles to fracture.



FIGURE 8-22. The implant body fractured along with the abutment screw in this patient. This is more common in long-term implant patients.

Screw Loosening

Abutment screw loosening has been detected in an overall average of 6% of implant prostheses.[6] Single-tooth crowns exhibited the highest rate of abutment screw loosening and in early screw designs and concepts averaged 25%. Recent studies indicate this ratio has been reduced in single crowns to an overall 8% average, with multiple-unit fixed prostheses at a 5% average and implant overdentures at 3%. Screw loosening may cause considerable complications. A loose screw may contribute to crestal bone loss because bacteria are able to harbor in the open interface. When an abutment screw becomes loose on a cemented crown, the crown may need to be cut off the abutment to gain access to the abutment screw (Figure 8-23).

The greater the stress applied to the prostheses (single tooth vs. overdentures), the greater the risk of abutment screw loosening. Cantilevers increase the risk of screw loosening because they increase the forces to the implant system in direct relationship to the length of the cantilever.[42] The greater the crown height attached to the abutment, the greater the force applied to the screw and the greater the risk of screw loosening (or fracture)[43] (Figure 8-24).

The height or depth of an antirotational component of the implant body also can affect the amount of the force applied to the abutment screw. The higher (or deeper) the hex height, the less stress applied to the screw and a corresponding lower risk for abutment screw loosening.[43] The platform dimension upon which the abutment is seated is even more important than the hex height dimension. Larger-diameter implants, with larger platform dimensions, reduce the forces applied to an abutment screw and change the arc of displacement of the abutment on



FIGURE 8-23. Abutment screw loosening may cause a considerable complication. The loose screw decreases the impact force to the cement seal. As a result, the crown could not be removed from the abutment. To tighten the abutment screw, the crown was cut off. The loose screw also contributed to crestal bone loss around the implant.

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FIGURE 8-24. Cantilevers and an increase in crown height increase the force magnitude and increase the risk of screw loosening or implant component fracture.



FIGURE 8-25. Marginal bone loss around the crestal portion of an implant often occurs during the first year. Early reports use the first thread as the baseline for bone loss. Hence, this implant would have no bone loss. The bone loss to the first thread may have a different cause than the bone loss beyond the first thread.

the crest module.[43] For example, in a report by Cho et al., abutment screw loosening over a 3-year period was almost 15% for the 4-mm implant diameter but less than 6% for the 5-mm implant diameter.[44] Therefore, methods to decrease stress to the abutment screw may be used to decrease the incidence of complications related to screw loosening.

As a consequence of these biomechanical complications, the evaluation, diagnosis, and modification of treatment plans related to stress conditions are of considerable importance. Therefore, after the implant dentist has identified the sources of additional force on the implant system, the treatment plan is altered in an attempt to minimize their negative impact on the longevity of the implant, bone, and final restoration.

Marginal Bone Loss

Crestal bone loss has been observed around the permucosal portion of dental implants for decades. It has been described after exposure and loading of successfully osseointegrated implants regardless of surgical approaches. It can range from loss of marginal bone to complete failure of the implant.[45,46]

Adell et al. were the first to quantify and report the marginal bone loss around machined screw–type implants (Nobel Biocare).[17] The report also indicated greater magnitude and occurrence of bone loss during the first year of prosthesis loading, averaging 1.2 mm during this time frame, with a range of 0 to 3 mm. (Implants with more than 3 mm of bone loss were not included in the report.) This report measured bone loss from the first thread as the 0-mm baseline, not from the original level of crestal bone at insertion, which was 1.8 mm above this baseline point. Thus, the actual first-year crestal bone loss averaged 3.3 mm around the implants observed (Figure 8-25).

The initial transosteal bone loss around an implant forms a V- or a U-shaped pattern, which has been described as *ditching* or *saucerization* around the implant.[47] The current hypotheses for the causes of crestal bone loss have included biological causes of reflection of the periosteum during surgery, preparation of the implant osteotomy, the position of the microgap between the abutment and implant body, bacterial invasion, and the establishment of a biological width. Biomechanical factors may also contribute to crestal bone loss and include micromovement of the abutment components and factors of biomechanical stress[48–50] (Box 8-4).

BOX 8-4 Causes of Crestal Bone Loss Around Dental Implants

Biologic Causes
- Periosteal reflection
- Implant osteotomy
- Autoimmune response
- "Biologic width"
- Implant crest module design

Biomechanical Causes
- Occlusal trauma
- Implant crest module design
- Implant body design
- Micromovement of components

Marginal crestal bone loss may influence esthetics because the height of the soft tissue (e.g., free gingival margin and interdental papilla) is directly related to the marginal bone. If the tissue shrinks as a consequence of the bone loss, the emergence profile of the crown elongates, and the papilla may disappear next to the adjacent tooth or implant (Figure 8-26). If the soft tissue does not shrink, the increase in pocket depth may be related to the presence of anaerobic bacteria and periimplantitis and cause additional bone loss or exudate.[51] An understanding of the causes of marginal crestal bone loss around dental implants and early implant failure is critical in preventing such occurrences; fostering long-term periimplant health; and improving long-term implant success rates and, foremost, implant prosthesis success.

Over the years, the cause of marginal bone loss has kept the implant community busy with academic debates and clinical studies. Clinical consequences are such that all phases of

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FIGURE 8-26. Marginal bone loss around an implant may cause the tissue to shrink. This results in an elongated emergence profile of the crown and may cause loss of the interdental papilla.



FIGURE 8-27. At stage II uncovery, the marginal bone level most often is similar to the initial day of surgery and may even have grown over the top of the implant. Because the periosteum is reflected and bone is prepared to insert the implants at stage I surgery, the cause of the frequently occurring early crestal bone loss is usually not related to the reflection of the periosteum or the osteotomy preparation.

implant dentistry, from diagnosis and treatment planning to the final stages of occlusion and prosthesis delivery, must focus on its reduction or elimination. The causes of crestal bone loss are multifactorial and may include both biological and biomechanical factors.

Biological Causes

Periosteal Reflection Hypothesis

Periosteal reflection causes a transitional change in the blood supply to the crestal cortical bone. Ninety percent of the arterial blood supply and 100% of the venous return are associated with the periosteum in the long bones of the body.[52] When the periosteum is reflected off the crestal bone, the cortical bone blood supply is affected dramatically, causing osteoblast death on the surface from trauma and lack of nutrition. These events have fostered the periosteal reflection theory as a cause of early bone loss around an endosteal implant. Some have suggested that a tissue punch surgery to remove crestal tissue at the implant site and allow direct access to the bone for implant insertion is preferred because the periosteum is not reflected and therefore less crestal bone loss would be observed.

Although crestal bone cells may die from the initial trauma of periosteal reflection, the blood supply is reestablished after the periosteum regenerates. Cutting cones develop from monocytes in the blood and precede new blood vessels into the crestal regions of bone. Osteoblasts then are able to remodel the crestal bone anatomy.[53] Composite bone forms rapidly on periosteal surfaces to restore its original condition. In addition, the underlying trabecular bone is also a vascular source because its blood supply often is maintained despite crestal periosteal reflection. The greater the amount of trabecular bone under the crestal cortical bone, the less crestal bone loss is observed.[54] To place the implant in sufficient available bone, an implant ridge is usually 5 mm or wider at the crest. As a result, trabecular bone is readily available to assist in cortical blood supply and remodeling around the implants. The cortical bone is remodeled to its original contour without significant loss of height.

The periosteal reflection theory would lead to a generalized horizontal bone loss of the entire residual ridge reflected, not the localized ditching pattern around the implant that typically is observed. In addition, generalized bone loss already would be directly noticeable at the second-stage uncovery of the implant body 4 to 6 months after stage I implant placement surgery. Yet generalized bone loss rarely is observed at the second-stage uncovery surgery (Figure 8-27). Therefore, the periosteal reflection hypothesis does not appear as a primary causal agent of marginal crestal bone loss around an implant.

Implant Osteotomy Hypothesis

Preparation of the implant osteotomy has been reported as a causal agent of early implant bone loss. Bone is a labile organ and is sensitive to heat. The implant osteotomy causes trauma to the bone in immediate contact with the implant, and a devitalized bone zone of about 1 mm is created around the implant. A renewed blood supply and cutting cones are necessary to remodel the bone at the interface. The crestal region is more susceptible to bone loss during initial repair because of its limited blood supply and the greater heat generated in this denser bone, especially with the less efficient cutting of countersink drills used in this region[55,56] (Figure 8-28). This condition supports implant osteotomy preparation as a causal agent for marginal crestal bone loss around the implant.

If heat and trauma during implant osteotomy preparation are responsible for marginal crestal bone loss, the effect will be noticeable at the second-stage uncovery surgery 4 to 6 months later. However, the average bone loss of amounts in most all reports is not observed at stage II uncovery. In fact, bone often has grown over the first-stage cover screw, especially when level or slightly countersunk below the bone.

Reports in the literature indicate that the range of bone loss from stage I to stage II surgery averages 0.2 to 1 mm. For example, Manz observed that bone loss average at second-stage surgery was 0.9 mm regardless of the bone density.[57] Hoar et al. reported an average of only 0.2 mm bone loss at stage II uncovery[58] (Figure 8-29). One should remember that these bone loss amounts are averages of bone loss reported, not the range of bone loss observed. Therefore, if 2 mm of bone loss is found on one implant and the next nine implants exhibit no bone loss, the average bone loss would be 0.2 mm. Most implants at stage II uncovery do not demonstrate bone loss. The surgical system or approach may influence these data, but usually this bone loss remains minimal. Therefore, the implant osteotomy

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FIGURE 8-28. The crest module drill used during the preparation of an implant osteotomy may create trauma to the crestal bone region around the implant.

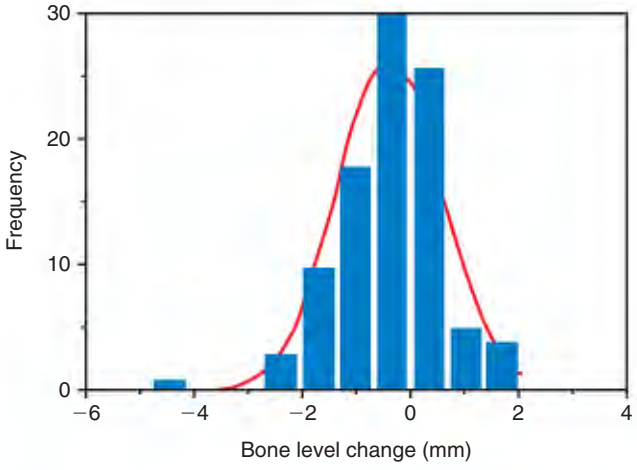


FIGURE 8-29. The average bone loss at stage II uncovery in the Hoar et al.[58] report was 0.2 mm. The range of bone loss was +2 mm to −4 mm. The cause of bone loss for the implants with −2 to −4 mm is most likely different than those with bone gain.

hypothesis for marginal crestal bone loss cannot be primarily responsible for the routinely observed phenomenon of 1 mm or more bone loss below the first thread on the implant body.

Autoimmune Response of Host Hypothesis

The primary cause of bone loss around natural teeth is bacteria induced. Studies demonstrate that bacteria are the causative element for vertical defects around teeth. Occlusal trauma may accelerate the process, but trauma alone is not deemed a determining factor.[59] The implant gingival sulcus in a partially edentulous implant patient exhibits a bacterial flora similar to that of natural teeth.[51] A logical assumption is that if implants are similar to teeth, the marginal implant bone loss is caused primarily by bacteria, with occlusal factors playing a contributing or accelerating role.

In a prospective study of 125 implants, Adell et al. reported 80% of implant sulcular regions were without inflammation.[60]



FIGURE 8-30. Exudate around an implant is more likely to be present when the probing depth is greater than 5 mm, and an anaerobic environment exists around the implant.

Lekholm et al. found that deep gingival pockets around implants were not associated with crestal bone loss.[61] Yet the marginal crestal bone loss beyond the first thread of screw-type implants after occlusal loading is a common radiologic finding. If bacteria were the causal agent for the initial bone loss, why does most bone loss occur the first year (3.3 mm) and less (0.1 mm) each successive year? The implant sulcus depth progressively increases from the early bone loss, impairing hygiene and making anaerobic bacteria more likely as the cause of bacteria-related bone loss. If bacteria are responsible for 3.3-mm average early crestal bone loss as reported by Adell et al., what local environmental changes occur to reduce their effect by 15 times after the first year? The bacteria autoimmune theory cannot explain the marginal bone loss condition when it follows the pattern most often reported.

Although the bacteria theory does not explain adequately the routine initial marginal bone loss phenomenon during the first year after loading, this does not mean that bacteria are not a major contributor to bone loss around an implant. Threads and porous implant surfaces exposed to bacteria are reported to cause a more rapid loss of bone around an implant.[62] Poor hygiene also is reported to accelerate the bone loss observed around endosteal implants.[10,63] To state that bacteria are never involved in marginal bone loss around an implant would be incorrect. Bone loss often is associated with bacteria as a causal agent, especially when the sulcus depth is greater than 5 mm or an abutment screw becomes loose (Figure 8-30). However, when most bone loss occurs in the first year and less bone loss is observed afterward, the hypothesis of bacteria as the primary causal agent for the early crestal bone loss cannot be substantiated.

"Biological Width" Hypothesis

The sulcular regions around an implant and around a tooth are similar in many respects. The rete peg formation within the attached gingiva and the histologic lining of the gingiva within the sulcus are similar in implants and teeth.[64] A free gingival margin forms around an implant with nonkeratinized sulcular epithelium, and the epithelial cells at its base are similar to the junctional epithelial cells described with natural teeth.[65] However, a fundamental difference characterizes the base of the gingival sulcus.

For a natural tooth, an average biological width of 2.04 mm exists between the depth of the sulcus and the crest of the alveolar bone.[66] It should be noted that the biological "width" is

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actually a height dimension with a greater range in the posterior region compared with the anterior and may be greater than 4 mm in height.[67] In teeth, it is composed of a connective tissue (CT) attachment (1.07 mm average) above the bone and a junctional epithelial attachment (0.97 mm average) at the sulcus base, with the most consistent value between individuals being the CT attachment.[68]

The junctional epithelial "attachment" of a tooth is not a true attachment. A periodontal probe easily separates the hemidesmosomal close approximation of the epithelial cells. High-volume air from a syringe may blow it off; plaque destroys it and the placement of impression string in the sulcus displaces it. In other words, the mucopolysaccharide close approximation of the hemidesmosome is not an attachment (Figure 8-31).

Eleven different gingival fiber groups comprise the CT attachment zone observed around a natural tooth and tissue: dentogingival (coronal, horizontal, and apical), alveologingival, intercapillary, transgingival, circular, semicircular, dentoperiosteal, transseptal, periosteogingival, intercircular, and intergingival.[68] At least six of these gingival fiber groups insert into the cementum of the natural tooth: the dentogingival (coronal, horizontal, and apical), dentoperiosteal, transseptal, circular, semicircular, and transgingival fibers. In addition, some crestal fibers from the periodontal fiber bundles also insert into the cementum above the alveolar bone. These Sharpey fibers form a true attachment to the tooth, preventing a periodontal probe from invading the periodontal ligament (PDL) space and delaying the ingress of plaque.

The biological width allows gingival fibers of the CT attachment zone to establish direct contact with the natural tooth and acts as a barrier to the bacteria in the sulcus to the underlining periodontal tissues. When a crown margin invades the biological width, the crestal bone recedes to reestablish a favorable environment for the gingival fibers[69,70] (Figure 8-32).

Many surgical protocols recommend the placement of endosteal implants at or below the crest of the ridge during the first-stage surgery. The abutment-to-implant body connection has been called a "microgap" and compared to a crown margin (Figure 8-33). Berglundh et al. observed 0.5 mm of bone loss below the abutment–implant connection within 2 weeks after stage II uncovery and abutment connection in dogs.[65] Lindhe et al. reported an inflammatory CT extending 0.5 mm above and below this abutment–implant connection.[71] Wallace and Tarnow stated that the biological width concept of a tooth also applies to implants with the abutment–implant connection acting as a crown margin and contributes to the marginal bone loss observed.[72,73]

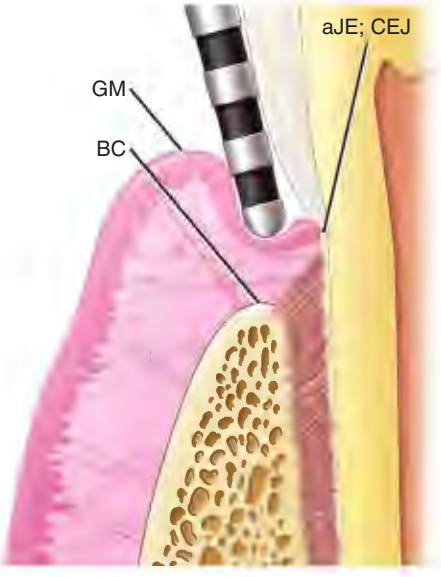


FIGURE 8-31. The biological width of a natural tooth has a connective tissue zone that inserts into the cementum of the tooth. A periodontal probe will penetrate the sulcus and the junctional epithelial attachment (aJE). *BC*, Bone crest; *CEJ*, cementoenamel junction; *GM*, gingival margin.

The biological width for implants has been reported by Cochran et al. to be 3.3 mm, but unlike the biological width dimension for teeth, they also included the sulcus depth.[74] Therefore, according to this theory, crestal bone loss of approximately 2 mm would occur when an abutment–implant connection was placed at the crest of the bone. The biological width theory seems attractive to explain the lack of bone loss from the first stage surgery and the early bone loss seen within the first few months after the second-stage abutment placement even when the implant is not loaded.

In a typical implant gingival region, only two of the gingival fiber groups are found around a tooth (circular and periosteogingival fibers), and no periodontal fibers are present[64] (Figure 8-34). These fibers do not insert into the implant body below the abutment margin as they do into the cementum of natural teeth.[75] Instead, the collagen fibers around an implant run parallel to the implant surface, not perpendicular, as with natural teeth.[64,65] Hence, the implant only has a junctional epithelial "attachment" system. The gingival and periosteal fiber groups are responsible for the CT attachment component of the biological width around teeth, and these are not present around the transosteal region of an implant. Therefore, the "biological width" around the abutment–implant connection should not be compared with the CT attachment of a tooth.

James and Keller were first to begin a systematic study to investigate the biological seal phenomenon of the soft tissue around dental implants.[64] Hemidesmosomes help form a basal lamina–like structure on the implant, which can act as a biological seal.[76] However, collagenous components of the linear body cannot physiologically adhere to or become embedded into the implant body.[77] The hemidesmosomal seal has a circumferential band of gingival tissue to provide mechanical protection against tearing.[78] However, the mucopolysaccharide layer is less adherent to an implant surface than a natural tooth root. The hemidesmosome of the natural tooth has a lamina lucida and a lamina densa. The hemidesmosome next to an implant has a lumina lucia, lamina densa, and sublamina lucida (which is less adherent).

The biological seal around dental implants can prevent the migration of bacteria and endotoxins into the underlying bone. It is unable, however, to constitute an attachment component of the biological width similar to the one found with natural teeth. A dental probe introduced into an implant sulcus may proceed past this close approximation of tissue, and the probe may proceed to the crestal bone (Figure 8-35). The amount of early crestal bone loss therefore seems unlikely to be the result of the remodeling of the hard and soft tissues to establish a hemidesmosomal seal below an abutment connection. This process is unnecessary for an implant because no CT attachment zone or components of the linear body are embedded into an implant.

The "microgap" of an abutment-to-implant connection is not a space, not even a microspace. This distance between the

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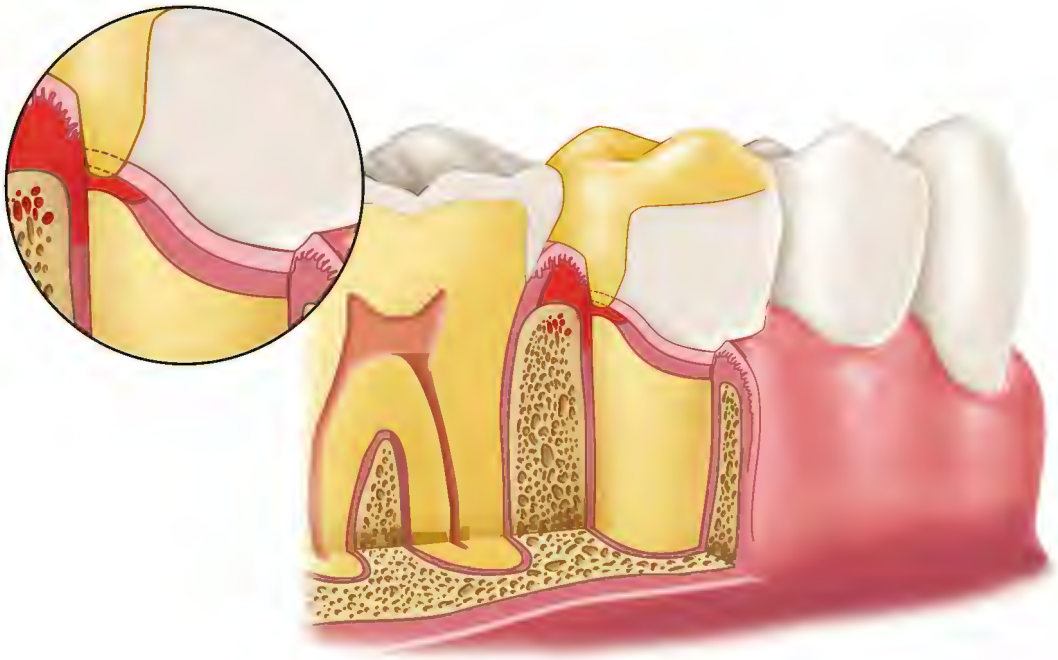


FIGURE 8-32. When the margin of a crown invades the biologic width of a tooth, the bone recedes, and the biologic width is reestablished on the root of the tooth.

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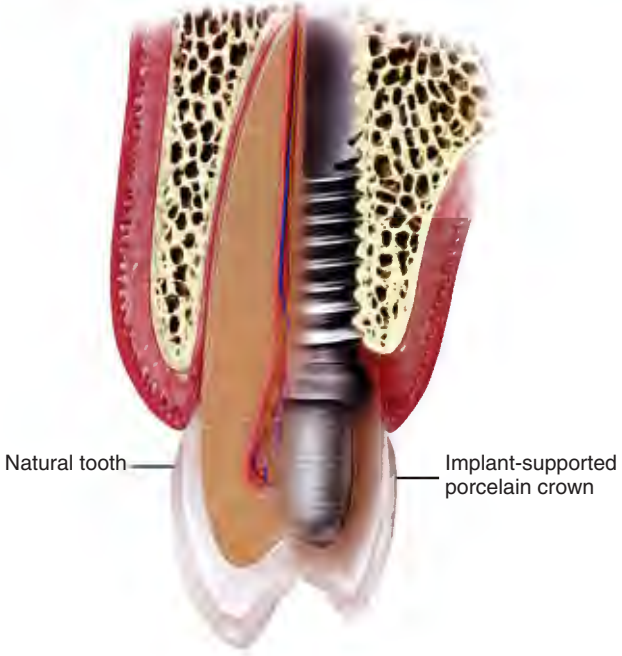


FIGURE 8-33. The abutment-to-implant connection has been compared to a crown margin. Hence, in this hypothesis, when the connection is placed at the bone crest, the bone is lost to reestablish a biological width.

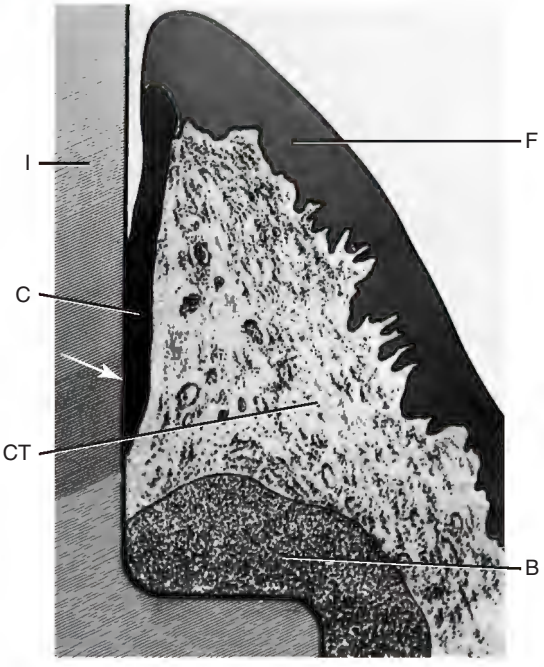


FIGURE 8-34. There are primarily two soft tissue fiber groups around an implant: circular fibers and crestal bone fibers. Neither of these fiber types inserts into the implant or the abutment. *B,* Bone; *C,* junctional epithelial attachment zone; *CT,* connective tissue; *F,* free gingiva; *I,* implant.

components is 0 microns. It is a connection, not a "gap" (Figure 8-36). There may be a crevice between the components, depending on the connection design, but it has a 0-micron space because it is a metal contact. However, if the abutment screw becomes loose or flexes with a lateral load, it may introduce periodic movement at the interface between the components.

The crevice between the cover screw and the implant body during initial healing is similar to the crevice of the abutment–implant connection, yet bone can grow over the cover screw. Therefore, the crevice, in and of itself, may not be the cause of bone loss.[74] However, when the cover screw is removed and the abutment is connected and exposed to the oral environment,

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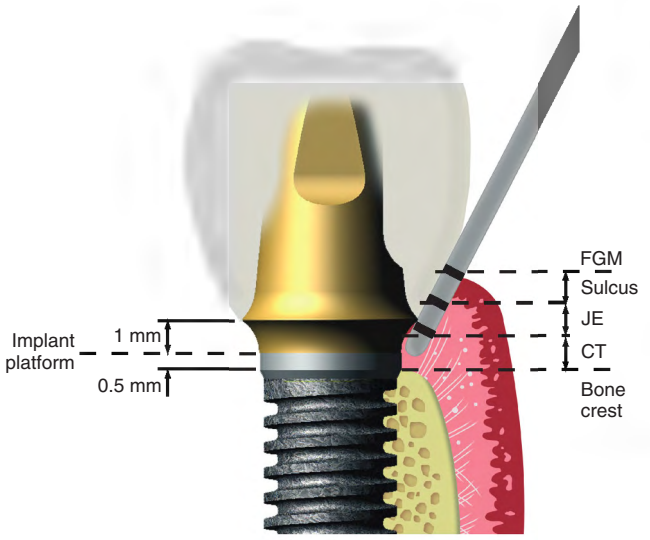


FIGURE 8-35. The periimplant probe penetrates the sulcus and junctional epithelial attachment, and there is no connective tissue attachment zone. *CT,* Unattached connective tissue; *FGM,* free gingival margin; *JE,* junctional epithelium.



FIGURE 8-36. The abutment-to-implant connection does not have a "gap." The space is 0 microns because it is a connection. (Bio-Horizons, Birmingham, AL.)

bone loss is usually observed for at least 0.5 mm below the connection.[74,79] This may be a result of the gross movement of the components. Therefore, some cause of bone loss from the connection is evident, but it is limited in scope (depending on the crest module design).[80]

The biologic width cause of bone loss implies that all implant designs would lose at least 2 mm to establish a biologic width from the abutment-to-implant connection. Rather than 2 to 3 mm of bone loss from an abutment to the implant connection that corresponds to a "biologic width," many reports with several different implant designs indicate less than 1 mm of bone loss from the abutment-to-implant connection when it is



FIGURE 8-37. The bone loss from the abutment-to-implant connection is often less than 1 mm (depending on implant design).

placed at the crest of the ridge (see Figures 8-8 and 8-37). In addition, the biological width hypothesis cannot explain the several millimeters of marginal crestal bone loss, which has also been observed on occasion. One-piece implants that extend through the tissue at the initial implant placement surgery and have no abutment–implant connections may also demonstrate several millimeters of crestal bone loss. For example, plate form (blade) implants, transosteal implants, pins, one-piece screw implants, and even subperiosteal implants may demonstrate the marginal crestal bone loss phenomenon.[47] However, it is true that bone loss does occur around an implant connection after the cover screw is removed and an abutment–implant connection is exposed even though the bone was initially present, and this bone loss may be observed within 4 weeks.[61,74,79,81] The bone loss of 0.5 mm below the abutment–implant connection exposed to the oral environment may be called the "implant biologic width" because it occurs with almost every implant design. The primary question remains, when the surgeon places the implant abutment connection at or slightly above the bone, how can the bone loss of the "implant biological width" be limited?

Implant Crest Module Design Hypothesis

Biological width–related bone loss implies that all implants lose the same amount of bone regardless of the implant design or surface condition. Several reports in the literature note that different bone loss amounts are related to implant macro- and microgeometry and therefore may affect the "biological width" dimensions or the amount of early crestal bone loss before occlusal loading.[9,80,82] The crest module of an implant body is that portion between the abutment-to-implant body connection to the bone load-bearing design of the implant body (i.e., thread, rough surface condition, plateau).

A study by Hermann et al. evaluated six different scenarios of implant design and attachment connection.[79,81] Two conditions were one-piece implants with no abutment-to-implant connection. One of the one-piece implants had an implant design with a rough surface placed at the crest of bone; another one-piece design had smooth metal for 1.5 mm below the crest before a rough surface on the implant body (Figure 8-38). No load was applied to the implants for 6 months. During the first month, the implants with a smooth neck below the bone lost 1.5 mm of bone to the subcrestal roughened area, and the next 5 months, the bone level remained at this level (Figure 8-39).

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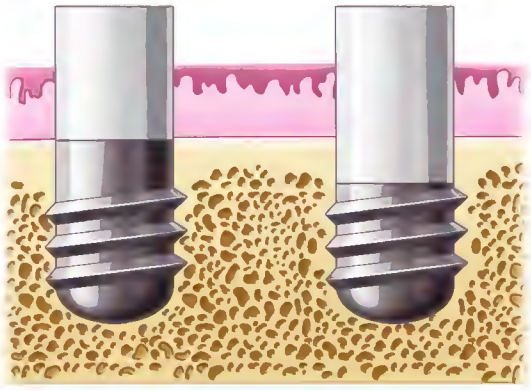


FIGURE 8-38. Two different one-piece implant designs were evaluated for crestal bone loss before loading. The implant on the *left* had a rough surface placed at the bony crest, and the implant on the *right* placed 1.5 mm of smooth metal below the bone.

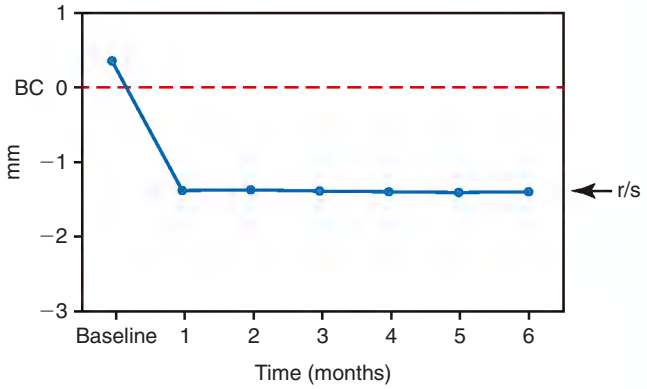


FIGURE 8-39. When the one-piece implant with 1.5 mm of smooth metal was placed below the crest of bone (BC), the bone was lost within the first month to the roughened area on the implant body. For the following 5 months, the bone remained at this level. *r/s,* Rough surface.

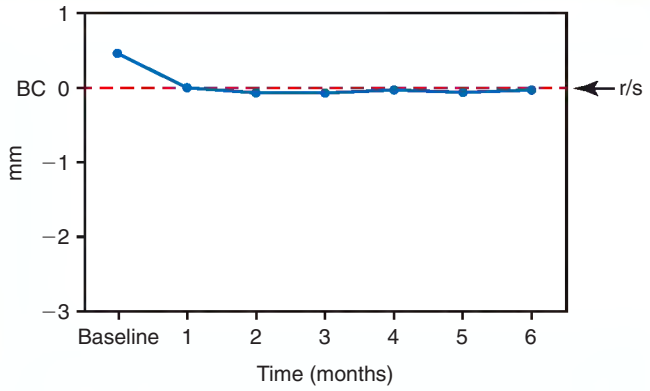


FIGURE 8-40. The implant with a roughened surface was placed at the bony crest (BC). The bone level remained at this landmark through the complete 6-month period. *r/s,* Rough surface.



FIGURE 8-41. Two implants with a similar body design were inserted and evaluated for early crestal bone loss. The implant on the left (a) had a roughened surface placed at the bone crest, and the implant on the right (b) had smooth metal placed below the bone with the first thread 2 mm below the crest.

The one-piece implant with the roughened surface positioned at the crest of bone did not lose any bone and maintained the bone at the crest for a full 6 months (Figure 8-40). Neither of these implant designs were loaded during the 6-month period.

A similar study with a one-piece implant design was performed by Gotfredsen et al.[83] However, in this study, the two-implant designs were slightly different. One implant had a rough surface placed at the crest of bone (similar to the Hermann et al. study). The other implant had a machined surface for 2 mm placed below the bone (similar to the Hermann et al. report). But in this case, a machined first thread (instead of a rough surface) was placed at this 2-mm depth (Figure 8-41). The initial bone response for the rough-surface implants positioned at the bony crest had no crestal bone loss (Figure 8-42), but bone was lost to the first thread in the one-piece implant with machined metal below the crest of bone (Figure 8-43).

Both the Hermann et al. and Gotfredsen et al. studies were in good-quality bone without an occlusal load. Hence, it appears the extent of the "implant biologic width" bone loss is directly related to the amount of smooth metal on the crest module that is placed below the bone before a rough-surface condition or the position of the first thread for implants with a machined-surface condition. Yet many manufacturers have smooth surface conditions on the crest module (Figure 8-44). The concept of a smooth surface is so plaque will not adhere if bone loss occurs. However, the smooth surface condition on the crest module is directly related to the occurrence and the amount of bone loss.

The initial bone loss around an implant after it is exposed to the oral environment occurs to either the rough surface of the implant abutment below the connection, or when a rough surface is absent, occurs to the first thread on the implant body.[74,79] The more apical the rough region or first thread, the more bone loss observed. The bone loss from this phenomenon occurs before the implant is loaded with the prosthesis. It is logical to relate this marginal bone loss to the "implant biological width." The amount, however, may be less than 1 mm or more than 4 mm (depending on the implant crest module design) compared with the more consistent 2 mm for a tooth. The location of the rough surface condition or first thread is a different distance from the abutment–implant connection for several implant designs. A smooth polished or machined 4-mm collar of the crest module below the bone before the first thread

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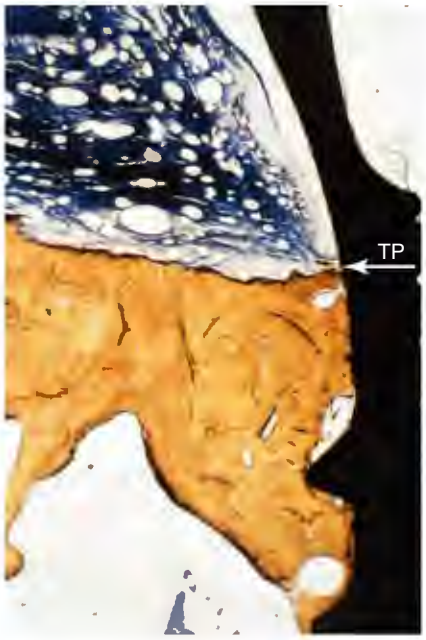


FIGURE 8-42. The implant body with a roughed surface at the crest maintained the bone during the study. (No occlusal load was applied.) *TP,* Initial bone level.



FIGURE 8-43. The implant body with a smooth metal portion below the crestal bone lost bone to the first thread. *TP,* Initial bone level.

has been associated with greater bone loss after permucosal extension into the mouth than a smooth or machined 2-mm collar below the bone above the first thread and different when the rough surface is positioned at the bone crest (Figure 8-45). Therefore, the "implant biological width" concept appears to be related to the implant crest module surface condition and implant crest module design.

In conclusion, the amount of bone loss from the "implant biological width" occurs within 1 month after the implant is permucosal, whether the implant is loaded or not, and is related to the crest module implant design and the position of the

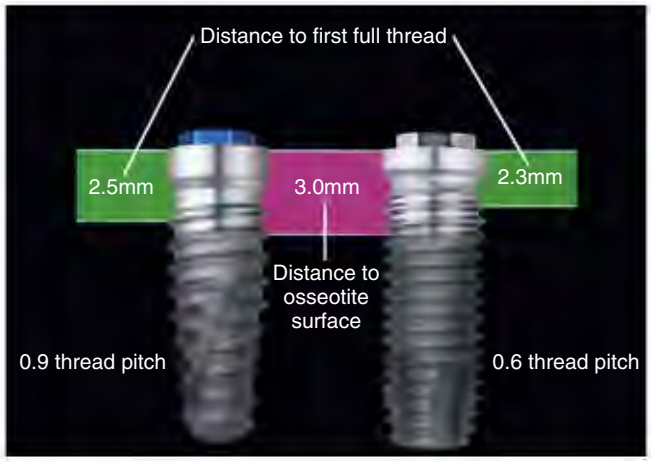


FIGURE 8-44. Many implant designs have smooth implant body designed on the crest module of the implant body (Biomet; 3i implants).



FIGURE 8-45. An implant design with a smooth crest module of 4 mm before the first thread often loses 4 mm of bone. The amount of early crestal bone loss is directly related to the amount of smooth metal placed below the bone.

abutment–implant connection in relation to the bone and appears to be unrelated to the density of the bone. Hence, the dental surgeon can limit the "implant biologic width" bone loss by not countersinking the implant below the bone (which positions the abutment–implant position more apical) and using an implant design that has a crest module that is roughened or has a first thread below the abutment–implant crest module position (Figures 8-46 and 8-47).

The "implant biologic width" concept does not explain the range of crestal bone loss observed after loading or the difference in the bone loss in soft bone compared with denser bone after loading.

Biomechanical Causes

Occlusal Trauma Hypothesis

A controversy exists as to the role of occlusal load in the bone loss observed after an implant prosthesis delivery.[48] The bone loss addressed from occlusal trauma is that portion beyond the crest module and below the first thread or rough-surface condition of an implant body (in other words, bone loss around the implant body portion designed to distribute the occlusal load;

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FIGURE 8-46. The bone loss around an implant may be reduced when the implant is not countersunk below the bony crest. Countersinking the implant places the abutment connection below bone, and when the cover screw is removed and the abutment inserted, the bone remodels below the abutment implant connection to the first thread or roughened region on the implant body.



FIGURE 8-47. An implant with roughened surface or a thread positioned at the bone crest may maintain the bone with more frequency than when smooth metal is placed below the bone.



FIGURE 8-48. The bone loss after bone loading is measured from the first thread or the portion beyond the rough surface of the implant body. The implant on the *left* has bone loss beyond the rough surface and to the fourth thread, and the implant on the *right* has bone loss beyond the rough surface that was placed at the crest and to the second thread (Straumann ITI).

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Figure 8-48). Some articles state that periimplant bone loss without implant failure is primarily associated with biological formations or complications.[49,50,84] Other authors suggest a correlation of crestal bone loss to occlusal overload.[85–87] The determination of the etiology of bone loss around dental implants is needed in order to minimize its occurrence and foster long-term periimplant health, which may ultimately determine implant prosthesis survival.[88]

Occlusal trauma may be defined as an injury to the attachment apparatus as a result of excessive occlusal force.[89] The association of occlusal trauma and bone loss around natural teeth has been debated since Karolyi claimed a relationship in 1901.[90] A number of authors conclude trauma from occlusion is a related factor in bone loss around natural teeth, although bacteria is a necessary agent.[91–95]

On the other hand, Waerhaug and many others state that there is no relationship between occlusal trauma and the degree of periodontal tissue breakdown.[96] According to Lindhe et al., "trauma" from occlusion cannot induce periodontal tissue breakdown.[97] Occlusal trauma may lead to tooth mobility from an insult to the periodontal ligament that can be transient or permanent but does not affect the marginal crestal bone levels around a tooth. By extrapolation of this rationale, several authors have also concluded that occlusal trauma is not related to marginal bone loss around a dental implant.[98] However, most articles agree that occlusal trauma can cause implant failure. Hence the issue is, does occlusal trauma cause crestal bone loss without causing the loss of the complete bone–implant interface?

Occlusal trauma is a condition that is more under the control of the dentist than biological factors. The treatment plan, implant position, implant number, and occlusal design may all affect the magnitude, direction, and duration of the occlusal load. To establish further a correlation between marginal bone loss and occlusal overload, related articles from engineering principles, mechanical properties of bone, physiology of bone, implant design biomechanics, animal studies, and clinical reports were procured.[87]

Engineering Principles

Cellular biomechanics and the relationship of modulus of elasticity mismatch between titanium and bone have been previously presented in this chapter. Hence, stress can cause bone loss from too much microstrain on the bone, and the complete interface may break down, causing early implant failure.

The *composite beam analysis* is an engineering principle that states that when two materials of different elastic moduli are placed together with no intervening material and one is loaded, a stress concentration increase will be observed where the two materials first come into contact.[99] In an implant–bone interface, the stress contour increase of greater magnitude is at the crestal bone region. This phenomenon was observed in both photoelastic and three-dimensional finite element analysis (Figures 8-49 and 8-50) studies when implants were loaded within a bone simulant. These greater stresses may lead to strains above the pathologic overload zone and cause crestal bone loss. The marginal bone loss observed clinically and radiographically around implants after occlusal loading follows a similar pattern as the stress contours in these reports.[100]

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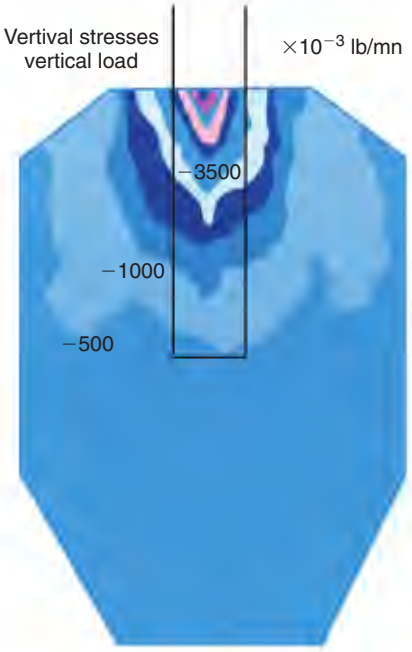


FIGURE 8-49. A three-dimensional finite element analysis of a titanium implant in a bone model after axial loading. The V-shaped pattern of strain is greatest at the crestal region and decreases in intensity as the stress is dissipated throughout the implant length.



FIGURE 8-50. A photoelastic study of a loaded implant in a bone simulant demonstrates the increase in stress contours are primarily at the crestal region.

Bone Mechanical Properties

Bone density is directly related to the strength and elastic modulus of bone.[38] In denser bone, there is less strain under a given load compared with softer bone (Figure 8-51). As a result, there is less bone remodeling in denser bone compared with softer bone under similar load conditions.[19] A decrease in bone remodeling can result in a reduction of bone loss. In a prospective human study, Manz observed the amount of marginal bone

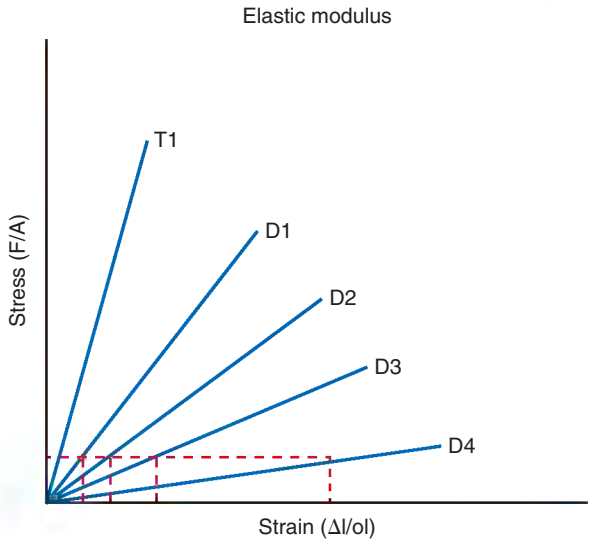


FIGURE 8-51. The modulus of elasticity for bone is related to its density. The hardest bone is more stiff than the softest bone.

loss next to an implant was related to the density of bone.[57] The initial periimplant bone loss from implant insertion to uncovery was similar for all bone qualities. These implants were positioned so the abutment–implant connection was at the crest of the ridge, and a two-stage surgical approach was used. Six months after prosthesis delivery, the average additional radiographically observed periimplant bone loss ranged from 0.68 mm for quality, 1 to 1.1 mm for quality 2, 1.24 mm for quality 3, and 1.44 mm for quality 4 bone (Figure 8-52). In other words, the more dense the bone, the less periimplant bone loss was observed 6 months after prosthesis delivery. This indicates that the marginal bone loss in this report after loading is not from the "implant biologic width" because the same implant design was used in all situations. However, the 0.68-mm bone loss of the most dense quality of bone may be (at least in part) from the "biological width" from the abutment-to-implant connection.

A clinical report by Appleton et al. demonstrated that progressively loaded single-tooth implants in the first premolar region of human beings exhibited greater bone density increase in the crestal half of the implant interface and less marginal bone loss compared with nonprogressively loaded implants in the same jaw region and even the same patient on the contralateral side[101,102] (Figure 8-53). An increase in bone density is related to an increase in bone strength, an increase in elastic modulus, and a decrease in marginal bone loss. Hence, these entities are related to each other and support that the marginal bone loss may be related to occlusal stress (and the strength of the bone).

Animal Studies

Several animal studies in the literature demonstrate the ability of bone tissue to respond to a dental implant. For example, Hoshaw et al. inserted dental implants into a dog femur perpendicular to the axis of the long bone and perpendicular to the direction of the osteons.[103,104] After applying a tensile load to the implants for only 5 days, the bone cells reorganized to follow the implant thread pattern and resist the load. This unique bone pattern was only observed for 3 to 4 mm around the implants. Crestal bone loss was also noted around implants

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loaded versus the nonloaded implants and explained as stress overload (Figure 8-54). To rearrange its osteal structure, bone must remodel. The remodeling process in this report was in response to the biomechanical load. Hence, biomechanical load may strain the bone, which may result in bone remodeling around the implant to modify its structure or cause bone loss at the crestal region (where greater strains are evident).

Miyata et al. placed crowns on integrated dental implants with no occlusal contacts (control group) and premature interceptive occlusal contacts of 100 microns, 180 microns, and 250 microns in a monkey animal model.[105–107] After only 4 weeks of premature occlusal loads, the implants were removed in a block section and evaluated. The crestal bone levels for 100 microns and control implants with no loading were similar. However, statistically significant crestal bone loss was observed in the 180-micron group, and even more loss was evident in the 250-micron group (Figure 8-55). The 250-micron group experienced two to three times the bone loss of the crowns with moderate prematurities. Hence, the greater the occlusal force, the greater the bone loss observed.

Duyck et al. used a dog model to evaluate the crestal bone loss around screw-type dental implants with no loads (controls), static loads, or dynamic loads.[108] The dynamic-loaded implants were the only group to demonstrate crestal bone loss. Because the only variable in these two studies was the intensity or type of occlusal load applied to the implants, these animal reports imply that dynamic occlusal loading may be a factor in crestal bone loss around rigid fixated dental implants. These studies also question the "biological" bone loss because the static-loaded implants did not lose bone, and the range of bone loss was directly related to the amount of stress.

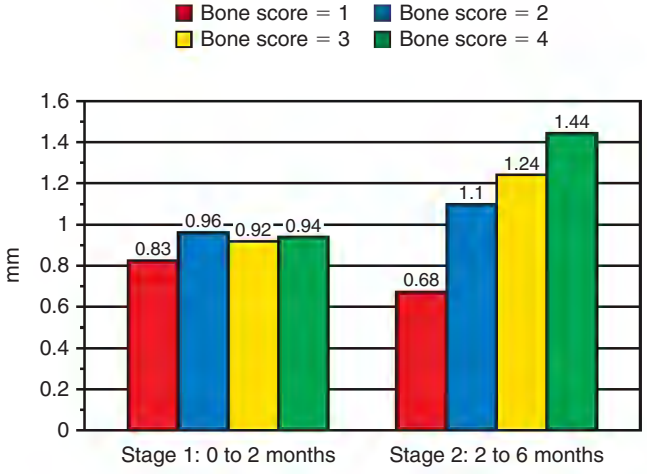


FIGURE 8-52. Mean periimplant vertical bone change for study intervals by bone quality score. Manz observed that the amount of bone loss from stage 1 to stage 2 was similar regardless of bone quality. However, after 6 months of loading, the amount of marginal bone loss was directly related to the quality of the bone, with type 4 (the softest bone) exhibiting the greatest bone loss. (Reproduced from Manz MC: Radiographic assessment of peri-implant vertical bone loss: DIRG Implant Report No 9, *J Oral Maxillofac Surg* 55(suppl):62–71, 1997.)



FIGURE 8-53. Less crestal bone loss and an increase in bone density were present in a human study around implants progressively loaded in the maxillary first premolar region.

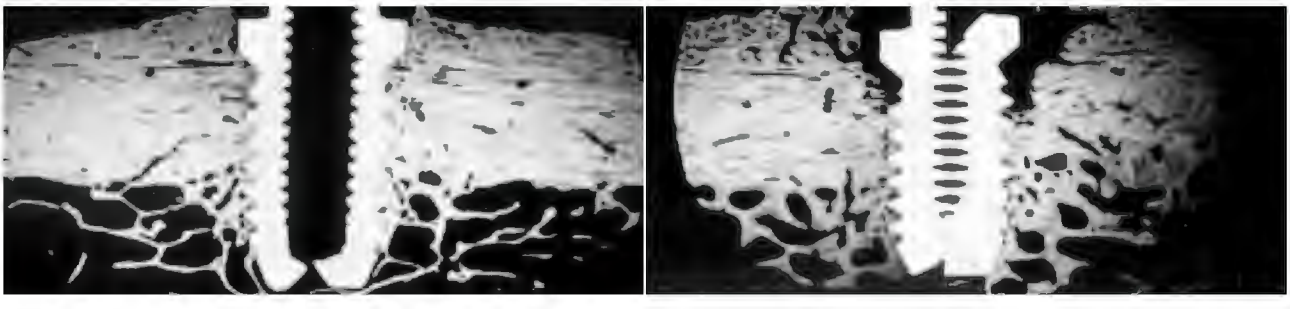


FIGURE 8-54. Loaded threaded implants in dog tibiae showed that the fine trabecular bone in the apical region became coarse trabecular bone after loading. In addition, crestal bone loss was observed on the loaded implants *(bottom)* versus nonloaded implants *(top)*. (From Hoshaw SJ, Brunski JB, Cochran GVB: Mechanical loading of Brånemark fixtures affects interfacial bone modeling and remodeling, *Int J Oral Maxillofac Implants* 9:345–360, 1994.)

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FIGURE 8-55. Miyata et al.[105–107] loaded integrated implants for only 4 weeks with premature contacts on crowns of 100, 180, and 250 μm. **A,** The implants with 100 μm had no crestal bone loss. **B,** The implants with 180-μm premature contacts demonstrated a V-shaped crestal bone loss. **C,** The implants with 250-μm premature contacts demonstrated greater bone loss than the 180-μm group. The higher stresses resulted in more crestal bone loss. (From Miyata T, Kobayashi Y, Araki H, et al: The influence of controlled occlusal overload on periimplant tissue, 3: A histologic study in monkeys, *Int J Oral Maxillofac Implants* 15:425–431, 2000.)

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FIGURE 8-56. Rangert et al. observed that cantilevers on fixed partial dentures increase the marginal bone loss on the implant next to the cantilever. Note that the more distal implant has the same crest module design and no radiographic bone loss.

Clinical Reports

Clinical reports have shown an increase in marginal bone loss around implants closest to a cantilever used to restore the lost dentition[109–111] (Figure 8-56). Cantilever length and an increase in occlusal stress to the nearest abutment are directly related and point to the fact that the increase in marginal bone loss may be related to occlusal stress[112] (Figure 8-57). Quirynen et al. evaluated 93 implant patients with various implant restorations and concluded that the amount of crestal bone loss was definitely associated with occlusal loading.[85] These authors also reported increased crestal bone loss around implants in patients with no anterior occlusal contacts and parafunctional habits in full-arch fixed prostheses in both jaws. No anterior occlusal contacts relate to group function occlusion that increases the force (stress) during mandibular excursions. Parafunctional habits also increase the force and duration of a load. In a study of 589 consecutive implants, Naert et al. suggested overload from parafunctional habits may be the most probable cause of both implant loss and marginal bone loss after loading[113] (Figure 8-58).

Rangert et al. have noted that occlusal loads on an implant may act as a bending moment, which increases stress at the marginal bone level and can cause implant body fracture.[114] Before the fracture of the implant body, marginal bone loss was noted in this retrospective clinical evaluation (Figure 8-59). The same occlusal stress that caused implant fracture is the logical cause of the periimplant bone loss before the event.

Rosenberg et al. found microbial differences in implant failures from both overload and biological complications.[115] Uribe et al. presented the case of a mandibular implant crown with a marginal periimplantitis and osseous defect.[116] Histologic analysis revealed an infiltrate and a central zone of dense fibroconnective tissue with scanty inflammatory cells. According to the authors, this finding differs from chronic inflammatory tissue associated with infectious periimplantitis and can be directly related to occlusal overload.

Jung et al. evaluated the range of marginal bone loss over a 1-year period after loading. They concluded that the range in bone loss was directly related to the amount of occlusal load.[117] A clinical report by Leung et al. observed radiographic angular

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crestal bone loss to the seventh thread around one of two implants supporting a fixed prosthesis in hyperocclusion 2 weeks after prosthesis delivery.[118] The prosthesis was removed, and over the next few months, radiographic observation showed that the crestal defect was repaired to almost the initial level without any surgical or drug intervention. The prosthesis was then seated with proper occlusal adjustment. The bone levels stabilized at the second thread of the implant and remained stable over the next 36 months. This report indicates that bone loss from occlusal overload is not only possible but may even be reversible when found early in the process.

These clinical reports do not provide statistical analyses to demonstrate a clear link between occlusal stress and bone loss. However, they indicate a consensus by some authors that occlusal overload may be related to the incidence of periimplant bone loss around the cervical aspect of an implant.[82] Therefore, although no prospective clinical study to date has clearly demonstrated a direct relationship between stress and bone loss without implant failure, many reports in the literature agree that a causal relationship exists.

Implant Body Design Hypothesis

Different amounts of marginal bone loss have been reported for different implant body designs and often extend beyond the crest module and within the implant body. The design and



FIGURE 8-57. A cantilever to the mesial and to the buccal is present on the second premolar implant. The buccal bone loss on the implant is related to the increased occlusal force.



FIGURE 8-58. Patients with parafunction have a higher incidence of crestal bone loss.

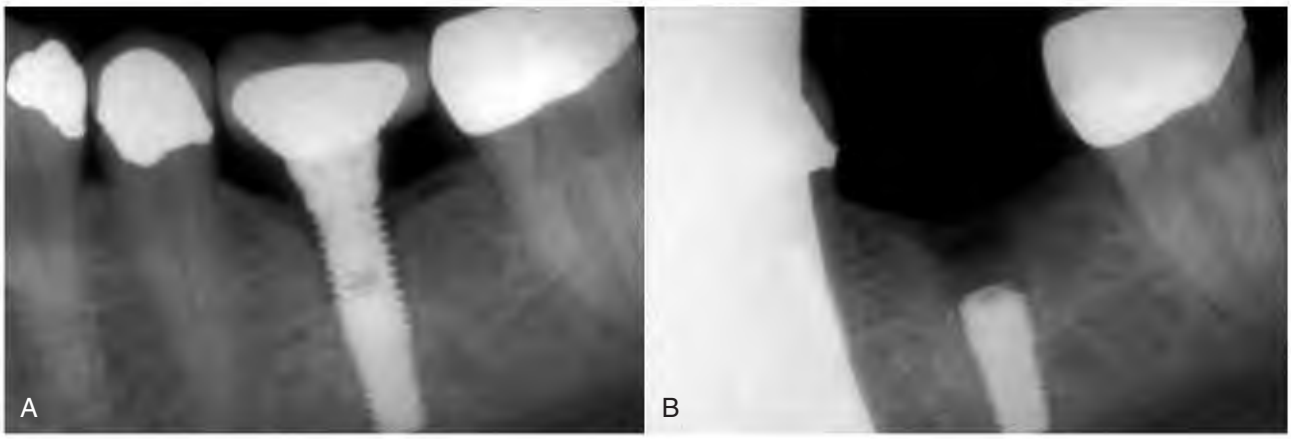


FIGURE 8-59. **A,** An implant with bone loss to the seventh thread after occlusal loading. **B,** A few months later, the implant fractured.

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surface condition of the implant body may affect the amount of strain distributed to an implant–bone interface.[119] A report by Zechner et al. evaluated the periimplant bone loss around functionally loaded screw-type implants with machine-surfaced V threads or a sandblasted or acid-etched square-thread design[120] (Figure 8-60). Both these implant designs had a similar abutment–implant connection and crest module design. Four interforaminal implants were placed in the mandible (where the most ideal bone density usually resides) in 36 patients and followed for 3 to 7 years. Over this period, the range of bone loss in the study was 0.1 to 8.5 mm for machined V-threaded implants and 0.2 to 4.8 mm for rough-surfaced square-threaded implants. Whereas more than 20% of the V-threaded implants lost more than 4 mm of bone, less than 3% of the square threads lost more than 4 mm. Less than 1-mm bone loss was reported for more than 20% of the rough-surface square-threaded implants compared with less than 5% of the machined-surfaced V-threaded implants (Figure 8-61). There were no clinical findings of inflammation or exudate in either design groups.

The range of bone loss with the different implant surface conditions and thread designs in this report by Zechner et al. suggests that more than the biological width, microgap position, or surgical causes are involved in the individual implant marginal bone loss process. All implants in this report were in the anterior mandible, and the implant connection was similar in both groups. The implant body design differences contribute to different stress–strain conditions in bone, with higher stresses in machined V-shaped threads versus rough square threads. This indicates biomechanical stress or occlusal loads as one of the causes of marginal bone loss around an implant.

A prospective study by Karousis et al. also indicated that different implant designs and surface conditions correspond to different incidences of crestal bone loss.[121] Three different implant designs from the same manufacturer were evaluated over 10 years in a prospective report. Whereas one implant body design lost more than 5 mm of bone 26% of the time, the other two designs reported 37% and 39% incidences. More than 6 mm of marginal bone loss occurred in 22% of the implants with the first design compared with 35% and 33% for the other two designs. These results indicate that one implant design may result in less marginal bone loss than another and point to the fact that clinical reports with similar healing and loading protocols but of variable implant body designs and surface conditions may yield different amounts of crestal bone loss. The implant design and surface condition affect the amount of stress transferred to the bone, and a different amount of bone loss for different implant designs is an indicator that biomechanical stress is related to bone loss. Hence, the crestal bone loss around an implant is multifactorial with both biological and biomechanical causes (see Box 8-4).

In the field of orthopedics, hip joint replacement has several complications, including wound infection, periprosthetic fracture, dislocation, mechanical failure, and osteolysis.[122] *Osteolysis* refers to the bone resorption that occurs around both cemented and uncemented orthopedic implants (Figure 8-62). Aseptic loosening from osteolysis of the bone–implant interface is the leading cause of late joint replacement failure (10% within 10 years). Mechanical loading factors primarily are associated with this condition.[123,124] Patient factors that increase loading failure include body weight and activity level.[125] An animal model and human report have linked the resorption of bone at the interface to mechanical overload.[126] Orthopedic reports in the literature accept that mechanical overload can cause bone resorption at the bone–implant interface.[127]

The metal most often used in hip replacement therapy is the same as many dental implants (titanium alloy), and the bone–implant interface is very similar to a dental implant. In addition, potential causative elements encountered intraorally, such as oral bacteria contamination, microgap position, and microbial-related bone loss, are eliminated in this aseptic environment. It is logical to assume that these studies further support a relationship between marginal bone loss around implants and biomechanical stress.



FIGURE 8-60. Zechner et al. compared crestal bone loss for the implant design on the *left* (a V-shaped machined thread) with the implant design on the *right* (a roughened square thread) in the anterior mandible for 3 to 7 years.[120]

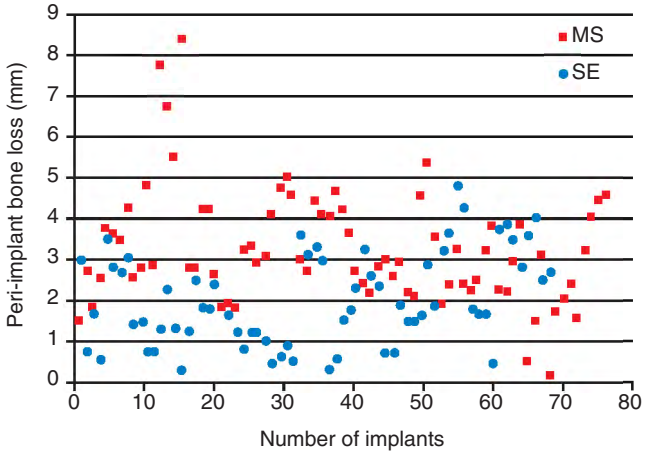


FIGURE 8-61. Most of the implants that lost more than 4 mm of bone were of the machined V-shaped thread design (MS; *red squares*). The implants that lost less than 1 mm of bone were primarily roughened square-thread designs (SE; *blue dots*).

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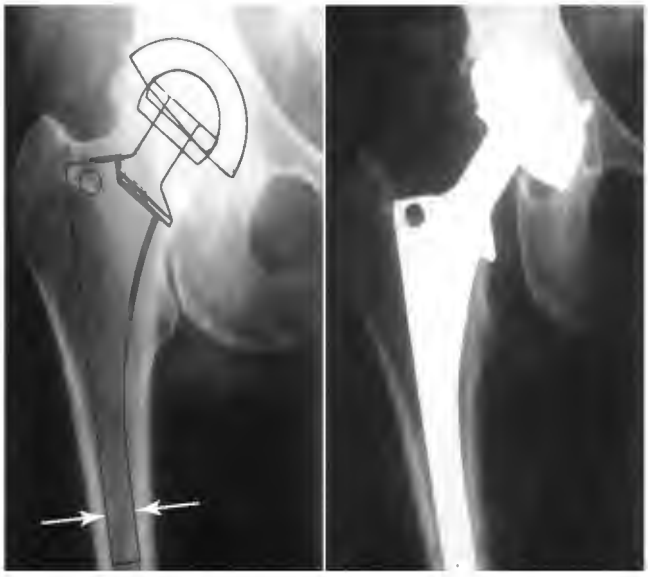


FIGURE 8-62. Bone loss around orthopedic implants (osteolysis) is primarily caused by mechanical stress to the bone–implant interface.

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Arrest of Crestal Bone Loss

A puzzling element in the relationship between occlusal force and periimplant bone loss is the lack of continued bone loss until the implant fails. For example, in the Adell et al. report, the first-year bone loss from the first thread averaged 1.2 mm. Years subsequent to the first year showed an average of 0.05 to 0.13 mm of bone loss per year.[17] Other studies report an average first-year bone loss of 0.93 mm from the first thread with a range from 0.4 to 1.6 mm and a mean loss of 0.1 mm after the first year.[46] This is a primary reason the biological width hypothesis for early crestal bone loss is attractive. The early crestal bone loss has been observed so frequently that proposed criteria for successful implants often do not even include the first-year bone loss amount.[60]

Implant crown height may be measured from the occlusal plane to the crest of the bone. The crown height is a vertical cantilever, which may magnify the stresses applied to the prosthesis. As a result of the greater crown height from the vertical bone loss, occlusal overload will be increased after crestal bone loss occurs.[128] Therefore, if occlusal loading forces can cause crestal bone loss, the resulting increased moment forces should further promote the loss of bone until the implant fails. Yet most clinical studies indicate the rate of bone loss decreases after the first year of loading and is minimal thereafter.

As a result of the bone arrest after the first year, many authors conclude that occlusal trauma is not a cause of bone loss around an implant. There are two reasons why the bone levels may become stable after initial marginal bone loss even when the cause is from occlusal overload: bone physiology and implant design mechanics.

Bone Physiology

The bone is less dense and weaker at stage 2 implant surgery than it is 6 to 12 months later after prosthetic loading.[129] Bone is 60% mineralized at 4 months and takes 52 weeks to complete its mineralization.[130] Partially mineralized bone is weaker than fully mineralized bone. In addition, the microscopic organization of bone progresses during the first year. Woven bone is unorganized and weaker than lamellar bone, which is organized and more mineralized. Lamellar bone develops several months after the woven bone repair has replaced the devitalized bone caused by the surgical insertion trauma around the implant.[129] The occlusal stress levels may be high enough to cause woven bone microfracture or overload during the first year, but the increase in bone strength achieved after complete mineralization and organization may be able to resist the same stress levels during the subsequent years.

As functional forces are placed on an implant, the surrounding bone can adapt to the stresses and increase its density, especially in the crestal half of the implant body during the first 6 months to 1 year of loading. In a histologic and histomorphometric study of bone, Piattelli et al. reported reactions to unloaded and loaded nonsubmerged implants in monkeys.[131] The bone changed from a fine trabecular pattern after initial healing to a more dense and coarse trabecular pattern after loading, especially in the crestal half of the implant interface (Figure 8-63). Hoshaw loaded threaded implants in dogs with a tensile load and noted that the fine trabecular bone pattern became coarse trabecular bone around the implant.[103,104] In addition, the bone reorganized to a more favorable condition to assist the direction and type of occlusal load.

Fine trabecular bone is less dense than coarse trabecular bone.[38] Because the density of bone is directly related to its strength and elastic modulus, the crestal bone strength and biomechanical mismatch between titanium and bone may diminish gradually during the functional loading phase.

The stresses applied to the periimplant bone may be great enough to cause bone resorption during the first year because bone strains are greatest at the crest. However, the stresses applied below the crest of bone are of less magnitude and may correspond to the physiologic strain that allows the bone to gain density and strength (see Figures 8-48 and 8-64). As a result, the occlusal load that causes bone loss initially (overload) is not great enough to cause continued bone loss when the bone matures and becomes more dense.

A clinical report by Appleton et al. demonstrated that progressively loaded single-tooth implants in the first premolar region of humans exhibited less bone loss and a greater bone density increase in the crestal half of the implant interface compared with nonprogressively loaded implants in the same jaw region and even in the same patient on the contralateral side[101,102] (see Figure 8-53). Marginal bone loss is less in the mandible compared with the maxilla in several clinical reports. The bone is denser in the mandible than the maxilla. The reduced crestal bone loss that has been reported in the mandible, in greater bone densities, and in progressively loaded implants point to the fact that stress–strain is a primary etiology of crestal bone loss after the implant is loaded. Therefore, the stresses at the crest of the ridge may cause microfracture or overload during the first year and the change in bone strength after loading and mineralization is complete alters the stress–strain relationship and reduces the risk of microfracture during the following years.

Implant Design Biomechanics

Implant design may affect the magnitude or type of forces applied to the bone–implant interface. A cylinder implant design transmits more shear forces to the bone than a V or square thread. Bone is strongest under compressive forces, 30% weaker under tensile loads, and 65% weaker to shear forces.[132] Bone may heal to a roughened cylinder implant design above

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FIGURE 8-63. **A,** In evaluating the bone around an implant after healing in a monkey model, a fine trabecular pattern is noted. **B,** When the implant was loaded, the fine trabecular bone became coarse trabecular bone, especially at the crestal region. When the stresses are too great, bone loss occurs. When the stresses are within the physiologic range, the bone density increases. (From Piattelli A, Ruggeri A, Franchi M, et al: A histologic and histomorphometric study of bone reactions to unloaded and loaded non-submerged single implants in monkeys: a pilot study, *J Oral Implantol* 19:314–319, 1993.)

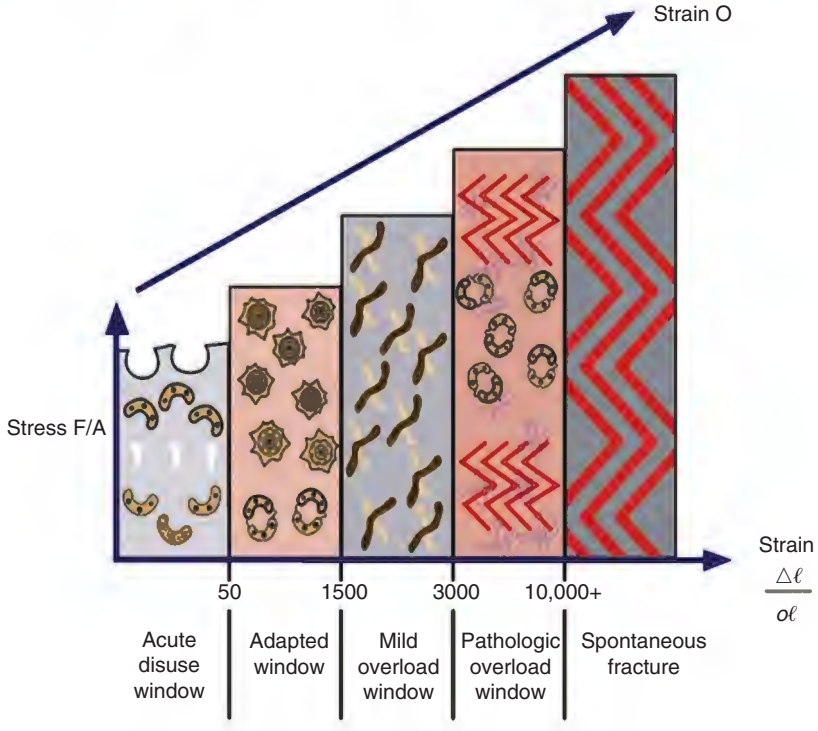


FIGURE 8-64. The pathologic overload zone may exist at the crestal bone after occlusal loading, but the strains away from the crest may be in the adapted window and increase the strength of bone.

the first thread (including the implant crest module) from the time of implant insertion to implant uncovery, but when placed under loading conditions, the weaker shear interface of a cylinder is more likely to overload the bone. The first thread of the implant is where the type of force changes from primarily shear to compressive or tensile loads. Therefore, in many situations, the 35% to 65% increase in bone strength, through changes from shear to compressive or tensile loads, is sufficient to halt the bone loss process. This may be one of the reasons why implant designs with a 2-mm roughened cylinder above the first thread and a 4-mm rough cylinder above the first thread both lose bone to this "first thread" landmark.[18] A previous review addressed the range of bone loss with different implant designs. Because implant crest module and implant body designs may affect the amount of bone loss and the implant design contributes to the force transfer of the bone–implant interface, the stress-related theory for one of the etiologies of crestal bone loss is further enhanced.

Discussion

Marginal bone loss has been observed around the permucosal portion of dental implants for decades. Hypotheses for the causes of crestal bone loss have included the reflection of the periosteum during surgery, preparation of the implant osteotomy, level of the microgap between the abutment and implant

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body, bacterial invasion, the establishment of a biological width, the implant crest module surface conditional design, and occlusal overload.

A key for the most probable cause of marginal bone loss around an implant is the time period under review. The time periods of a two-stage implant approach may be divided into five phases: (1) surgical phase (day 1 of the surgery to implant uncover), (2) the uncovery of the implant to prosthetic loading, (3) the early loading period of the prosthesis, (4) the intermediate period (1 to 5 years), and (5) the long-term period (more than 5 years) (Box 8-5).

The most likely cause of the range of bone loss during phase I (the surgical phase) is the osteotomy preparation. The more common cause of phase 2 (implant uncovery) bone loss are from the position of the abutment–implant connection relative to the crest of ridge and the crest module implant surface condition and design. The more common reasons for phase 3 (the early loading period) bone loss are the amount of occlusal load and the implant body design. These factors are influenced by the bone density around the implant. Phase 4 (intermediate period) bone loss most often is related to implant body design and bacteria-related factors. The bone loss during the long-term period, phase 5, is most often related to bacterial–host response conditions (Box 8-6).

Clinicians have certain variables under their control that may influence the amount of periimplant bone loss. The position of the microgap in relation to the bony crest and the implant crest module design are primarily under the control of the implant surgeon. The implant treatment plan, occlusal load, and implant body design influence phases 3 and 4 of this time period. On the other hand, the autoimmune or bacterial response of the patient and the patient response to the surgical trauma of implant placement are variables that often escape the control of the dentist.

BOX 8-5 Crestal Bone Loss Related to Periods of Time

1. Surgical phase
2. Uncovery to prosthetic loading
3. Early loading period
4. Intermediate period (1–5 years)
5. Long-term period (>5 years)

BOX 8-6 Most Likely Cause of Crest Bone Loss Related to Time

1. Surgical phase
   a. Osteotomy preparation
2. Implant uncovery to prosthetic load
   a. Position of abutment–implant connections
   b. Crest module surface condition and design
3. Early loading period
   a. Amount of occlusal load
   b. Implant body design and surface condition
   c. Bone density
4. Intermediate period
   a. Implant body design
   b. Bacteria-related factors
5. Long-term period
   a. Bacterial–host response

Summary

Literature from cellular biomechanics, engineering principles, differences in bone loss related to bone density, animal studies, and clinical reports all substantiate that occlusal overload may be an etiology of periimplant bone loss. Literature related to orthopedic joint replacement devices clearly indicates that biomechanical stress and overload contribute to bone loss at the implant interface. The increase in bone mineralization and organization during the first year, the increase in bone density at the implant interface, and the type of force changes at the first thread of the implant body all are factors that may halt the bone loss phenomenon after the initial marginal loss. Although this occlusal overload concept does not negate other factors related to marginal bone loss, it is more clinician dependent than most other parameters. Treatment plans that emphasize occlusal stress reduction to the prosthesis are therefore mandated.

After the final prosthesis is delivered to the patient, many events responsible for marginal bone loss have already occurred, but others such as occlusal overload and its relationship to the quality of bone persist. Occlusal overload is one factor most in control of the dentist through a stress reduction treatment plan (i.e., key implant positions and implant number), implant design, and occlusal philosophy. Because a relationship between occlusal overload and crestal bone loss exists, approaches to decrease stress to an implant interface appear appropriate.

Effect on Treatment Planning

Understanding the relationships of stress and related complications provides a basis for a consistent treatment system. A general concept in engineering is to determine the cause of a complication and develop a method to reduce the conditions that cause the problem. The clinical success and longevity of endosteal dental implants as load-bearing abutments are controlled largely by the biomechanical milieu in which they function.[128] The stress treatment theorem, developed by the author, states that almost all treatment related to the science of implant dentistry should be centered around the biomechanical aspects of stress.[18,133]

Stress-related conditions that affect treatment planning in implant dentistry include the bone volume lost after tooth loss, bone quality decrease after tooth loss, complications of surgery, implant positioning, initial implant interface healing, initial loading of an implant, implant design, occlusal concepts, prosthesis fixation, marginal bone loss, implant failure, component fracture, prosthesis fracture, and implant fracture. Biomechanical parameters are excellent predictors of increased risks because they are objective and can be measured. One can not only predict which condition presents greater stress and therefore greater risk but also how much the risk is increased.

A risk factor is not an absolute contraindication, but it significantly increases the complication rate. With so many variables, success or failure in implant dentistry is often a complex subject and not necessarily an exact science. But this does not mean a method cannot be established to decrease the risk. For example, smoking is a risk factor for longevity. A long-term smoker has a 75% less chance of living past 75 years of age. This does not mean that a long-term smoker always dies before the average life span of a nonsmoker; smoking is not a poison that

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kills immediately. Several years ago, the oldest person on earth, who was 116 years old, was a smoker. However, this does not negate the fact that smoking is a considerable risk factor for longevity. Likewise, force factors are a considerable risk factor. Greater forces in one aspect of treatment do not always equal implant failure or complications, especially because so many factors are involved, including the density of bone around the implant. Yet the risks may be considerably reduced by decreasing the overall stress to the overall system. To assess the increase in risk factors, each factor is considered separately. The goal is to decrease the overall risk.

Understanding the relationships of stress and related complications provides a basis for a consistent treatment system. The stress treatment theorem has evolved into a particular sequence of treatment planning (Box 8-7).

Prosthesis Design

Partially and completely edentulous patients want teeth, not implants. The final result (the prosthesis) should be visualized before the selection of the foundation (the implants). The design of the prosthesis is related to a number of factors. Nearly all treatments for partially edentulous patients are planned as a fixed restoration. The fixed restoration must consider the soft tissue and whether it requires a surgical or prosthetic replacement approach.

Completely edentulous patients may be treated with either a removable overdenture or a fixed prosthesis. In either approach, the loss of bone from tooth loss and methods to reduce future bone loss are part of the treatment plan. Almost all patients should eventually have a completely implant-supported restoration.

Patient Force Factors

An implant team should evaluate more than 60 items before developing a treatment plan.[18] Of all these conditions, the factors that influence the amount of patient stress may influence treatment more than several other factors combined.[133] Because stress equals force divided by the area to which the forces are applied, the amount of force is directly related to the amount of stress. There are several force factors from the patient to consider, including (1) bruxism, (2) clenching, (3) tongue thrust, (4) crown height, (5) masticatory dynamics, (6) arch location, and (7) the opposing arch. The forces applied to the restoration also differ by their (1) magnitude, (2) duration, (3) type, and (4) predisposing factors (e.g., cantilevers).

Some patient force factors are more important than others. For example, severe bruxism is the most significant factor and, on a risk scale from 1 to 10, is a 10.[134] Forces from bruxism are often the most difficult forces to contend with on a long-term basis.[135] As a result of this condition, marginal implant bone loss, unretained abutments, and fatigue fractures of implants or prostheses are more likely. The increase in force magnitude and duration is a significant problem. A bruxing patient is at higher risk in two ways. The magnitude of the force increases because the muscles become stronger and the number of cycles on the prosthetic components is greater as a result of the parafunction. Eventually, "something" will break if the occlusal disease cannot be reduced in intensity or duration. No long-term implant system is without complications in patients with severe bruxism.

The second highest risk factor is severe clenching, which is a 9 on the risk scale.[136,137] Cantilevers, including crown height, are next on the list, followed by masticatory muscle dynamics. The position of the implant in the arch has a risk of 5 and the opposing arch a 4 on the scale (denture = 1, implant prosthesis = 4). These numbers are arbitrary because they are influenced by the other force factors. However, the clinician should evaluate the patient force conditions and their influencing severity factors. As the overall risk number increases, the biomechanical complication risks increase. The overall treatment plan should be modified when risk factors increase to decrease the overall force or increase the area of support (or both).

Bone Density

The density of bone is directly related to the strength of the bone. Misch et al. have reported on the biomechanical properties of four different densities of bone in the jaws.[138] Dense cortical bone (D1) is 10 times stronger than the soft, fine trabecular bone (D4). D2 bone is approximately 50% stronger than D3 bone. In addition, the stiffness of the bone is affected by the bone density. Young's modulus for compact bone is 10 times larger than trabecular bone. The denser the bone, the stiffer the bone and the less biomechanical mismatch to titanium during loading.

When the bone is soft, the implant number, size, and design should be modified to increase area. In soft bone, progressive bone loading changes the density of the implant–bone contact. The bone is given time to respond to a gradual increase in occlusal load. This increases the quality of bone at the implant interface and improves the overall support system mechanism.

Key Implant Positions

In any prostheses, certain implant positions are more important from a stress management perspective.[139–141] Cantilevers are a force magnifier and represent a considerable risk factor in implant support, screw loosening, crestal bone loss, fracture, and any other item negatively affected by force. Therefore, implant position should aim at the elimination of cantilevers whenever possible, especially when other force factors are increased.

In a five- to 14-unit prosthesis, intermediary abutments are also important in order to limit the edentulous spans to less than three pontics. Whereas a three-pontic prosthesis flexes 18 times more than a two-pontic prosthesis (27 times more than a one-pontic restoration), a two-pontic restoration flexes eight times more than a one-pontic prosthesis.

The canine is an important implant position. The occlusal scheme, direction of force, and magnitude of force require a canine implant whenever this site is available. This is especially important whenever the canine and two adjacent teeth are missing. Therefore, when the two premolars, a first premolar and lateral, or a lateral and a central are missing next to a canine, a canine implant is warranted.

BOX 8-7 Stress Treatment Theorem Sequence of Treatment Planning

- Prosthesis design
- Patient force factors
- Bone density in implant sites
- Key implant positions and number
- Implant size
- Available bone
- Implant design

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The first molar is a key implant position in any partially edentulous arch or full-arch maxillary restoration. The magnitude of the force in the area is four times that in the anterior region and twice that in the premolar region. When a first molar is required in an implant prosthesis for a partially edentulous patient, a first molar implant is indicated.

Implant Number

Treatment plans should incorporate methods to reduce stress and minimize its initial and long-term complications. Several parameters are in the doctor's control to improve the environment of the transosteal region to manage stress around and within endosteal implants. The definition of *stress* is force divided by the functional area over which it is applied. One biomechanical approach to decrease stress is to increase the surface area of the implant support system.[128]

The overall stress to the implant system may be reduced by increasing the area over which the force is applied. The most effective method to increase the surface area of implant support is by increasing the number of implants used to support a prosthesis (see Figure 8-32). For example, Bidez and Misch demonstrated that force distributed over three abutments results in less localized stress to crestal bone than two abutments.[142] This study applies only to implants that are splinted together. Therefore, the number of pontics should be reduced and the number of implant abutments should be increased whenever forces are increased compared with a treatment plan for an ideal patient with minimal force factors.

The retention of the prosthesis is also improved with a greater number of splinted abutments. This approach also decreases the incidence of unretained restorations. Splinted implants also decrease porcelain fracture. The overall amount of stress to the system is reduced, and the marginal ridges on the implant crowns are supported by the connectors of the splinted crowns, with resulting compressive forces rather than shear loads on the porcelain.

Common clinical sense indicates that it is better to err with one extra implant than to err with too few. One implant too few, and the whole treatment may fail. One implant too many, and rarely is a problem noticed. Placing one implant for each buccal root is rarely indicated regardless of the total number of risk factors. However, one implant for each tooth missing may be indicated in the posterior regions of the mouth for a large, young, male patient with severe parafunction. Rarely are more than 10 implants required in a completely edentulous arch, and more rarely are fewer than five implants suggested.

Implant Size

An excessive implant length is not critical at the crestal bone interface in good bone quality but rather for initial stability and the overall amount of bone–implant interface.[143] The increased length also provides resistance to torque or shear forces when abutments are screwed into place.[144] However, the extra length does little to decrease the stress that occurs at the transosteal region around the implant at the crest of the ridge during occlusal loading.[145,146] Excessive implant length is not as effective a method to decrease stress from force factors, with the exception of immediate loading or poor bone quality.

On the other hand, with improper biomechanical management, shorter implants may have higher failure rates after loading.[39] Therefore, the initial treatment plan should use implants at least 10 mm in length; 12 to 15 mm is more ideal. Softer bone types require longer implants than denser bone.

The surface area of each implant is directly related to the width of the implant. Wider root form implants have a greater area of bone contact than narrow implants (of similar design), resulting from their increased circumferential bone contact areas. Each 0.25-mm increase in implant diameter may increase the overall surface area approximately 5% to 10% in a cylinder implant body. Bone augmentation in width may be indicated to increase implant diameter by 1 mm when force factors are greater than ideal. In addition, it has been suggested that an increase in implant diameter may be more effective than implant staggering to reduce stress.[147] The supplemental implant support gained from the greater diameter not only decreases stress but also decreases the likelihood of implant fracture and reduces the force to the abutment screw, which results in less screw loosening.

It is interesting to note that the natural teeth are narrower in the anterior regions of the mouth, where the amount of force generated is less. The natural teeth increase in diameter in the premolar region and again in the molar region as the amount of force increases, with a total 300% surface area increase from the lower anterior teeth to the maxillary molars. The length of natural teeth roots do not increase from anterior to posterior regions of the arch, but their cross-section does.

Available Bone

After the previous steps to the treatment plan sequence have been determined, the available bone in the potential implant sites is evaluated. If adequate bone is present to position the preselected implant position, number, and size, the treatment sequence proceeds to the next factor. If available bone is not present, bone augmentation or modification is required. If these options are not possible, the sequence of treatment is begun again, starting from the prosthesis design.

In the past, the available bone was the first condition evaluated, and the implant position and number were determined from this condition, with little regard to prosthesis design or implant size.[17] This treatment plan approach often led to the high complication rates related to increased stress conditions.

Implant Design

Implant macrodesign may affect surface area even more than an increase in width. A cylinder (bullet-shaped) implant provides 30% less surface area than a conventional threaded implant of the same size. Strong et al. have identified 11 different variables that affect the overall functional surface area of an implant.[148] A threaded implant with 10 threads for 10 mm has more surface area than one with five threads. A thread depth of 0.2 mm has less surface area than an implant with 0.4 mm. Therefore, implant design may be the easiest method to increase surface area significantly and decrease overall risk to the implant interface.

Summary

An understanding of the etiology of the most common implant complications has led to the development of a stress-based treatment plan theorem. After the implant dentist has identified the sources of forces on the implant system, the treatment plan can be designed to minimize their negative impact on the implant, bone, and final restoration. Under these conditions, a consistent solution is an increase in implant–bone surface area. Additional implants are the solution of choice to decrease stress along with an increase in implant width or height and the use

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of more implants to decrease the number of pontics and dissipate stresses more effectively to the bone structure, especially at the crest. The retention of the final prosthesis or superstructure is further improved with additional implant abutments. The amount of bone in contact with the implant is increased as a multiple of the number of implants.

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CHAPTER 9

Prosthetic Options in Implant Dentistry

Carl E. Misch

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Implant dentistry is similar to most aspects of medicine in that treatment begins with a diagnosis of the patient's condition. Many treatment options stem from the diagnostic information. Traditional dentistry provides limited treatment options for completely edentulous patients because a complete denture is the only option. In partial edentulism, more options exist, but there are also limitations because the dentist cannot add abutments, so the restoration design is directly related to the existing oral condition. On the other hand, implant dentistry can provide a range of abutment locations in either completely or partially edentulous patients. Bone augmentation may further modify the existing edentulous condition in both the partial and total edentulous arch and therefore also affects the final prosthetic design. As a result, in implant dentistry, a number of treatment options are available for most partially and completely edentulous patients. Therefore, after the dental diagnosis of the current stomatognathic system is complete, the implant treatment plan of choice is patient and problem based. Not all patients should be treated with the same restoration type or design even when their oral conditions are similar.

Almost all human-made creations, whether art, buildings, or prostheses, require the end result to be visualized and precisely planned for optimal results. Blueprints indicate the finest details for buildings and are fabricated before the actual construction begins. The end result should be clearly identified before the project begins and even before foundation requirements are established. Yet implant dentists often forget this simple but fundamental axiom.

Historically in implant dentistry, a predetermined implant and the bone available for implant insertion dictated the number and locations of dental implants. The prosthesis then was often determined after the position and number of implants were selected (Figure 9-1). This concept is now being reintroduced with computed tomography technology directed toward finding existing bone locations for implant insertion. However, the ideal goal of implant dentistry is not to place implants. Rather, the ideal goals of implant dentistry are to replace a patient's missing teeth to normal contour, comfort, function, esthetics, speech, and health regardless of the previous atrophy, disease, or injury of the stomatognathic system. It is the final restoration, not the implants, that accomplishes these goals. In other words, patients are missing teeth, not implants.

To satisfy predictably a patient's needs and desires, the prosthesis should first be designed. In the stress treatment theorem, the final restoration is first planned, similar to the architect designing a building before making the foundation.[1] Every building construction is designed with detailed blueprints prior to the foundation determinants. Similar guidelines should be used in implant dentistry. Only after the prosthesis is envisioned can the abutments, implant bodies and available bone requirements be determined to support the specific predetermined restoration.[2]

Completely Edentulous Prosthesis Design

Completely edentulous patients are too often treated as though cost were the primary factor in establishing a treatment plan. However, the doctor and staff should specifically evaluate and ask patients about both their needs and desires.[3] Some patients have a strong psychological need to have a fixed prosthesis (FP) as similar to natural teeth as possible. On the other hand, some patients do not express serious concerns whether the restoration is fixed or removable as long as specific problems are addressed. To assess the ideal final prosthetic design, the existing anatomy is evaluated *after* it has been determined whether a fixed or removable restoration is required to address patient desires. An axiom of implant treatment is to provide the most predictable,



FIGURE 9-1. The dentist should select the implant type and position after determining a clear indication for a prosthesis. The final restoration, not the implant type and position, should be determined first. This patient wanted a fixed restoration in the maxilla and mandible. The surgeon only used one implant type (a mandibular staple implant). As a consequence, the patient was forced to accept the overdenture in the mandible with soft tissue support in the posterior region (a hydroxyapatite graft was also placed). The mandibular staple also was used in the maxilla, which required a LeFort I (downfracture) procedure. The maxillary abutments are in the middle of the palate. The consequences of the maxillary procedure were sloughing and loss of the maxilla.

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most cost-effective treatment that will satisfy the patient's anatomical needs and personal desires.

In a completely edentulous patient, a removable implant-supported prosthesis is often the treatment planned because of reduced cost, and it may offer several advantages over a fixed implant restoration. The reduced cost is related to fewer implants required when the soft tissues are also used to support the prosthesis. In these cases, the implants are placed in the anterior regions, and the implants are primarily used for improved retention and to add some stability to the restoration. Because the implants are inserted into the anterior regions of the jaws for this treatment option, less bone augmentation is required. The anterior regions of the jaws have more available bone in height than the posterior regions. Posterior regions of the jaws also resorb four times or faster than anterior regions. Because bone augmentation is usually not required, the overall treatment time is reduced because the bone graft does not require maturation for 4 or more months. Facial esthetics of a completely edentulous patient may be enhanced by a removable prosthesis (RP), especially in the maxilla. The facial flanges of the overdenture may support the lips and face when bone width and height is lost. These contours do not affect oral hygiene procedures because the prosthesis may be removed. The prosthesis may also be removed at night to reduce the risk of nocturnal parafunction. In addition, long-term complications may be easier to treat because the prosthesis may be removed and corrected in the dental laboratory (Box 9-1).

There are also many benefits of a fixed implant restoration compared with an RP. A fixed implant restoration may be indicated for either partially or completely edentulous patients. The psychological advantage of fixed teeth is a major benefit, and edentulous patients often believe the implant teeth are better than their experience with compromised natural teeth. The improvement over their removable restoration is significant. Some completely edentulous patients require a fixed restoration because their oral condition makes the fabrication of teeth difficult if a superstructure and RP are planned. For example, when a patient has abundant bone and implants have already been placed, the lack of crown height space may not permit an RP.

BOX 9-1 Advantages of Removable Implant-Supported Prostheses in Completely Edentulous Patients

1. The treatment may be less expensive for the patient.
2. Fewer implants may be required.
3. Less bone augmentation may be necessary before implant insertion.
4. Treatment will be shorter if no bone augmentation is required.
5. Facial esthetics can be enhanced with labial flanges and denture teeth compared with customized metal or porcelain teeth. The labial contours of the removable restoration can replace lost bone width and height and support the labial soft tissues without hygienic compromise.
6. Daily home care is easier.
7. The prosthesis can be removed at night to manage nocturnal parafunction.
8. Long-term treatment of complications is facilitated.

Fixed prostheses often last longer and have fewer complications than overdentures because attachments do not require replacement, and acrylic denture teeth wear faster than porcelain to metal.[4] In addition, the chance of food entrapment under a removable overdenture is often greater than for a fixed restoration because soft tissue extensions and support are often required in the latter.

The completely implant-supported overdenture requires the same number of implants as a fixed implant restoration. Thus, the cost of implant surgery may be similar for fixed or removable restorations. The laboratory fees for a fixed hybrid prosthesis may be similar to those for an overdenture bar, copings, attachments, and overdenture. Yet because the denture or partial denture fees are much less than FPs, many clinicians charge the patient a much lower fee for removable overdentures on implants. However, chair time and laboratory fees are often similar for fixed or removable restorations that are completely implant supported. As a result, one should consider increasing the patient fees for overdentures to a level more in line with fixed restorations (Box 9-2).

Most often, treatment plans for completely edentulous patients consist of a maxillary denture and a mandibular overdenture with two implants. However, in the long term, this treatment option may prove a disservice to the patient. The lack of posterior implant support in the mandible will allow posterior bone loss to continue.[5] Paresthesia, facial changes, and reduced posterior occlusion to the maxillary prosthesis are to be expected. As a consequence, the upper denture becomes less stable. In addition, the maxillary arch will continue to lose bone, and the bone loss may even be accelerated in the premaxilla (Box 9-3).[6,7] When this available bone dimension is lost, the patient will have more difficulty with retention and stability of the restoration in either arch. The doctor should diagnose the amount of bone loss and its consequences on facial esthetics, function, and psychological and overall health. Patients should

BOX 9-2 Advantages of Fixed Restorations in Completely or Partially Edentulous Patients

1. Psychological (feels more like natural teeth)
2. Abundant bone and inadequate crown height for a removable overdenture
3. Longevity (lasts the life of the implants)
4. Less maintenance (no attachments to change or adjust)
5. Less food entrapment
6. Similar implant number as completely implant-supported overdentures
7. Similar laboratory fees as complete implant-supported overdenture

BOX 9-3 Consequence of Posterior Soft Tissue–Supported Overdenture and Maxillary Denture

- Continued posterior bone loss
- Paresthesia
- Facial changes
- Reduced posterior occlusion to the maxillary prosthesis (with less stability)
- Continued bone loss in the maxillary arch

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be made aware of future compromises in bone loss and its associated problems with minimal treatment options, which do not address the continued loss of bone in regions where implants are not inserted.

It is even more important to visualize the final restoration at the onset with a fixed-implant restoration. After this first important step, the individual areas of ideal or key abutment support are determined to assess whether it is possible to place the implants to support the intended prosthesis. The patient's force factors and bone density in the region of implant support are then evaluated. The additional implants to support the expected forces on the prosthesis designed may then be determined, with implant size and design selected to match force and area conditions. Only then is the available bone evaluated to assess whether it is possible to place the implants to support the intended prosthesis. In inadequate bone or implant abutment situations, the existing oral conditions must be improved or the needs and desires of the patient must be reduced. In other words, either the mouth must be modified by augmentation to place implants in the correct anatomical positions or the mind of the patient must be modified to accept a different prosthesis type and its limitations.

Partially Edentulous Prosthesis Design

A common axiom in traditional prosthodontics for partial edentulism is to provide a fixed partial denture whenever applicable.[8,9] The fewer natural teeth missing, the better the indication for a fixed partial denture. This axiom also applies to implant prostheses in partially edentulous patients.[10] Ideally, the fixed partial denture is completely implant supported rather than joining implants to teeth.[11] This concept leads to the use of more implants in the treatment plan. Although this may be a cost disadvantage, it is outweighed by significant intraoral health benefits. The added implants in the edentulous site result in fewer pontics, more retentive units in the restoration, and less stress to the supporting bone. As a result, complications are reduced, and implant and prosthesis longevity are increased.

Prosthetic Options

In 1989, Misch proposed five prosthetic options for implant dentistry[12] (Table 9-1). The first three options are FPs. These three options may replace partial (one tooth or several) or total dentitions and may be cemented or screw retained. They are used to communicate the appearance of the final prosthesis to all of the implant team members, including the laboratory and patient. These options depend on the amount of hard and soft tissue structures replaced and the aspects of the prosthesis in the esthetic zone. Common to all fixed options is the inability of the patient to remove the prosthesis. Two types of final implant restorations are RPs; they depend on the amount of implant support, retention, and stability, not the appearance of the prosthesis.

Fixed Prostheses

FP-1

An FP-1 is a fixed restoration and appears to the patient to replace only the anatomical crowns of the missing natural teeth. To fabricate this restoration type, there must be minimal loss of hard and soft tissues (Figure 9-2). The volume and position of the residual bone must permit ideal placement of the implant in a location similar to the root of a natural tooth (Figure 9-3).

TABLE 9-1
Prosthodontic Classification

Type	Definition
FP-1	Fixed prosthesis; replaces only the crown; looks like a natural tooth
FP-2	Fixed prosthesis; replaces the crown and a portion of the root; crown contour appears normal in the occlusal half but is elongated or hypercontoured in the gingival half
FP-3	Fixed prosthesis; replaces missing crowns and gingival color and a portion of the edentulous site; prosthesis most often uses denture teeth and acrylic gingiva but may be porcelain to metal
RP-4	Removable prosthesis; overdenture supported completely by implants (usually with a superstructure bar)
RP-5	Removable prosthesis; overdenture supported by both soft tissue and implants (may or may not have a superstructure bar

From Misch CE: Bone classification training keys, *Dent Today* 8:39-44, 1989.

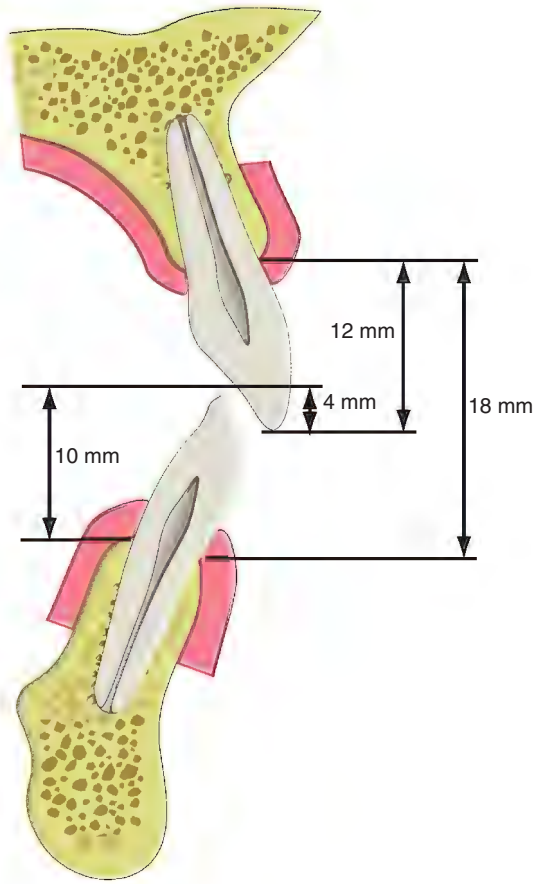


FIGURE 9-2. The healthy natural teeth have abundant bone and ideal soft tissue. The ideal hard and soft tissue allows ideal esthetics.

The final restoration appears very similar in size and contour to most traditional FPs used to restore or replace natural crowns of teeth.

The FP-1 prosthesis is most often desired in the maxillary anterior region, especially in the esthetic zone during smiling

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(Figure 9-4), The final FP-1 restoration appears to the patient to be similar to a crown on a natural tooth. However, the implant abutment can rarely be treated exactly as a natural tooth prepared for a full crown. The cervical diameter of a natural tooth is approximately 6.5 to 10.5 mm with an oval to triangular cross-section. However, the implant abutment is usually 4 to 5 mm in diameter and round in cross-section. In addition, the placement of the implant rarely corresponds exactly to the crown–root position of the original tooth. The thin labial bone lying over the facial aspect of a maxillary anterior root remodels after tooth loss and the crest width shifts to the palate, decreasing 40% within the first 2 years.

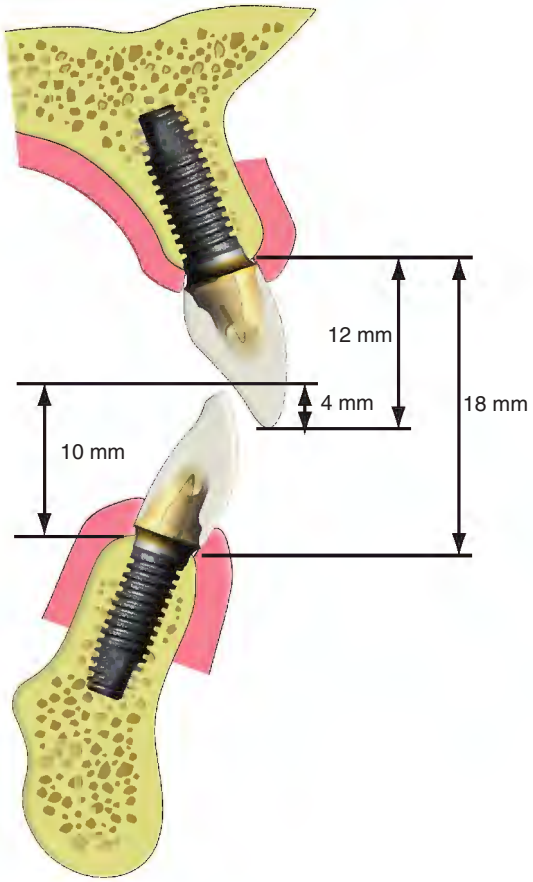


FIGURE 9-3. The bone and soft tissue must be ideal in volume and position to obtain an FP-1 appearance for the final restoration. When multiple teeth are replaced, bone and tissue augmentation is usually required to obtain an FP-1 prosthesis.

The occlusal table of the crown should also be modified in unesthetic regions to conform to the implant size and position and to direct vertical forces to the implant body. For example, posterior mandibular implant-supported prostheses have narrower occlusal tables at the expense of the buccal contour because the implant is smaller in diameter and placed in the central fossa region of the tooth.[13] Maxillary posterior teeth often have reduced occlusal tables from the palatal aspect because the buccal cusp is often within the esthetic zone (Figure 9-5).

The width or height of the crestal bone is frequently lacking after the loss of multiple adjacent natural teeth; therefore, bone augmentation is often required before implant placement to achieve natural-looking crowns in the cervical region. There are no interdental papillae in edentulous ridges; therefore, soft tissue augmentation also is often required to improve the interproximal gingival contour. Ignoring this step causes open "black" triangular spaces (where papillae should usually be present) when the patient smiles. FP-1 prostheses are especially difficult to achieve when more than two adjacent teeth are missing. The bone loss and lack of interdental soft tissue complicate the final esthetic result, especially in the cervical region of the crowns.

The restorative material of choice for an FP-1 prosthesis is porcelain to noble-metal alloy. A noble-metal substructure can easily be separated and soldered in case of a nonpassive fit at the metal try-in, and noble metals in contact with implants corrode less than nonprecious alloys. Any history of exudate around a subgingival base metal margin will dramatically increase the corrosion effect between the implant and the base metal. A single tooth FP-1 crown may use aluminum oxide cores and porcelain crowns or ceramic abutments and porcelain crowns. However, the risk of fracture may increase with the latter scenario because impact forces are greater on implants than natural teeth.



FIGURE 9-4. **A,** An implant is positioned in the maxillary right canine position. The hard and soft tissue conditions are ideal for a crown of normal contour and size. **B,** The maxillary right canine implant crown in position. The soft tissue drape is similar to a natural tooth, and the crown contour is similar to the clinical crown contour of a natural tooth. This is the goal of an FP-1 prosthesis.

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FIGURE 9-5. This full-arch prosthesis has posterior crown contours that are narrower than natural teeth, because the implant is smaller in diameter than the tooth. As a general rule, the maxillary arch has reduced lingual contours and the mandibular posterior prosthesis has reduced buccal contours.

FP-2

An FP-2 fixed prosthesis appears to restore the anatomical crown and a portion of the root of the natural tooth. The volume and topography of the available bone are more apical compared with the ideal bone position of a natural root (1–2 mm below the cement–enamel junction) and dictate a more apical implant placement compared with the FP-1 prosthesis. As a result, the incisal edge of the restoration is in the correct position, but the gingival third of the crown is overextended, usually apical and lingual to the position of the original tooth. These restorations are similar to teeth exhibiting periodontal bone loss and gingival recession (Figure 9-6).

The patient and the clinician should be aware from the onset of treatment that the final FP-2 prosthetic teeth will appear longer than healthy natural teeth (without bone loss). The esthetic zone of a patient is established during smiling in the maxillary arch.[14] The number of teeth displayed in a smile is variable. Fewer than 10% of the population limits their smile to the anterior six teeth. Almost 50% of people show up to the first premolar. Only 4% of our patients display almost all the maxillary teeth during a smile (Figure 9-7), If the teeth do not

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FIGURE 9-6. **A,** An FP-2 prosthesis has longer clinical crowns than healthy natural teeth. The soft tissue drape is also reduced around the prosthesis. **B,** The FP-2 prosthesis appears of normal contour in the esthetic zone during a high smile and/or speech.

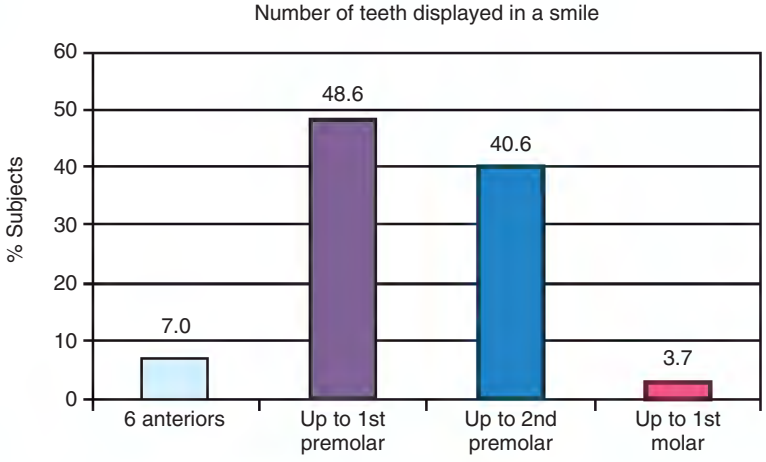


FIGURE 9-7. The number of teeth observed during a high smile line is variable. Almost 50% of patients display the teeth up to a first premolar. Fewer than 4% of patients display the maxillary teeth to the first molar. (Adapted from Tjan AH, Miller GD, The JG: Some esthetic factors in a smile, *J Prosthet Dent* 51:24-28, 1984.)

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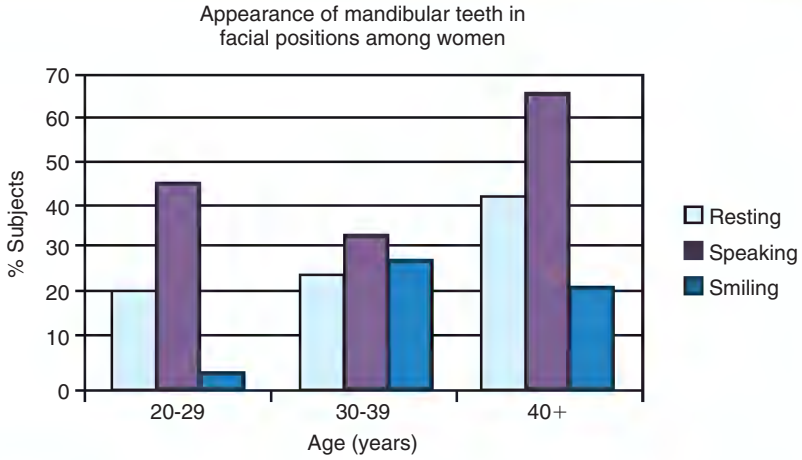


FIGURE 9-8. The appearance of the lower anterior teeth is primarily evaluated during sibilant sounds of speech, and older patients show more teeth than younger patients.



FIGURE 9-9. The number of teeth displayed in a smile may include the first molars *(top)* or be limited to the first premolar *(bottom)*. The soft tissue is also observed around the teeth.

show during smiling or speech, an FP-2 restoration is not a compromise.

The low lip position is evaluated during sibilant sounds of speech (e.g., Mississippi). It is not unusual for patients to show less lower anterior teeth during smiling, especially in younger patients. Older patients are most likely to show the anterior teeth and gingiva during speech, with men showing more than women (Figure 9-8).

Likewise, if the high lip line during smiling or the low lip line during speech does not display the cervical regions, the longer teeth are usually of no esthetic consequence, provided that the patient has been informed before treatment (Figure 9-9).

As the patient becomes older, the maxillary esthetic zone is altered. Whereas only 10% of younger patients do not show any soft tissue during smiling, 30% of 60-year-old adults and 50% of 80-year-old adults do not display gingival regions during smiling (Figure 9-10).

The low lip position of the mandibular lip during speech is not affected as much as the maxillary lip during the high smile line. Rarely do younger or middle-age patients show the lower gingival during speech. Only 10% of older patients show the mandibular soft tissue during speech. Hence, FP-2 restorations in the mandible are common and usually of no compromise[14,15] (Figure 9-11).

A multiple-unit FP-2 restoration does not require as specific an implant position in the mesial or distal position because the cervical contour is not displayed during function. The implant position may be chosen in relation to bone width, angulation, or hygienic considerations rather than purely esthetic demands (compared with the FP-1 prosthesis). On occasion, the implant may even be placed in an embrasure between two teeth. This often occurs when replacing mandibular anterior teeth with a full-arch fixed restoration. If this occurs, the incisal two thirds of the two crowns should be ideal in width, as though the implants were not present. Only the cervical region is compromised. Although the implant is not positioned in an ideal mesiodistal position, it should be placed in the correct facial-lingual position to ensure that contour, hygiene, and direction of forces are not compromised (Figure 9-12).

The material of choice for an FP-2 prosthesis is precious metal to porcelain. The amount and contour of the metal work is different than for an FP-1 restoration and is more relevant in an FP-2 prosthesis because the amount of additional volume of tooth replacement increases the risk of unsupported porcelain in the final prosthesis, when the metal work is undercontoured.

FP-3

The FP-3 fixed restoration appears to replace the natural teeth crowns and has pink-colored restorative materials to replace a portion of the soft tissue, especially the interdental papillae. As with the FP-2 prosthesis, the original available bone height has decreased by natural resorption or osteoplasty at the time of implant placement. To place the incisal edge of the teeth in proper position for esthetics, function, lip support, and speech, the excessive vertical dimension to be restored requires teeth that are unnatural in length. However, unlike the patient requirements for an FP-2 prosthesis, the patient may have a normal to high maxillary lip line during smiling or a low

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FIGURE 9-10. **A,** A full-arch maxillary implant prosthesis. Note that the maxillary right anterior implant is in an embrasure. **B,** The maxillary full arch FP-2 restoration in place. **C,** The FP-2 prosthesis appears as natural teeth in the esthetic zone. **D,** The high smile line of the same patient. The low position of the maxillary lip during smiling permitted the fabrication of an FP-2 prosthesis.



FIGURE 9-11. An FP-2 complete mandibular fixed prosthesis from an occlusal view. The anterior teeth appear ideal in width and contour.



FIGURE 9-12. Almost every implant is in the interproximal embrasure of this mandibular FP-2 restoration. The technician fabricated the incisal aspect of the restoration without regard to the mesiodistal position of the implants.

mandibular lip line during speech. As a consequence, the soft tissue drape should also be replaced. Prosthetic replacement of the soft tissue drape (FP-3 prosthesis) is most often desirable when multiple adjacent teeth are missing (Figure 9-13).

The ideal high smile line occurs in almost 70% of the population and the maxillary lip displays the interdental papilla of the maxillary anterior teeth but not the soft tissue above the midcervical regions (Figure 9-14). Approximately 7% of men and 14% of women have a high smile or "gummy" smile and display the interdental papillae and at least some of the gingival tissues above the free gingival margin of the teeth.[14] Patients in both of these categories of high lip line should have the soft tissue replaced by either the prostheses or the patient's soft tissue (Figures 9-15 and 5-16).

The patient may also have greater esthetic demands even when the teeth are out of the esthetic smile and speech zones. Patients complain that the display of longer teeth appears unnatural even though they must lift or move their lips in unnatural positions to see the covered regions of the teeth. As a result of the restored gingival color of the FP-3, the teeth have a more natural appearance in size and shape, and the pink restorative material mimics the interdental papillae and cervical emergence region (Figure 9-17). The addition of gingival-tone acrylic or porcelain for a more natural FP appearance is often indicated with multiple implant abutments because bone loss

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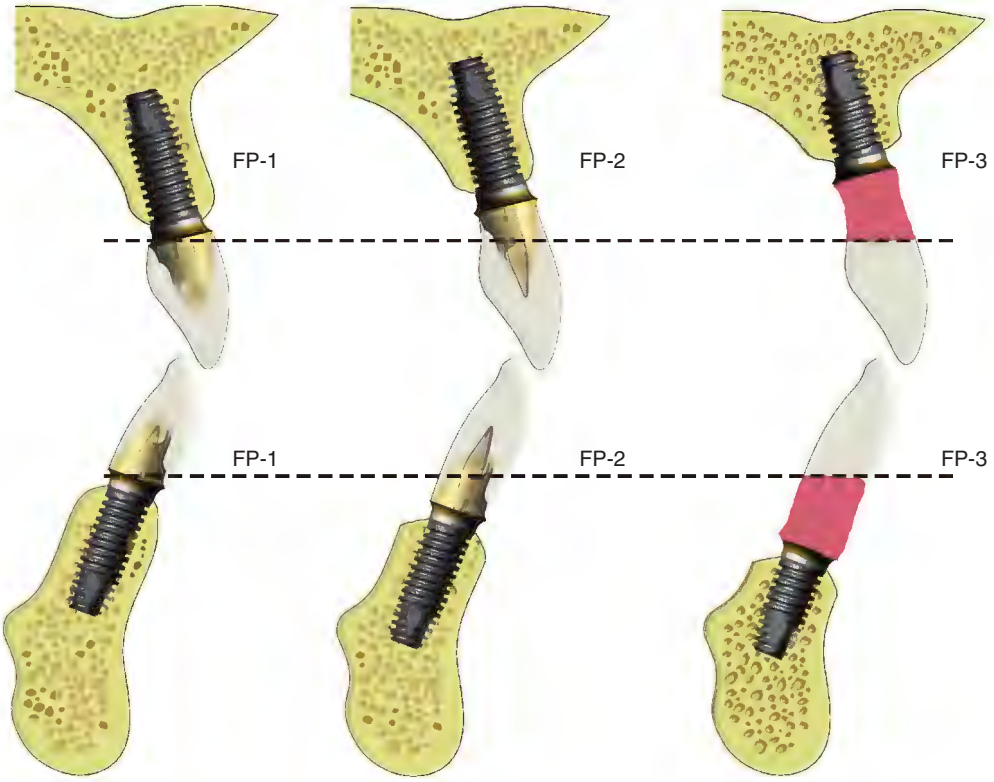


FIGURE 9-13. Fixed restorations have three categories: FP-1, FP-2, and FP-3. The restoration type is related to the contour of the restoration. (FP-1 is ideal, FP-2 is hypercontoured, and FP-3 replaces the gingiva drape with pink porcelain or acrylic.) The difference between FP-2 and FP-3 most often is related to the high maxillary lip position during smiling or the mandibular lip position during sibilant sounds of speech. FP-2 and FP-3 restorations often require more implant surface area support by increasing implant number or size.

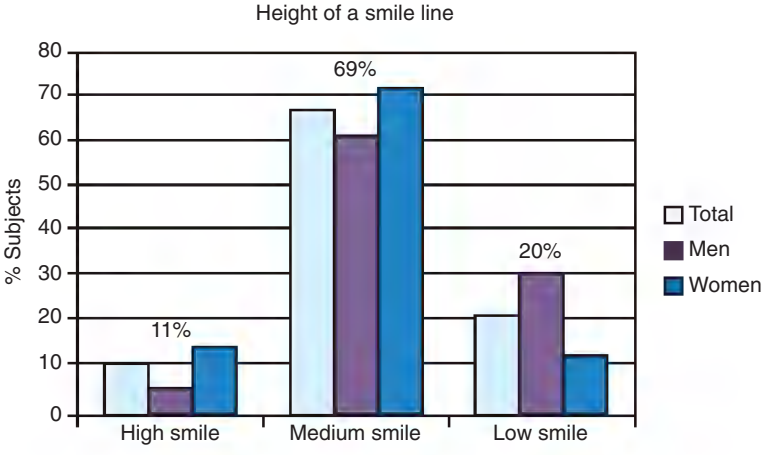


FIGURE 9-14. A smile that shows interdental papillae but no cervical tissue is ideal and found in 70% of patients. A low smile line shows no soft tissue during smiling and is seen in 20% of patients (more men than women). A high smile line displays interdental papillae and the cervical regions above the teeth and are observed in 11% of patients (women more often than men). (Adapted from Tjan AH, Miller GD, The JG: Some esthetic factors in a smile, *J Prosthet Dent* 51:24-28, 1984.)

is common with these conditions, and the soft tissue drape is more difficult to appear ideal (Figure 9-18).

There are basically two approaches for an FP-3 prosthesis: (1) a hybrid restoration of denture teeth and acrylic with a metal substructure[16] or (2) a porcelain–metal restoration (Figure 9-19). An FP-3 porcelain-to-metal restoration is more difficult to fabricate for the laboratory technician than an FP-2 prosthesis. The pink porcelain is harder to make appear as soft tissue and usually requires more baking cycles. This increases the risk of porosity or porcelain fracture.

The primary factor that determines the restoration material is the amount of crown height space.[17,18] An excessive crown height space means a traditional porcelain–metal restoration will have a large amount of metal in the substructure because the porcelain thickness should not be greater than 2 mm thick. Otherwise there is an increase in porcelain fracture.

Precious metals are indicated for implant restorations to decrease the risk of corrosion and improve the accuracy of the casting because nonprecious metals shrink more during the casting process. However, the large amount of metal in the substructure acts as a heat sink and complicates the application of porcelain during the fabrication of the prosthesis. In addition, as the metal cools after casting, the thinner regions of metal cool first and create porosities in the structure. This may lead to

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fracture of the framework after loading. Furthermore, when the casting is reinserted into the oven to bake the porcelain, the heat is maintained within the casting at different rates; thus, the porcelain cool-down rate is variable, which increases the risk of porcelain fracture. In addition, the amount of precious metal in the casting adds to the weight and cost of the restoration.



FIGURE 9-15. **A,** An intraoral view of a maxillary full arch FP-3 restoration shows how it replaces the interdental papillae with pink porcelain. **B,** The high maxillary lip line during smiling shows the interdental papillary regions in the anterior maxilla. Therefore, the fixed prosthesis replaces the gingival regions in the esthetic zone by soft tissue surgery or, as in this case, with the final restoration (FP-3).

An alternative to the traditional porcelain–metal FP is a hybrid restoration. This restoration design uses a smaller metal framework, with denture teeth and acrylic to join these elements together. This restoration is less expensive to fabricate and is highly esthetic because of the premade denture teeth and acrylic pink soft tissue replacements. In addition, the intermediary acrylic between the denture teeth and framework may reduce the impact force of dynamic occlusal loads. The hybrid prosthesis is easier to repair in the case of porcelain fracture because the denture tooth may be replaced with less risk than adding porcelain to a traditional porcelain–metal restoration. However, the fatigue of acrylic is greater than the traditional prosthesis; therefore, repair of the restoration is more commonly needed.

The crown height space determination for a hybrid versus the traditional porcelain–metal restoration is 15 mm from the bone to the occlusal plane.[18] When less than this dimension is available, a porcelain-to-metal restoration is suggested. When a greater crown height space is present, a hybrid restoration is often fabricated.

Implants placed too facial or lingual or in embrasures are easier to restore when vertical bone has been lost and an FP-2 or FP-3 prosthesis is fabricated because the greater crown heights allow the correction of incisal edge positions, and even extremely high smile lip lines do not expose the implant abutments. However, the FP-2 or FP-3 restoration has greater crown height compared with the FP-1 fixed types of prostheses; therefore, a greater moment of force is placed on the implant cervical regions, especially during lateral forces (e.g., mandibular excursions or with cantilevered restorations). As a result, additional implant abutments or shorter cantilever lengths should be considered with these restorations.

An FP-2 or FP-3 prosthesis rarely has the patient's interdental papillae or ideal soft tissue contours around the emergence of the abutments because these restorations are used when there is more crown height space and the lip does not expose the soft tissue regions of the patient. In the maxillary arch, wide open embrasures between the implants may cause food impaction or speech problems. These complications may be solved by using a removable soft tissue replacement device or making overcontoured cervical restorations. The maxillary FP-2 or the FP-3 prosthesis is often extended or juxtaposed to the maxillary soft tissue so that speech is not impaired. Hygiene is more difficult

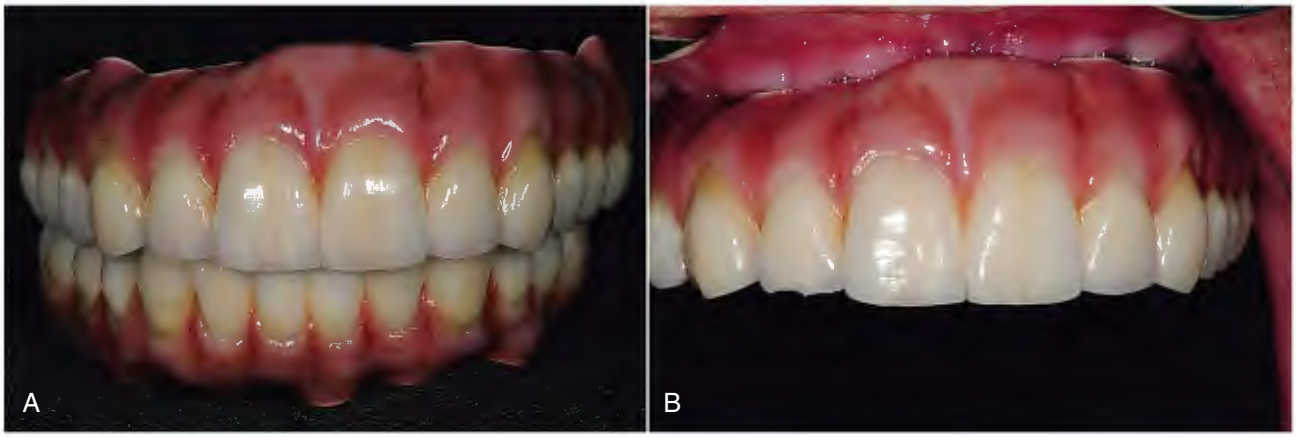


FIGURE 9-16. **A,** Maxillary and mandibular FP-3 prosthesis with pink porcelain on a porcelain-to-metal restoration. **B,** An intraoral view of the maxillary FP-3 prosthesis. The pink porcelain permits the teeth to appear as normal size.

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to control, although access next to each implant abutment is provided.

The mandibular FP-2 and FP-3 restorations may be left above the tissue, similar to a sanitary pontic. This facilitates oral hygiene in the mandible, especially when the implant permucosal site is level with the floor of the mouth and the depth of the vestibule. However, if the space below the restoration is too great, the lower lip may lack support in the labiomental region (Table 9-2).



FIGURE 9-17. An FP-3 mandibular full arch fixed prosthesis. The teeth look of normal size, and the patient may want this option even though the soft tissue drape is not exposed during speech.

Removable Prostheses

There are two types of RPs based on support, retention, and stability of the restoration[10,19] (see Table 9-1) (Figure 9-20). Patients are able to remove the restoration but not the implant-supported superstructure attached to the abutments. The difference in the two categories of removable restorations is not in appearance (as it is in the fixed categories). Instead, the two removable categories are primarily determined by the amount of implant support.

The most common removable implant prostheses are overdentures for completely edentulous patients. Traditional removable partial dentures with clasps on implant abutment crowns have not been reported in the literature with any frequency. No long-term studies are currently available. On the other hand, complete removable overdentures have often been reported with predictability for many decades.[20-24] As a result, the removable prosthetic options are primarily overdentures for the completely edentulous patient.



FIGURE 9-18. **A,** Two porcelain-to-metal fixed prostheses. The maxillary arch is an FP-3 prosthesis with pink porcelain. The mandibular arch has a full arch FP-2 restoration. **B,** The maxillary FP-3 prosthesis with pink porcelain on a porcelain-to-metal fixed prosthesis and FP-2 restoration in the mandible during with a smile to evaluate the maxillary lip position.



FIGURE 9-19. **A,** An FP-3 porcelain-to-metal restoration in the maxilla and an FP-3 hybrid with acrylic–metal and denture teeth in the mandible. **B,** The maxillary FP-3 porcelain to metal and mandibular FP-3 hybrid prosthesis during a smile.

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TABLE 9-2
Comparison of Porcelain-to-Metal versus Hybrid Prostheses (FP-3)

Consideration	Porcelain	Hybrid Metal
Occlusal vertical	≤15 mm	≥15 mm dimension
Technique	Same	Same
Retention	Cement or screw	Cement or screw
Precision of fit	Same	Same
Esthetics	Same	Same
Soft tissue	Difficult	Easier
Teeth	Difficult	Easier (pre-made)
Time or appointments	Same	Less
Weight	More	Less
Cost	More	Less
Impact forces	More	Less
Volume (bulk)	Same	Same
Long term	Same	Same
Occlusion	Same	Same
Speech	Same	Same
Hygiene	Same	Same
Complications	Same	Same
Aging of materials	Less	More

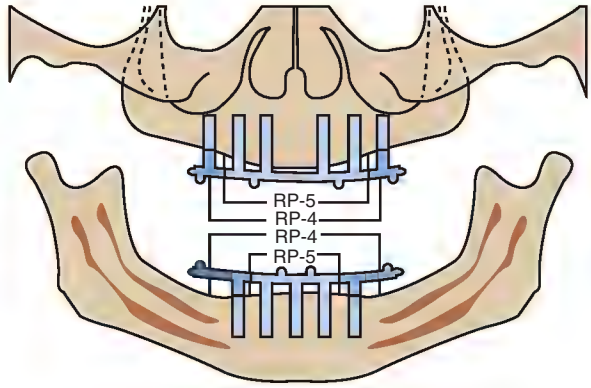


FIGURE 9-20. Removable restorations have two categories based on implant support. RP-4 prostheses have complete implant support in both the anterior and posterior regions. In the mandible, the superstructure bar often is cantilevered from implants positioned between the foramina. The maxillary RP-4 prosthesis usually has more implants and no cantilever. An RP-5 restoration has primarily anterior implant support and posterior soft tissue support in the maxilla or mandible. Often fewer implants are required, and bone grafting is less indicated.

RP-4

RP-4 is an RP completely supported by the implants, teeth, or both.[25] The restoration is rigid when inserted: overdenture attachments usually connect the RP to a low-profile tissue bar or superstructure that splints the implant abutments. Usually five to seven implants in the mandible and six to eight implants in the maxilla are required to fabricate completely implant-supported RP-4 prostheses in patients with favorable dental criteria (Figure 9-21).

The implant placement criteria for an RP-4 prosthesis is different than that for an FP. Denture teeth and acrylic require more prosthetic space for the removable restoration. In addition, a superstructure and overdenture attachments must often be added to the implant abutments. This requires a more lingual and apical implant placement compared with the implant position for an FP.

The implants in an RP-4 prosthesis (and an FP-2 or FP-3 restoration) should be placed in the mesiodistal position for the best biomechanical and hygienic situation. On occasion, the position of an attachment on the superstructure or prosthesis may also affect the amount of spacing between the implants. For example, a Hader clip requires the mesiodistal implant spacing to be greater than 6 mm from edge to edge and as a consequence reduces the number of implants that may be placed between the mental foramina.

The RP-4 prosthesis may have the same appearance as an FP-1, FP-2, or FP-3 restoration. A porcelain-to-metal prosthesis with attachments in selected abutment crowns can be fabricated for patients with the cosmetic desire of an FP. The overdenture attachments permit improved oral hygiene or allow the patient to sleep without the excess forces of nocturnal bruxism on the prosthesis.

RP-5

RP-5 is an RP combining implant and soft tissue support. The amount of implant support is variable.[10] A completely edentulous mandibular overdenture may have (1) two of three anterior implants independent of each other primarily for retention; (2) splinted implants in the canine regions to enhance retention and stability, (3) three splinted implants in the premolar and central incisor areas to provide improved retention and lateral stability; or (4) four or five implants splinted with a cantilevered bar to improve retention, stability, and support which reduces soft tissue abrasions and limits the amount of soft tissue coverage needed for prosthesis support. The primary advantage of an RP-5 restoration is the reduced cost because fewer implants may be inserted compared with a fixed restoration and there is less demand for bone augmentation, often required for additional implants. The prosthesis is very similar to traditional overdentures supported by natural teeth (Figure 9-22).

A preimplant treatment denture may be fabricated to evaluate to occlusal vertical dimension or ensure the patient's esthetic satisfaction.[17] This technique is especially indicated for patients with demanding needs and desires regarding the final esthetic result or with severely reduced vertical dimensions with their present prosthesis. The implant dentist can also use the treatment denture as a guide for implant placement. The patient can also wear the treatment prosthesis during the healing stage. After the implants are uncovered, the superstructure is fabricated within the guidelines of the existing treatment restoration. After this is achieved, the preimplant treatment prosthesis may be converted to the RP-4 or RP-5 restoration.

The clinician and the patient should realize that the bone will continue to resorb in the soft tissue–borne regions of the prosthesis. Relines and occlusal adjustments every few years are common maintenance requirements of an RP-5 restoration. Bone resorption in the posterior regions with RP-5 restorations may occur two to three times faster than the resorption found with full dentures.[5] This can be a factor when considering this type of treatment in young patients despite the lesser cost and low failure rate.

Conclusion

In traditional dentistry, the restoration reflects the existing condition of the patient. Existing natural abutments are first

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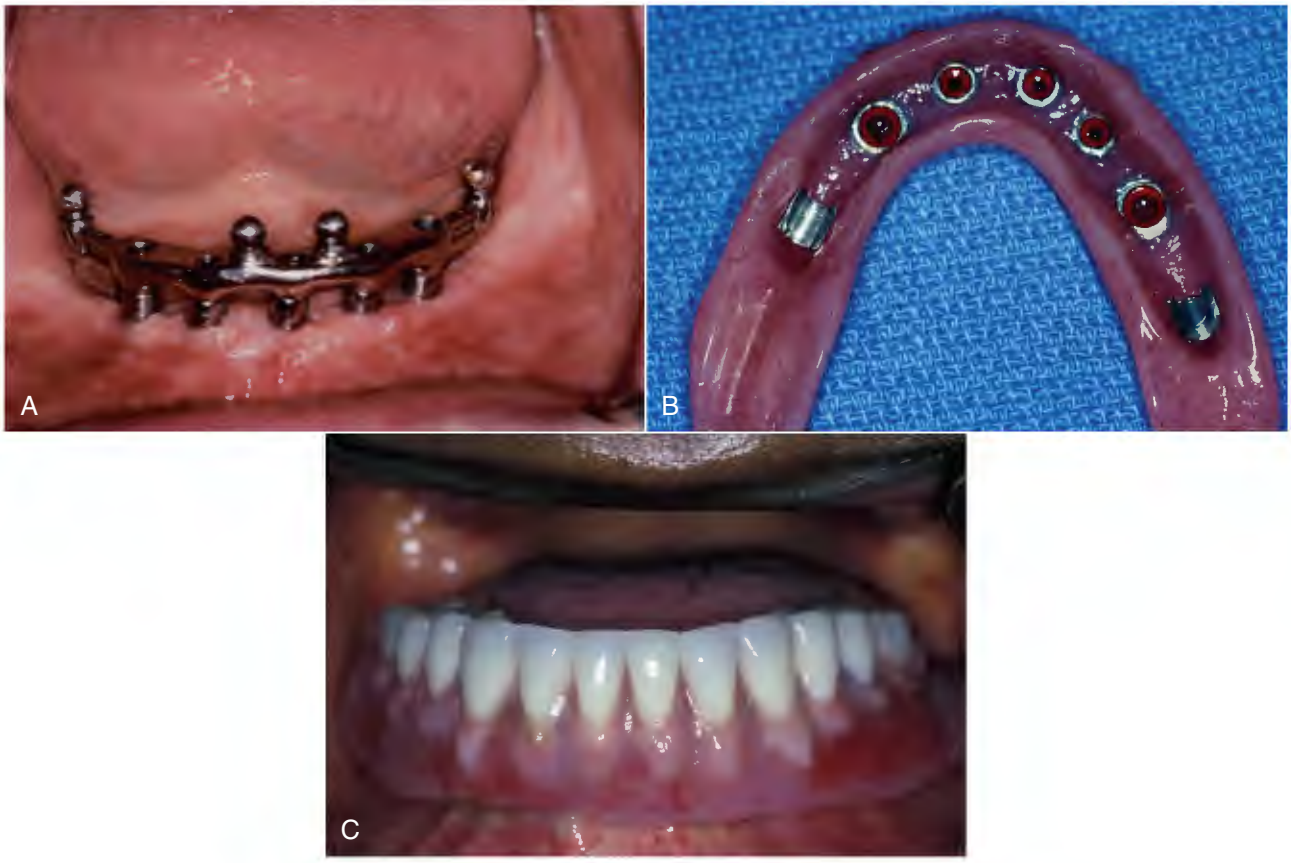


FIGURE 9-21. **A,** An RP-4 restoration is a removable prosthesis (usually an overdenture) that is completely implant supported. In this patient, the mandibular restoration has five implants between the mental foramina and a cantilevered bar to the posterior regions. The prosthesis is rigid during function and therefore requires attention to implant position and an implant number similar to an FP-3 restoration. **B,** The mandibular overdenture for an RP-4 prosthesis has attachments that permit a rigid restoration during function. **C,** An intraoral view of an RP-4 prosthesis appears as a mandibular denture but is rigid during function.

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FIGURE 9-22. Intraoral view of three mandibular implants inserted between the foramina. A bar connects the implants and can support an RP-5 mandibular overdenture. Soft tissue support of the restoration is required in the posterior regions because the implant position and number are not conducive to a completely implant-supported prosthesis.

evaluated, and a removable or fixed restoration is fabricated accordingly. Implant dentistry is unique because additional foundation units may be created for a desired prosthodontic result. Therefore, both the psychological and anatomical needs and desires of the patient should be determined. The prosthesis that satisfies these goals and eliminates the existing problems may then be designed. Whereas the prosthesis may be fixed or removable for completely edentulous patients, fixed restorations are planned for most partially edentulous patients.

If only one implant approach is used for all patients, the same surgical and prosthetic scenarios and flaws are invariably repeated. For example, if a two- or three-implant insertion is used on all edentulous mandibles, not only are the implant and surgery similar regardless of intraoral or extraoral conditions, but an RP-5 prosthesis will also usually result despite the patient's needs and desires.

The benefits of implant dentistry can be realized only when the prosthesis is first discussed and determined. An organized treatment approach based on the prosthesis permits predictable therapy results. Five prosthetic options are available in implant dentistry. Three restorations are fixed and vary in the amount of hard and soft tissue replaced; two are removable and are based on the amount of support for the restoration.

The amount of support required for an implant prosthesis should initially be designed similar to traditional

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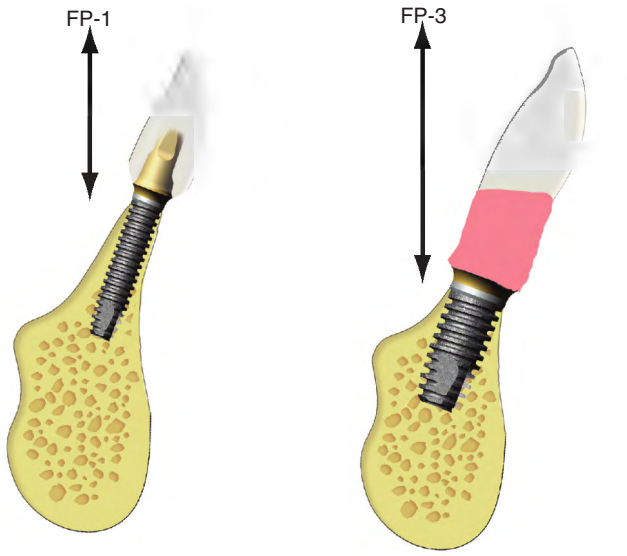


FIGURE 9-23. An FP-1 restoration *(left)* requires more bone height than an FP-3 prosthesis. An FP-3 restoration has a greater crown height and often requires more implant support when a cantilever or lateral load is applied to the prosthesis.

tooth-supported restorations. After the intended prosthesis is designed, the implants and treatment surrounding this specific result can be established. For example, an FP-1 prosthesis, when desired, may have a narrow implant inserted rather than an osteoplasty and a larger diameter implant (Figure 9-23). As a general rule, an FP-3 restoration requires more implant support than an FP-1 restoration whenever a cantilever or lateral load is applied because the crown height space is greater. Hence, the prosthetic option is one of the first factors to determine the overall implant treatment plan.

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CHAPTER **10**

Force Factors Related to Patient Conditions (A Determinant for Implant Number and Size)

Carl E. Misch

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Biomechanical stress is a significant risk factor in implant dentistry. Its magnitude is directly related to force. As a result, an increase in any dental force factor magnifies the risk of stress-related complications. Mechanical complication rates for implant prostheses are often the highest of all complications reported in the literature.[1] Mechanical complications include prosthetic and abutment screw loosening and may range to 8% for single teeth, 6% for multiple implants, and 3% for overdentures. Uncemented restorations also occur in more than 10% of the restorations. Porcelain fracture may affect up to half the patients with high stress factors, and resin veneer implant fixed partial dentures fracture 20% of the time. Crestal bone loss may be related to occlusal excessive forces.[2] Implant failure may also occur from overload and result in prosthesis failure. Retentive clips or attachments fracture in overdentures; the risk factor may average one in five. The fracture of the opposing prosthesis also increases in direct relationship to the force, with an average of 12% in implant overdentures opposing a denture. Fracture of the framework or substructure may also occur as a result of an increase in biomechanical forces.[3] In addition, implant body fracture may result from fatigue loading of the implant but fortunately occurs less often than most complications. All of these mechanical complications are often caused by excessive stress or cycles applied to the implant–prosthetic system (Box 10-1). Hence, force factors are an important aspect to consider when developing a treatment plan for implant dentistry.

The greater the biomechanical force, the fewer the number of cycles before fracture, so the incidence increases as the force increases. Different patient conditions place different amounts of force in magnitude, duration, type, and direction. In addition, several factors may multiply the number of loading cycles or increase the effect of these other conditions.

After the prosthesis option and key implant positions are determined, the potential force levels that will be exerted on the prosthesis should be evaluated and accounted for in order to modify the overall treatment plan. Several elements observed during the dental evaluation predict additional forces on future implant abutments. The initial implant healing, loading survival, marginal crestal bone loss, incidence of abutment or prosthetic screw loosening, unretained restorations, occlusal material fracture, and component fracture are all influenced by the patient's occlusal force factors. In addition, the patient force factors are a major influence on implant number and ideal size. There are five primary patient force factors affecting the stress environment of the implant and prosthesis: parafunction, crown height space (CHS), masticatory dynamics, arch position, and nature of the opposing dentition (Box 10-2).

Normal Forces Exerted on Teeth

The greatest *natural* forces exerted against teeth, and thus against implants, occur during mastication.[4,5] These forces are primarily perpendicular to the occlusal plane in the posterior regions, are of short duration, occur only during brief periods of the day, and range from 5 to 44 lb for natural teeth. The actual force on each tooth during function has been recorded on strain gauges in inlays.[6] A force of 28 psi was observed during chewing a raw carrot, and 21 psi was observed to chew meat. The actual time during which chewing forces are applied on the teeth is about 9 minutes each day.[7] The perioral musculature and tongue exert a more constant yet lighter horizontal force on the teeth or on

BOX 10-1 Mechanical Complications from Excessive Stress

- Abutment screw loosening
- Prosthesis loosening
- Uncemented restoration
- Porcelain fracture
- Resin veneer fracture
- Crestal bone loss
- Retentive clips and overdenture attachment fracture
- Opposing prosthesis fracture
- Fracture of prosthesis framework
- Implant body fracture
- Implant failure

BOX 10-2 Patient Force Factors

1. Parafunction
   a. Bruxism
   b. Clenching
   c. Tongue thrust or size
2. Crown height space
3. Masticatory dynamics
4. Arch position
5. Nature of the opposing dentition

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implants. These forces reach 3 to 5 psi during swallowing.[8] A person swallows 25 times per hour while awake and 10 times per hour while sleeping, for a total of 480 times each day.[7] Therefore, natural forces against teeth are primarily in their long axis, less than 30 psi, and for less than 30 minutes per day for all normal forces of deglutition and mastication (Box 10-3).

The maximum bite force differs from mastication force, varies widely among individuals, and depends on the state of the dentition and masticatory musculature.[9] There have been many attempts to quantify the normal maximum bite force. In 1681, Borelli suspended weights on a thread over the molars while the mandible was open. The maximum load recorded for which the person was still able to close ranged from 132 to 440 lb. A force of 165 lb was recorded on a gnathodynamometer, the first instrument to record occlusal force, which was developed by Patrick and Dennis in 1892. Black improved this early design and recorded average forces of approximately 170 lb.[10] The forces on the chewing side and the opposite side appear very similar in amplitude[11] (Table 10-1). More recent studies indicate normal maximum vertical biting forces on teeth can range from 45 to 550 psi.[12,13]

Forces of mastication placed on implant-supported bridges have been measured up to four times greater than natural teeth.[14] Implant-supported prostheses have less occlusal awareness than natural teeth, so the opposing implant prostheses do not reduce velocity before contact as with the natural dentition. Hence, the patient force factors are even more important to evaluate for implant prostheses.[15–21]

It should be emphasized that the maximum bite forces are not expressed by our patients in any routine fashion. However, there are conditions that approach these values and increase our risks of occlusal overload on the implant prosthesis. Most noteworthy are the parafunctional forces of bruxism and clenching because they modify the amount of force and the duration of force.

BOX 10-3 Normal Forces Exerted on Teeth

Bite Forces
Perpendicular to occlusal plane
Short duration
Brief total period (9 min/day)
Force on each tooth: 20 to 30 psi
Maximum bite force: 50 to 500 psi

Perioral Forces
More constant
Lighter
Horizontal
Maximum when swallowing (3–5 psi)
Brief total swallow time (20 min/day)

Parafunction

Parafunctional forces on teeth or implants are characterized by repeated or sustained occlusion and have long been recognized as harmful to the stomatognathic system.[22] These forces are also damaging when applied to implant prostheses.[23,24] The lack of rigid fixation during implant healing may be a result of parafunction on soft tissue–borne prostheses overlying the submerged implant. The most common cause of both early and late implant failure after successful surgical fixation is the result of parafunction. Such complications occur with greater frequency in the maxilla because of a decrease in bone density and an increase in the moment of force.[25] The presence of these parafunctional conditions must be carefully noted during the early phases of treatment planning.

Nadler has classified the causes of parafunction or nonfunctional tooth contact into the following six categories[26]:

1. Local
2. Systemic
3. Psychological

TABLE 10-1
Mean Maximum Biting Force Recorded on Natural Teeth or Implants*

Authors (Year)	Natural Teeth or Dental Implants	Mean Maximum Masticatory Force
Carr and Laney[79] (1987)	Conventional denture	59 N
	Implant-supported prostheses	112.9 N
Morneburg and Proschel[21] (2002)	Implant-supported three-unit FPD	220 N
	Single implant: anterior	91 N
	Single implant: posterior	12 N
Fontijn-Tekamp et al.[87] (1998)	Implant-supported prostheses	(unilateral)
	Molar region	50–400 N
	Incisal region	25–170 N
Mericske-Stern and Zarb[90] (1996)	Complete denture/implant-supported prostheses	35–330 N
van Eijden[12] (1991)	Canine	469 ± 85 N
	Second premolar	583 ± 99 N
	Second molar	723 ± 138 N
Braun et al.[13] (1995)	Natural teeth	738 ± 209 N (male > female)
Raadsheer et al.[78] (1999)	Male teeth	545.7 N
	Female teeth	383.6 N

*Comparison of available studies examining masticatory forces generated under varying loading condition. Study results are reported in Newtons (N) of force unless otherwise indicated. Differences between male and female force generation are noted in applicable studies.
FPD, Fixed partial dentures.

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4. Occupational
5. Involuntary
6. Voluntary

Local factors include tooth form or occlusion, as well as soft tissue changes such as ulcerations or pericoronitis. Systemic factors include cerebral palsy, epilepsy, and drug-related dyskinesia. Psychological causes occur with the greatest frequency and include the release of emotional tension or anxiety.[27] Occupational factors concern professionals such as dentists, athletes, and precision workers, as well as seamstresses and musicians who develop altered oral habits. Involuntary movements that provoke bracing of the jaws, such as during lifting of heavy objects or sudden stops while driving, contribute to parafunction. Voluntary causes include chewing gum or pencils, bracing a telephone between the head and shoulder, and pipe smoking.

The parafunctional groups presented in this chapter are divided into bruxism, clenching, and tongue thrust or size. The dental literature usually does not identify bruxism and clenching as separate entities. Although several aspects of treatment are similar, their diagnosis and treatment are in some ways different. As such, they are presented as different entities in this discussion.

The magnitude of parafunction may be categorized as absent, mild, moderate, or severe.[23] Bruxism and clenching are the most critical factors to evaluate in any implant reconstruction. No long-term success will be obtained with severe parafunction of bruxism or clenching. Therefore, the dentist should always try to diagnose the presence of these two conditions.

This does not mean that patients with moderate and severe parafunction cannot be treated with implants. A physician treats a patient with uncontrolled diabetes; however, the patient may lose their vision or need his or her feet amputated despite treatment. Unsuccessful treatment of the person with diabetes may not be the fault of the physician. Not recognizing diabetes in the presence of obvious signs and symptoms, of course, is another issue. Because patients with moderate to severe parafunction represent so many additional risks in implant dentistry, one must be aware of these conditions and the methods to reduce their noxious effects on the entire implant-related system. Unfortunately, parafunction may be a difficult entity to diagnose, especially if the patient is completely edentulous and is wearing a recently fabricated prosthesis.

Bruxism

Bruxism primarily concerns the horizontal, nonfunctional grinding of teeth. The forces involved are in significant excess of normal physiologic masticatory loads. Bruxism may affect the teeth, muscles, joints, bone, implants, and prostheses.[28] These forces may occur while the patient is awake or asleep and may generate increased force on the system several hours per day. Bruxism is the most common oral habit. Sleep clinic studies have evaluated nocturnal bruxism and found approximately 10% of those observed had obvious movement of the mandible with occlusal contacts.[29,30] More than half of these patients had tooth wear affecting esthetics. Only 8% of these patients were aware of their nocturnal bruxism, and only 25% of the patients' spouses were aware of the nocturnal habit. Muscle tenderness in the morning was observed less than 10% of the time.[31] A study on bruxing patients with implants showed 80% of sleep bruxism occurred during light sleep stages but did not cause arousal.[32] Therefore, patients with bruxism may or may not have obvious tooth wear affecting esthetics; may brux nocturnally, but their bed partners do not know most of the time; rarely have muscle tenderness when they are awake; and are usually unaware of their oral habit. In other words, nocturnal bruxism is sometimes difficult to diagnose.[33]

The maximum biting force of bruxing patients is greater than average. Just as an experienced weightlifter can lift more weight, the patient constantly exercising the muscles of mastication develops a greater bite force. A man who chews paraffin wax for an hour each day for a month can increase the bite force from 118 to 140 psi within 1 week.[34] Chewing gum, bruxism, and clenching may accomplish the same feat. Eskimos, with a very tenacious diet and who chew their leather to soften it before fabrication of clothing, have maximum bite forces above 300 psi. A 37-year-old patient with a long history of bruxism recorded a maximum bite force of more than 990 psi (four to seven times normal).[35]

Fortunately, the bite force does not continue to increase in most bruxing patients. When muscles do not vary their exercise regimen, their size and function adjust to the dynamics of the situation. As a result, the higher bite forces and muscle size usually do not continue in an unending spiral.

Diagnosis

Bruxism does not necessarily represent a contraindication for implants, but it does dramatically influence treatment planning. The first step is to recognize the condition before the treatment is rendered. The symptoms of this disorder may be ascertained by a dental history and may include repeated headaches, a history (or presence) of fractured teeth or restorations, repeated uncemented restorations, or jaw discomfort upon awakening.[22–36] Therefore, when the patient is aware of muscle tenderness or the spouse is conscious of the noise of bruxism during sleep, the diagnosis is readily obtained (Box 10-4). However, many patients do not attribute these problems to excessive forces on the teeth and report a negative history. A lack of these symptoms does not negate the possibility of bruxism.

Fortunately, many clinical signs warn of excessive grinding. The signs of bruxism include an increase in size of the temporalis and masseter muscles. These muscles and the external pterygoid may also be tender during palpation. In addition, other signs include deviation of the lower jaw on opening, limited occlusal opening, increased mobility of teeth, cervical abfraction of teeth, fracture of teeth or restorations, and uncemented crowns or fixed prostheses.[35]

A physical examination for the implant candidate should include palpation of the muscles of mastication. The masseter and temporalis muscles are easily examined during the initial appointment. Hyperactive muscles are not always tender, but tender muscles in the absence of trauma or disease is a sign of excess use or incoordination among muscle groups. The lateral pterygoid muscle is more often overused by the bruxing patient but is difficult to palpate. The ipsilateral medial pterygoid

BOX 10-4 Parafunction: Symptoms of Bruxism in the Dental History

- Frequent headaches
- History or presence of fractured teeth or restorations
- Repeated uncemented restorations
- Jaw discomfort upon awakening
- Muscle tenderness
- Spouse awareness during sleep

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muscle provides more reliable information in this region. It acts as the antagonist to the lateral pterygoid in hyperfunction and, when tender, provides a good indicator of overuse of the lateral pterygoid.[37] However, the most effective method to diagnose bruxism is to evaluate the wearing of the natural teeth[23] (Box 10-5).

Nonfunctional wear facets on the incisal edges occur most often on natural teeth rather than on crowns made of porcelain or metal occlusals, especially in the anterior mandible and maxillary canines. Enamel opposing enamel causes more occlusal material wear than almost any other combination (e.g., enamel opposing metal, metal opposing metal, etc.).[38] As a result, in a partially edentulous patient, enamel wear is easily observed in the bruxing patient.

Not only is enamel wear the easiest method to determine bruxism in a dentate patient, but Misch has noted the disorder may also be classified as absent, mild, moderate, or severe.[23,39,40] No anterior wear patterns in the teeth signifies an absence of significant bruxism. Mild bruxism has slight wearing of anterior teeth but is not a cosmetic compromise (Figure 10-1). Moderate bruxism has obvious anterior incisal wear facets but no posterior occlusal wear pattern (Figure 10-2). Severe bruxism has an absence of incisal guidance as a result of the excessive wear, and posterior wearing of the teeth is obvious (Figure 10-3).

Tooth wear is most significant when found in the posterior regions and changes the intensity of bruxism from the moderate to the severe category. Posterior wear patterns are more difficult to manage because they are usually related to a loss of anterior guidance in excursions, and when the posterior teeth contact in excursive jaw positions, greater forces against the teeth are generated.[41] The masseter and temporalis muscles contract when posterior teeth contact. With incisal guidance and an absence of posterior contact in a lateral excursion of this jaw, two thirds of these muscles do not contract and, as a consequence, the bite force is dramatically reduced. However, when the posterior teeth maintain contact, the bite forces are similar in excursions, as during posterior biting. Therefore, in a patient with severe bruxism, the occlusal plane or the anterior incisal guidance may need modification to eliminate all posterior contacts during mandibular excursions before the implant restoration.

Bruxing patients often repeat the same mandibular movements, which are different from border movements of the mandible and are in one particular direction. As a result, the occlusal wear is very specific and primarily on one side of the arch or even on only a few teeth (Figure 10-4). This engram pattern usually remains after treatment. If the restoring dentist reestablishes incisal guidance on teeth severely affected by an engram bruxing pattern, the incidence of complications on these teeth will be increased.

The most common complications on teeth restored in this "pathway of destruction" are porcelain fracture, uncemented prostheses, and root fracture.[35] When implants support the crowns in the "pathway of destruction," the implant may fail; fracture; or have crestal bone loss, abutment screw loosening, porcelain fracture, or unretained restorations.[39,40] If the patient continues the severe bruxism pattern, the question is not whether but when and which complications will occur. The dentist should tell the patient that these parafunctional habits

BOX 10-5 Parafunction: Clinical Signs of Bruxism

1 Increase in muscle size of temporalis and masseter muscles
2 Temporalis, masseter, or external pterygoid muscles tender to palpation
3 Mandibular deviation while opening
4 Limited occlusal opening
5 Tooth mobility
6 Cervical abfraction of teeth
7 Fracture of teeth or restorations
8 Uncemented crowns or restorations
9 Wearing of natural teeth
   a. Absent
   b. Mild
   c. Moderate
   d. Severe



FIGURE 10-1. **A,** Mild bruxism. Note the wear facet on the mandibular canine and the slight notch in the maxillary lateral incisor. **B,** Patients often grind their teeth in a specific, repeated movement of the mandible, called an engram. When the opposing wear facets of the teeth are in contact, one should note the occlusal position of the teeth. The patient shown in **A** has a working contact on the mandibular premolar with the maxillary canine in this engram position. The slight cervical abfraction of the mandibular first premolar is a consequence of the parafunction. The patient's posterior teeth should not occlude in this position to decrease the amount of force on the anterior teeth.

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FIGURE 10-2. **A,** Moderate bruxism of the central incisors (there is an esthetic consequence). **B,** The engram position placed the mandibular anterior teeth anterior to the maxillary incisal edge and caused the wear of the central incisors.



FIGURE 10-3. This patient has severe bruxism because occlusal wear is both anterior and posterior *(right)*. The incisal guidance should be reestablished before a maxillary arch fixed reconstruction.



FIGURE 10-4. This patient exhibits an engram pattern of bruxism primarily toward the left premolar to central incisors. The right canine and lateral incisor have far fewer wear facets. Incisal guidance should be restored before any left posterior restoration. This "pathway of destruction" is specific.

will cause these problems. Treatment may be rendered to repair these problems, but there will be complications if the bruxism is not reduced.

Bruxism changes normal masticatory forces by the magnitude (higher bite forces), duration (hours rather than minutes), direction (lateral rather than vertical), type (shear rather than compression), and magnification (four to seven times normal).[39,40] The method to restore severe bruxism may be problematic even when the desire is primarily cosmetic. As the anterior teeth wear, they may erupt, and the overall occlusal vertical dimension (OVD) remains unchanged. In addition, the alveolar process may follow the eruption of the tooth. As such, when the anterior teeth are restored for esthetics (or to obtain an incisal guidance), the reduced crown height cannot be increased merely by increasing the height of the crown to an average dimension.[37] However, in some patients, the teeth do not erupt as they wear, and the vertical occlusal dimension does decrease. Therefore, the severe wearing diagnosis must include the evaluation of the OVD. The following guidelines are suggested:

1. Determine the position of the maxillary incisor edge of the anterior teeth. They may be acceptable (if eruption occurred as they wore) or need greater coronal length to correct related incisal wear. The maxillary incisal edge should be in the proper position (either remain as present if acceptable or restore if not acceptable) (Figure 10-5, *A*).
2. Determine the desired OVD. This is not an exact dimension and may exist at several different positions without consequence. However, similar to most factors, there is a range that is patient specific and does follow guidelines. The most common methods to determine this dimension relate to facial measurements, closest speaking space, physiologic rest position, speech, and esthetics (Figure 10-5, *B* to *D*). This is one of the most important steps. If the vertical dimension is collapsed because of anterior and posterior occlusal wear, much more rehabilitation is required. This condition is observed more often when bruxism is severe, the anterior incisal guidance was lost, and, as a consequence, the severe bruxism wear is increased due to an increase in force factors. The accelerated occlusal wear may cause a loss of OVD. The OVD is rarely decreased when incisal guidance is still present because the posterior teeth maintain the dimension and the anterior teeth have time to erupt because the forces are less and the wear rate is slower.
3. Evaluate and restore the position of the lower anterior teeth where necessary. In the past, it has been stated that a reconstruction of the mouth begins with the lower anterior teeth.[37] However, the mandibular arch cannot be restored until the maxillary anterior teeth and OVD are established. Many esthetic and speech guidelines are available to help the

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FIGURE 10-5. **A,** Severe bruxism and loss of vertical dimension of the teeth. The maxillary and mandibular teeth are edge to edge. B, The facial vertical dimension is closed, so the teeth did not erupt as the severe wearing occurred. **C,** The present vertical dimension is closed, so the mandible has rotated forward, which positioned the teeth edge to edge. **D,** A picture of the patient's vertical dimension at rest when he was younger and the teeth were not worn.

restoring dentist with the position of the maxillary anterior teeth. For example, when a dentist begins the restoration of a completely edentulous patient, the maxillary anterior wax rim position is often first determined for similar reasons.

With natural teeth, the position of the lower anterior teeth should contact the lingual surfaces of the maxillary anterior teeth at the established OVD, and the amount of vertical overlap of the maxillary incisal edge and the angle of the incisal contacts in protrusive movements of the mandible determines the angle and height of the anterior guidance.[37] This dimension must be greater than the condylar disc assembly (the angle of the eminentia) so the posterior teeth will separate during mandibular excursions.

In patients with moderate to severe bruxism, the height of the vertical overjet and the angle of incisal guidance should not be extreme because the amount of the force on the anterior abutments, cement seals, and porcelain is directly related to these conditions (Figure 10-6). In other words, the greater the incisal overjet, the greater the distance between the posterior teeth in excursions and the greater the force generated on the anterior teeth during this movement. In patients with severe bruxism, the intensity of the force on the anterior teeth should be reduced because the duration of the force is increased.

When anterior tooth wear is accompanied by tooth eruption and maintenance of the OVD and alveolar bone in the region has extruded toward the incisal plane, the worn incisal edges of the teeth are not the only thing to be restored. The alveolar bone and cervical regions should be reduced, and crown lengthening should be performed on the teeth before their restoration. This is most often necessary in the mandibular anterior region when the lower anterior teeth are opposing a denture but may be observed in any region of the mouth after long-term severe bruxism. In addition, endodontic therapy may be required to allow proper anterior tooth preparation. In a combination syndrome with a mandibular class I partial denture opposing a denture, the lower anterior teeth may need to be extracted in order to obtain the correct incisal edge position (Figure 10-7).

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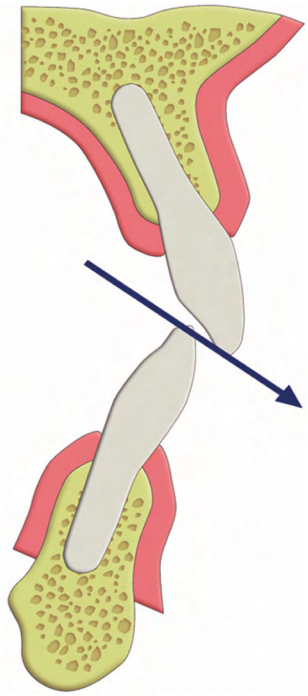


FIGURE 10-6. The incisal guidance for a patient with moderate to severe bruxism should be shallow (but steeper than the angle of the eminentia of the joint) to reduce the force on the anterior teeth during excursive movement of the mandible.

Crown lengthening and associated procedures are not necessary when the vertical dimension has been reduced in relation to the incisal wear and the teeth have not extruded or erupted related to this process. Instead, the teeth may be prepared in their present state, usually without reduction of the incisal edge for the crown preparation. The restoration restores the OVD and reestablishes anterior incisal guidance.

4. The posterior plane of occlusion is then determined. This may be accomplished first by using the maxillary arch or the posterior mandibular arch. However, it is best if the same bilateral posterior quadrants are addressed at the same time so that the posterior plane may be parallel to the horizontal plane. The maxillary posterior region is most often determined first in completely edentulous patients.

Fatigue Fractures

The increase in duration of the force is a considerable problem. Materials follow a fatigue curve, which is affected by the number of cycles and the intensity of the force[42,43] (Figure 10-8). A force can be so great that one cycle causes a fracture (e.g., a karate blow to a piece of wood). However, if a lower force magnitude repeatedly hits an object, the object will still fracture. The wire coat hanger that is bent does not break the first time, but repeated bends will fracture the material—not because the last bend was more forceful but because of fatigue.

A bruxing patient is at greater risk of fatigue fractures for two reasons. The magnitude of the forces increases over time as the muscles become stronger and the number of cycles increases on the prosthetic components. Eventually, one of the components (implant, screw, abutment, prosthesis) will break if the parafunction cannot be reduced in intensity or duration (Figure 10-9). No long-term prosthetic result is expected in patients with severe bruxism. Therefore, when the implant dentist has identified the sources of additional force on the implant system, the treatment plan is altered in an attempt to minimize the negative effect on the longevity of the implant, bone, and final restoration. All elements able to reduce stress or modify the fatigue factor should be considered.

Porcelain fracture is of particular concern with the implant prosthesis in a bruxing patient (Figure 10-10). In a report by Kinsel and Lin, 34% of patients with bruxism experienced porcelain fracture, and more than 15% of crowns in bruxing patients fractured porcelain.[44] When group function was used to restore these patients in lateral excursions, more than half of the patients experienced porcelain fracture with their implant prosthesis. Hence, it is appropriate in this category of patients to inform them of the porcelain fracture risk, use metal occlusal surfaces in nonesthetic regions, and use implant-protective occlusion concepts (which restore incisal guidance).

Occlusal Guards

The cause of bruxism is multifactorial and may include occlusal disharmony.[37] When an implant reconstruction is considered in a bruxing patient, occlusal analysis is warranted. Premature and posterior contacts during mandibular excursions increase stress conditions.[45] An elimination of eccentric contacts may allow recovery of periodontal ligament health and muscle activity within 1 to 4 weeks. Occlusal harmony does not necessarily eliminate bruxism, but this is no reason not to perform an occlusal analysis and eliminate the premature contacts. No study demonstrates an increase in parafunction after occlusal adjustment. Therefore, the ability to decrease the risk of occlusal overload on particular teeth and the added benefit of perhaps reducing parafunction is warranted in almost every patient diagnosed with a parafunctional habit of bruxism or clenching.

A night guard can be a useful diagnostic tool to evaluate the influence of occlusal disharmony on nocturnal bruxism. The Michigan night guard exhibits even occlusal contacts around the arch in centric relation occlusion and provides posterior disocclusion with anterior guidance in all excursions of the mandible.[46] This device may be fabricated with 0.5- to 1-mm colored acrylic resin on the occlusal surface. After 4 weeks of nocturnal wear, the muscles and periodontal ligament are restored. If the patient wears this device for an additional month or more, the influence of occlusion on the bruxism may be directly observed because there are no premature contacts while the device is worn. If the colored acrylic is still intact, the nocturnal parafunction has been reduced or eliminated. Therefore, occlusal reconstruction or modification may proceed. If the colored acrylic on the night guard is ground through, an occlusal adjustment will have little influence on decreasing this parafunctional habit. The night guard is still indicated to relieve stresses during nocturnal parafunction, but the treatment plan should account for the greater forces.

Forces from moderate to severe bruxism are the most difficult to address on a long-term basis. Education and informed consent of the patient are helpful to gain cooperation in eliminating or reducing the noxious effects. If the opposing arch is a soft tissue–supported removable prosthesis, the effects of the nocturnal habit may be minimized if the patient removes the prosthesis at night. The use of a night guard is helpful for a patient with a fixed prosthesis in order to transfer the weakest link of the system to the removable acrylic device. Centric contacts in centric relation occlusion and anterior-guided disocclusion of the posterior teeth in excursions are strongly suggested

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FIGURE 10-7. **A,** A patient with a maxillary denture opposing mandibular anterior natural teeth. Note that the maxillary incisors are above the lip and the plane of occlusion is low in the posterior. The mandibular incisors are superior to their natural position. **B,** A panoramic radiograph of the previous patient. The anterior maxilla is resorbed and the lower anterior teeth extruded along with the alveolar process. **C,** Extraction of the natural teeth was necessary to reduce their superior position and restore the correct incisal edge position. Five anterior implants will support a fixed prosthesis at the proper vertical dimension.

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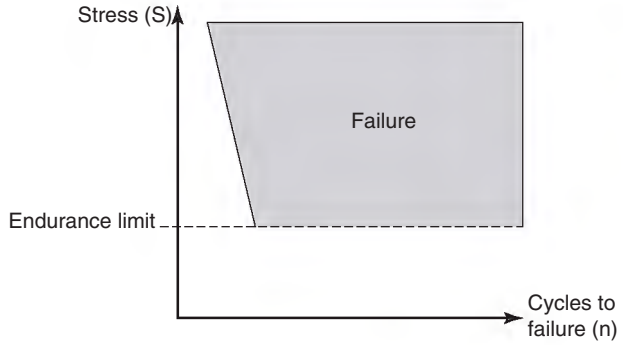


FIGURE 10-8. In a fatigue curve for a material, stress corresponds to the vertical axis and cycles to failure to the horizontal axis. A point exists at which the stress is so great that the material breaks with only one cycle. When the stress is low enough, the material will not break regardless of the number of cycles. The stress amount at the highest point of this safe zone is called the *endurance limit*. Patients with parafunction increase the amount of stress to the implant–prosthetic system and increase the number of the cycles at the higher stress levels. Fatigue failures are therefore common.

on the night guard, which may be designed to fit the maxilla or mandible.

Unlike teeth, implants do not extrude in the absence of occlusal contacts. As a result, in partially edentulous patients, the maxillary night guard can be relieved around the implant crowns so the remaining natural teeth bear the entire load.[23,39] For example, for a maxillary central implant restoration, the night guard is hollow over the restoration so no occlusal force is transmitted to the implant crown (Figure 10-11). When the restoration is in the mandible, the occluding surfaces of the maxillary night guard are relieved over the implant crowns so no occlusal force is transmitted to the implants (Figure 10-12).

A mandibular posterior cantilever on a full-arch implant prosthesis may also be taken out of occlusion with a maxillary night guard. When a posterior quadrant of implants supports a fixed prosthesis in the maxilla opposing mandibular teeth, a soft reline material may be placed around the implant crowns to act as a stress relief element and decrease the impact force on the restoration (Figure 10-13). When full-arch implant restorations are opposing each other, the night guard provides solely anterior contacts during centric occlusion and mandibular

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FIGURE 10-9. **A,** The patient has a cantilevered hybrid fixed prosthesis in the mandible. Severe bruxism is evident, with anterior and posterior wearing of the teeth. At this point, the patient should be informed that the incisal guidance of the restoration should be restored. **B,** The patient elected not to restore the incisal guidance of the restoration. As a consequence of higher forces with posterior contact during excursions, fatigue failure of the prosthesis occurred.

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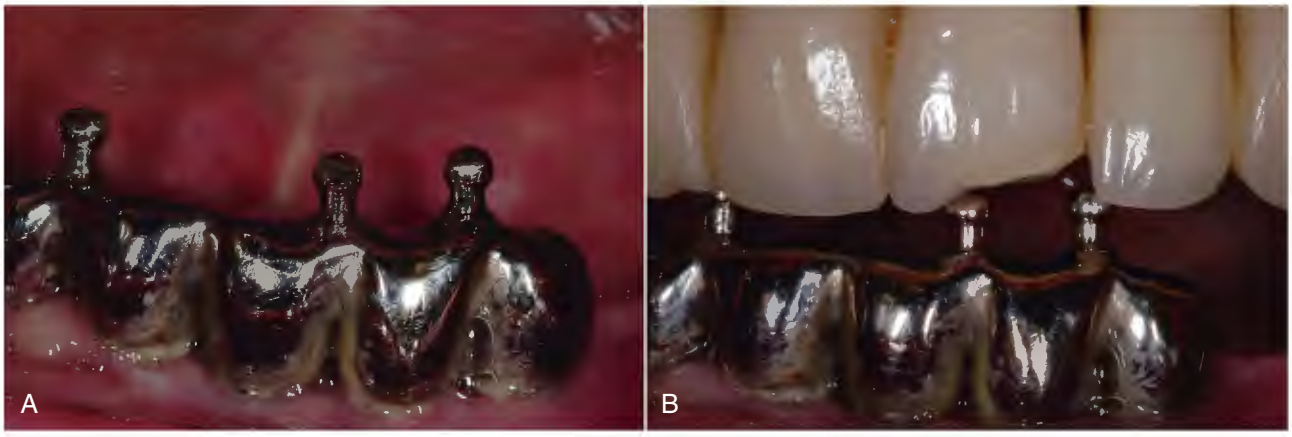


FIGURE 10-10. **A,** This patient does not wear the implant overdenture at night and has nocturnal bruxism, which caused the wearing of the anterior O-ring attachments. **B,** The nocturnal bruxism led to porcelain fracture of the fixed maxillary implant prosthesis.



FIGURE 10-11. A night guard for a partially edentulous patient restored with implants may be designed to transfer the force to the natural teeth. The guard is relieved around the maxillary left implant crown.



FIGURE 10-12. When the implant prosthesis *(lower right gold crown)* is in the opposing arch to the guard, there are no occlusal contacts in centric or during mandibular excursions on the night guard.

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FIGURE 10-13. A night guard with a rigid acrylic shell and a soft resilient liner can decrease stress in the maxillary right posterior implant prosthesis during parafunction episodes.



FIGURE 10-14. Full-arch implant prostheses opposing each other may have only anterior occlusal contact in centric and during mandibular excursions with the night guard in place.

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excursions (Figure 10-14). Thus, the parafunctional force is reduced on the anterior teeth and implants and eliminated in the posterior regions.

Treatment Planning

The implant treatment plan is modified primarily in two ways when implants are inserted in the posterior region with severe bruxism: (1) additional implants that are wider in diameter are one method used to reduce the overload risk, and (2) the anterior teeth may be modified to re-create the proper incisal guidance and avoid posterior interferences during excursions. The elimination of posterior lateral occlusal contacts during excursive movements is recommended when opposing natural teeth or an implant or tooth-supported fixed prosthesis. This is beneficial in two aspects: (1) because lateral forces dramatically increase stress at the implant–bone interface, the elimination of posterior contacts diminishes the negative effect of angled forces during bruxism,[46,47] and (2) the presence of posterior contacts during excursions, and almost all fibers of the masseter, temporalis, and the external pterygoid muscles contract and place higher forces on the anterior teeth and implants. On the contrary, during excursions in the absence of posterior contacts, fewer fibers of the temporalis and masseter muscles are stimulated, and the forces applied on the anterior implant–teeth system are reduced by as much as two thirds.[41]

Clenching

Clenching is a habit that generates a constant force exerted from one occlusal surface to the other without movement. The habitual clenching position does not necessarily correspond to centric occlusion. The jaw may be positioned in any direction before the static load; therefore, a bruxing and clenching combination may exist. The clench position most often is in the same repeated position and rarely changes from one period to another. The direction of load may be vertical or horizontal. The forces involved are in significant excess of normal physiologic loads and are similar to bruxism in amount and duration; however, several clinical conditions differ in clenching.[48,49]

Diagnosis

Many clinical symptoms and signs warn of excessive grinding. However, the signs of clenching are often less obvious. The forces generated during clenching are usually directed more vertically to the plane of occlusion, at least in the posterior regions of the mouth. Wearing of the teeth is usually not evident; therefore, clenching often escapes notice during the intraoral examination. As a result, the dentist must be more observant to the diagnosis of this disorder.[29]

Many of the clinical signs of clenching resemble bruxism. When a patient has a dental history or presence of muscle tenderness (often upon awakening) or tooth sensitivity to cold, parafunction is strongly suspected. In the absence of tooth wear, clenching is the prime suspect. Tooth mobility, temporalis or masseter muscle tenderness or hypertrophy, deviation of the mandible during occlusal opening, limited opening, stress lines in enamel, cervical abfraction, and material fatigue (enamel, enamel pits, porcelain and implant components) are all associated clinical signs of clenching.[48] All of these conditions may also be found in bruxing patients.[36] However, enamel wear has such a strong correlation to bruxism that it is the primary and often the only factor needed to evaluate for bruxism. A clenching patient has the "sneaky disease of force." Therefore, particular attention is paid to diagnose this disorder from less obvious clinical conditions. When the clinical signs of excessive force appear on the teeth, muscles, or joint in the absence of incisal wear, clenching is strongly suspected.

Muscle evaluation for clenching (and bruxism) includes deviation during opening of the jaw, limited opening, and tenderness of the temporomandibular joint (TMJ). Deviation to one side during opening indicates a muscle imbalance on the same side.[37] Limited opening is easily evaluated and may indicate muscular imbalance or degenerative joint disease. The normal opening should be at least 40 mm from the maxillary incisal edge to the mandibular incisal edge in an Angle's class I patient, taking into consideration an overjet or overlap. If any horizontal overjet or overlap exists, its value in millimeters is subtracted from the 40-mm minimum opening measurement.[50] The range of opening without regard for overlap or overjet has been measured in the range of 38 to 65 mm for men and 36 to 60 mm for women from incisal edge to edge.[51]

A common clinical finding of clenching is a scalloped border of the tongue. This finding is rarely present with bruxism (Figure 10-15). The tongue is often braced against the lingual surfaces of the maxillary teeth during clenching, exerting lateral pressures and resulting in the scalloped border. This braced tongue position may also be accompanied by an intraoral vacuum,

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FIGURE 10-15. A scalloped border of the tongue most often is found in a clenching patient. To maintain the force between the teeth, a vacuum is created in the mouth, and the impression of the lingual contours of the upper teeth is seen on the tongue.

BOX 10-6 Parafunction: Signs of Clenching in the Absence of Teeth Wear

- History or presence of temporalis or masseter muscle tenderness (often upon awakening)
- Tooth sensitivity to cold
- Tooth mobility
- Temporalis or masseter muscle hypertrophy
- Deviation of mandible during opening
- Limited opening
- Stress lines in enamel
- Cervical abfraction
- Material fracture (enamel pits, restorations)
- Scalloped border of tongue

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which permits a clench to extend for a considerable time, often during sleep. When the doctor asks the patient to open widely to evaluate maximum occlusal opening (while palpating the TMJ), the lateral tongue contour is observed to notice any scalloped border. When present, clenching is strongly suspected (Box 10-6).

Increased mobility of teeth may be an indication of a force beyond physiologic limits, bone loss, or their combination. This requires further investigation in regard to parafunction and is very important if an implant may be placed in the region of the mobile teeth. The rigid implant may receive more than its share of occlusal force when surrounded by mobile teeth. Fremitus, a vibration type of mobility of a tooth, is often present in the clenching patient. To evaluate this condition, the dentist's finger barely contacts the facial surface of one tooth at a time and feels for vibrations while the patient taps the teeth together. Fremitus is symptomatic of a local excess of occlusal loads.

Cervical erosion is often a sign of parafunctional clenching or bruxism (Figure 10-16). In the past, Black analyzed the eight most popular theories for gingival ditching of the teeth, finding all inconclusive.[10] This observation has frequently been called "toothbrush abrasion."[46] McCoy has reported this condition on every other tooth, only one tooth, and even on the teeth of some animals.[52] Parafunction was the common link among



FIGURE 10-16. Clenching habits are more difficult to diagnose because occlusal wear is often absent. This clenching patient has cervical abfraction of the mandibular anterior teeth. In this patient, the abfraction obviously is not from toothbrush abrasion.



FIGURE 10-17. This patient is missing a canine and has cervical abfraction of the premolar and molar (from group function and no canine). Because there is no occlusal wear of the anterior teeth, clenching is suggested.

patients presenting with this condition. The notched appearance of the cervical portion of the tooth directly correlates with the concentration of forces shown in three-dimensional finite analysis and photoelasticity studies.[53,54] Abfraction of teeth was also observed in cats, rats, and marmosets and was described in the literature as early as 1930.[55] A study of a noninstitutionalized older human population revealed that cervical abrasion was present in 56% of the participants.[56]

Not all gingival erosions are caused by parafunction. However, when present, the occlusion should be carefully evaluated along with other signs of excess force. If excessive forces appear to be the cause, the condition is referred to as *cervical abfraction*[57] (Figure 10-17). Other signs of enamel or occlusal material fatigue encountered in bruxing or clenching patients include occlusal invaginations or pits, stress lines in enamel, stress lines in alloy restorations or acrylic (lines of Luder), and material fracture (Figures 10-18 and 10-19). Fremitus also can be noticed clinically on many cervically eroded, nonmobile teeth.

Fatigue Fractures

The increase in force magnitude and duration is a significant problem, whether by bruxism or clenching. The fatigue curve

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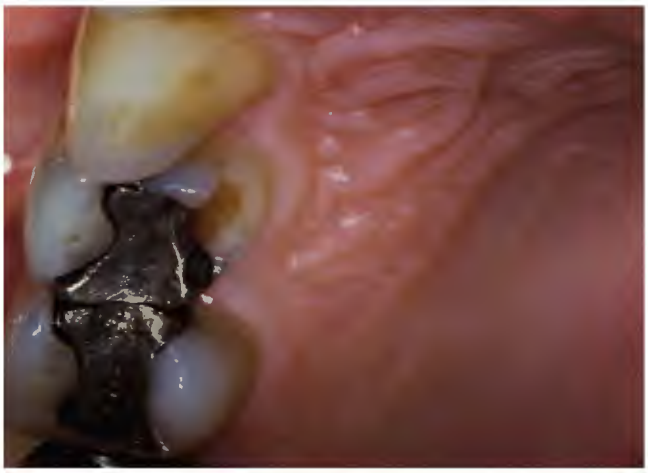


FIGURE 10-18. Enamel pits (cusp tips of premolars) and fractured cusps are clinical signs of clenching.



FIGURE 10-19. The patient exhibits clenching, diagnosed from the enlarged size of the masseter and temporalis muscles and a scalloped border of the tongue. The mandibular second molar is also fractured from mesial to distal.

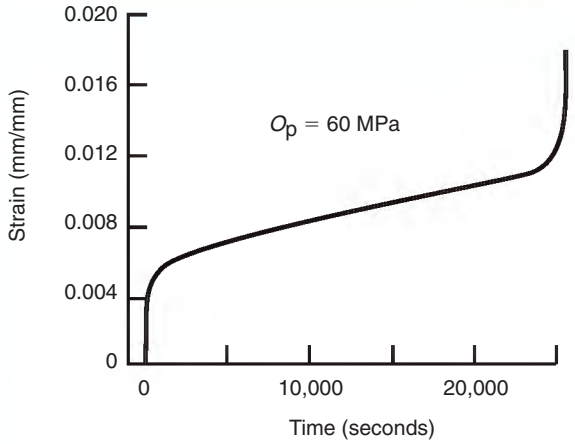


FIGURE 10-20. A creep curve for materials places strain on the vertical axis and time on the horizontal axis when a constant load is applied. This is a creep curve for bone at a constant load of 60 MPa. The bone changes shape (i.e., strain) at the initial stress condition and then at an increasing amount over time until the material (e.g., bone) fractures.

previously presented for bruxism also applies to clenching. In addition, clenching patients may experience a phenomenon called *creep*, which also results in fracture of components. Creep occurs in a material when an increasing deformation is expressed as a function of time when subjected to a constant load[43] (Figure 10-20). Although the cycles of load may not be present to affect the deformation of a material, the constant force is still able to cause fracture. In other words, something will break if the continued force is not abated or at least reduced in intensity or duration (Figure 10-21). This condition may also occur in bone, which may result with implant mobility and failure. All elements to reduce the excessive force of clenching and its consequence should be considered.

Occlusal Guards

Clenching affects the treatment plan in a fashion similar to bruxism. However, the vertical forces are less detrimental than horizontal forces, and alteration of the anterior occlusal scheme is not as critical as with bruxing patients. Night guards are also less effective. However, a hard acrylic shell and softer, resilient liner night guard, which is relieved over the implants, is often beneficial to a clenching patient. Unlike teeth, implants do not extrude. As a result, the night guard positioned on the arch with implants can be relieved around an intermediate implant(s), and the surrounding teeth bear the entire load. As with the bruxing night guard, an implant prosthesis in the arch opposing the guard may have all occlusal contacts eliminated (Figure 10-22). This also applies to cantilevered portions of an implant prosthesis. In a full-arch implant restoration, the night guard with only anterior occlusal contacts provides a biomechanical advantage to reduce the impact of the force during clenching[58] (Figure 10-23).

Prosthetic Considerations

A common cause of implant failure during healing is parafunction in a patient wearing a soft tissue–supported prosthesis over a submerged implant. The tissue overlying the implant is compressed during the parafunction. The premature loading may cause micromovement of the implant body in the bone and may compromise osteointegration. When an overlying soft tissue–borne restoration exerts pressure as a result of parafunction, pressure necrosis causes soft tissue dehiscence over the implant. This condition is not corrected by surgically covering the implant with soft tissue, but the soft tissue support region of the prosthesis over the implant should be generously relieved during the healing period whenever parafunction is noted. A removable partial denture over a healing implant is especially of concern. The acrylic between the soft tissue–borne region and metal substructure is usually less than 1 mm thick. Removing the thin acrylic region over the implant is often insufficient. Instead, a 6-mm-diameter hole through the metal substructure should be prepared (Figure 10-24).

The time intervals between prosthodontic restoration appointments may be increased to provide additional time to produce load-bearing bone around the implants through progressive bone-loading techniques.[59] Anterior implants submitted to lateral parafunction forces require further treatment considerations.[60] Additional implants are indicated, preferably of greater diameter. The excursions are canine guided if natural, healthy canines are present. Mutually protected occlusion, with additional anterior implants or teeth distributing forces, is

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FIGURE 10-21. **A,** This patient has cervical abfraction on the anterior teeth of this mandibular hybrid fixed implant-supported prosthesis from clenching. The patient refused to wear an occlusal guard at night. **B,** The abfraction continued and affected the denture teeth and cervical areas of the hybrid fixed-implant restoration in both the maxilla and mandible. The mandibular implants then fractured from fatigue and creep.

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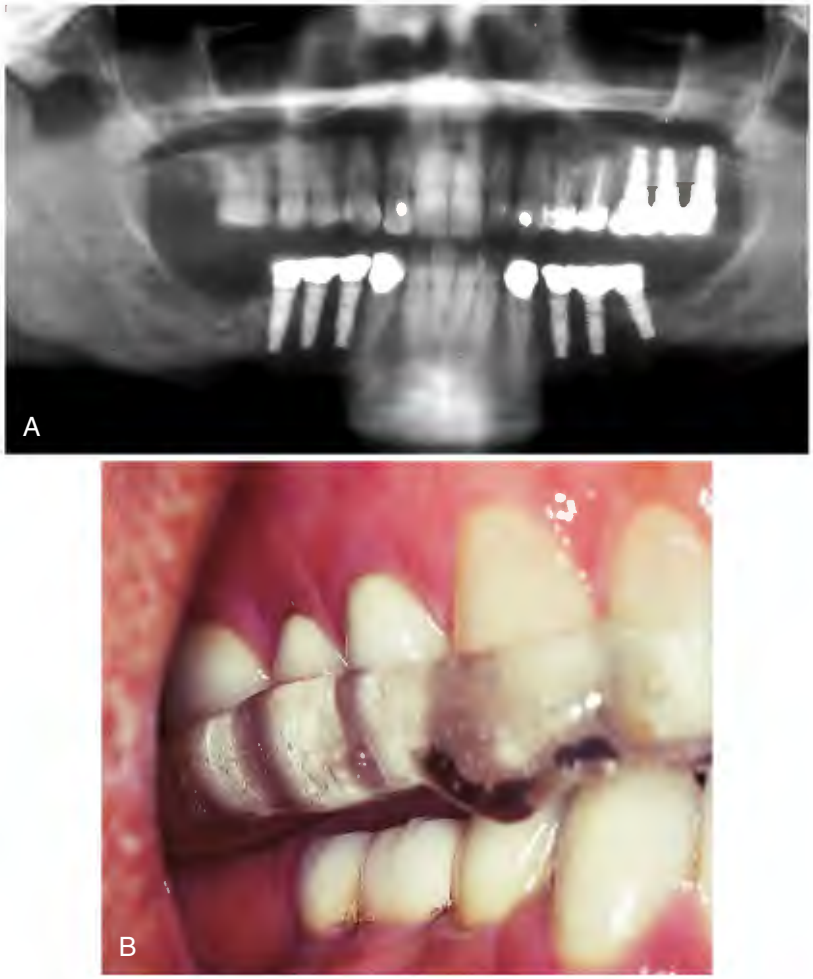


FIGURE 10-22. **A,** Panoramic radiograph demonstrating three posterior quadrants with implant prostheses in a clenching patient. **B,** The maxillary night guard has only anterior occlusion in both centric and mandibular excursions. The guard engages the posterior natural teeth, so extrusion of the posterior teeth will not occur.

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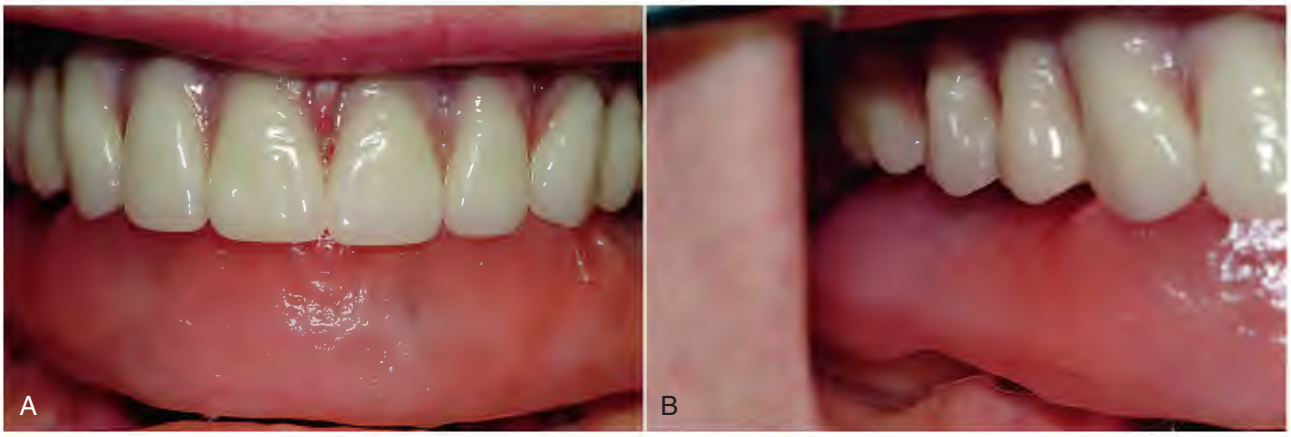


FIGURE 10-23. **A,** This clenching patient has a maxillary full-arch hybrid fixed implant prosthesis opposing a mandibular RP-4 overdenture. In place is a mandibular night guard appliance. **B,** At night, she removes her overdenture and wears a night guard with only anterior contact in both centric and excursions of the mandible.



FIGURE 10-24. When a removable partial denture is worn over healing implants, a 6-mm hole over each implant site reduces the risk of parafunctional loads transferred through the overlying tissue.



FIGURE 10-25. This patient fractured the porcelain on her fixed mandibular implant–supported restoration. The cervical regions were the primary sites of fracture because the patient had a clenching habit.

developed if the implants are in the canine position or if this tooth is restored as a pontic. The prosthesis may be designed to improve the distribution of stress throughout the implant system with centric vertical contacts aligned with the long axis of the implant whenever possible. Narrow posterior occlusal tables to prevent inadvertent lateral forces and to decrease the occlusal forces are beneficial.[60] Enamoplasty of the cusp tips of the opposing natural teeth is indicated to help improve the direction of vertical forces within the guidelines of the intended occlusion.

Clenching and bruxism increase the risk of mechanical failure, such as porcelain fracture, uncemented restoration, abutment screw fracture, implant body fracture, and crestal bone loss (Figure 10-25). Therefore, metal occlusal restorations, wider implant bodies, harder cement types (e.g., zinc phosphate vs. zinc oxide), titanium alloy implant bodies, and more implants splinted together are all beneficial.

Tongue Thrust and Size

Parafunctional tongue thrust is the unnatural force of the tongue against the teeth during swallowing.[61] A force of approximately 41 to 709 g/cm^2 on the anterior and lateral areas of the palate has been recorded during swallowing.[62] In orthodontic movement, a few grams of constant force are sufficient to displace teeth. Hence, these forces may cause clinical complications related to these forces.

Several different types of tongue thrust have been identified; anterior, intermediate, posterior, and either unilateral or bilateral may be found and in almost any combination (Figures 10-26 and 10-27). A common question is, "Which came first, the aberrant tongue position or the misalignment of teeth?" Regardless, this condition can contribute to implant healing and prosthetic complications. Although the force of tongue thrust is of lesser intensity than in other parafunctional forces, it is horizontal in nature and can increase stress at the permucosal site of the implant. This is most critical for one-stage surgical approaches and immediate restoration of implants in which the implants are in an elevated position at initial placement and the implant interface is in an early healing phase (Figure 10-28). If the natural teeth in the region of the tongue thrust were lost as a result of an aberrant tongue position or movement, the

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FIGURE 10-26. Many different types of tongue-thrust habits have been classified. This patient has an anterior tongue thrust and, as a result, does not have anterior guidance during any mandibular excursive movement.



FIGURE 10-27. This patient has a unilateral posterior tongue thrust. When the patient swallows, the tongue is forced between the maxillary canine and first premolar, the mandibular lateral incisor and canine, and the posterior edentulous regions in both arches. Posterior one-stage implants would receive an immediate horizontal load. The patient will feel that the implant prosthesis is constricting the tongue.

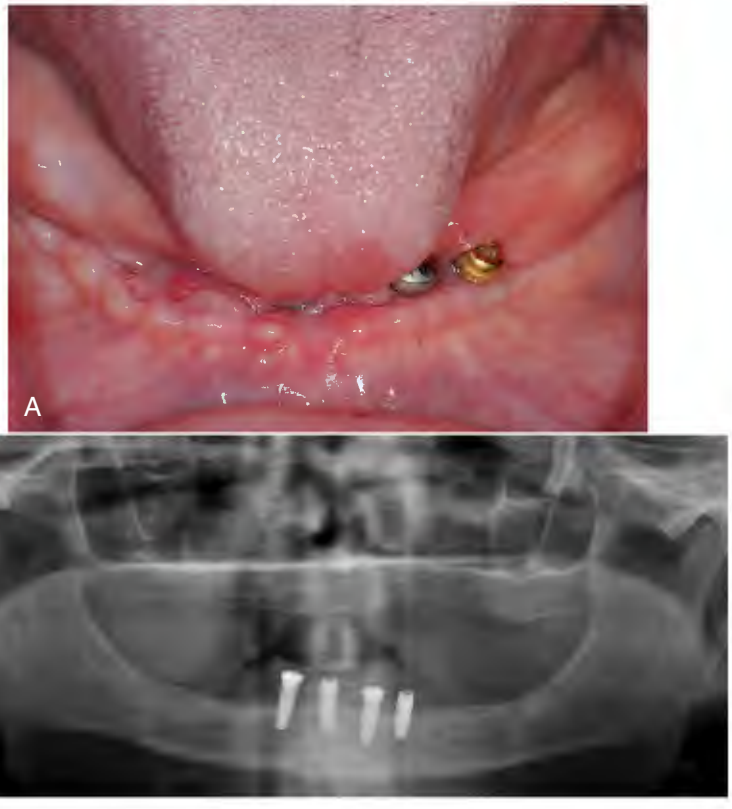


FIGURE 10-28. **A,** This patient has an anterior tongue thrust. Five anterior one-stage implants were inserted. **B,** One implant failed to integrate, and two implants lost one third to half of the crestal bone during initial healing.

implants are at increased risk during initial healing and early prosthetic loading.

The tongue thrust may also contribute to incision line opening after bone grafting or implant surgery, which may compromise both the hard and soft tissues. This is especially noteworthy in a bone augmentation procedure. A tongue-thrust habit may lead to tooth movement or mobility, which is of consequence when implants are present in the same quadrant. If the remaining teeth exhibit increased mobility, the implant prosthesis may be subject to increased occlusal loads.

The posterior tongue thrust may be acquired in patients wearing a maxillary denture opposing a Kennedy class 1 mandibular arch, without a mandibular prosthesis replacing the posterior teeth. Under these conditions, the maxillary denture often loses valve seal and drops posteriorly during centric occlusion or excursions because only anterior teeth contact. To limit this problem, the patient extends the lateral aspect of the tongue into the edentulous region to prevent the maxillary denture from dislodgement (Figure 10-29).

To evaluate anterior tongue thrust, the doctor holds the lower lip down, squirts water into the mouth with the water syringe, and asks the patient to swallow. A normal patient forms a vacuum in the mouth by positioning the tongue on the anterior aspect of the palate and is able to swallow without

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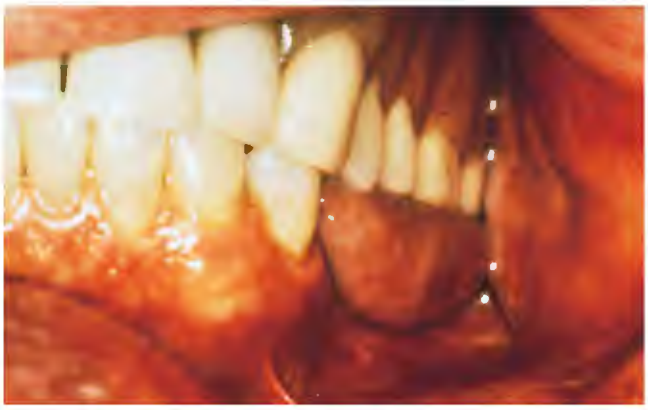


FIGURE 10-29. This patient has a maxillary complete denture and no posterior mandibular teeth. The patient has developed a posterior tongue position to support the denture and prevent it from dropping posteriorly when the patient occludes. Prosthetic complications of tongue biting are at a greater risk.



FIGURE 10-30. In a patient with missing teeth and no prosthetic replacement, such as a complete or partial denture, the tongue often increases in size. The tongue does not transfer an active lateral force during swallowing. This tongue type will adapt most often to a mandibular posterior implant prosthesis.

difficulty. A patient with an anterior tongue thrust is not able to create the vacuum needed to swallow when the lower lip is retracted because the seal and vacuum for the patient are achieved between the tongue and the lower lip. As a consequence, the patient is unable to swallow while the lower lip is withdrawn.

A posterior tongue thrust is evaluated by retracting one cheek at a time away from the posterior teeth or edentulous region with a mouth mirror, injecting water into the mouth with a water syringe and asking the patient to swallow. Visual evidence of the tongue during deglutition may also be accompanied by pressure against the mirror and confirms a lateral force (see Figure 10-27).

A potential prosthetic complication for a patient with a lateral tongue thrust is the complaint of inadequate room for the tongue after the mandibular implants are restored. A prosthetic mistake is to reduce the width of the lingual contour of the mandibular teeth to give the tongue more space. The lingual cusp of the restored mandibular posterior teeth should follow the curve of Wilson and have a proper horizontal overjet to protect the tongue during function. A reduction in the width of the mandibular posterior teeth often increases the occurrence of tongue biting and may not dissipate with time. When the lingual surface of the mandibular restoration is reduced, the entire prosthesis may need to be refabricated. The restoring dentist should identify the tongue position before treatment and inform the patient about the early learning curve for the tongue once the teeth are delivered on the implants (Box 10-7).

Even in the absence of tongue thrust, the tongue often accommodates to the available space, and its size may increase with the loss of teeth (Figure 10-30). As a result, a patient not wearing a mandibular denture often has a larger than normal tongue. The placement of implants and prosthetic teeth in such a patient results in an increase in lateral force, which may be continuous. The patient then complains of inadequate room for the tongue and may bite it during function. However, this condition is usually short lived, and the patient eventually adapts to the new intraoral condition. However, it has been observed a fixed restoration is more advantageous for this type of patient. A RP-5 restoration is much less stable in patients with tongue thrust or size issues, and patient complaints are more common with removable restorations in general.

BOX 10-7 Parafunction: Tongue Thrust and Size

1. Tongue thrust
   a. Less force than bruxism or clenching
   b. Is constant
   c. Horizontal direction
2. Several types possible
   a. Anterior
   b. Intermediate
   c. Posterior unilateral or bilateral
3. Incision line opening after surgery
4. Early loading risk for one stage or immediate restorations
5. Prosthetic complications

Crown Height Space

The interarch distance is defined as the vertical distance between the maxillary and mandibular dentate or dentate arches under specific conditions (e.g., the mandible is at rest or in occlusion).[63] A dimension of only one arch does not have a defined term in prosthetics; therefore, Misch proposed the term *crown height space*.[64] The CHS for implant dentistry is measured from the crest of the bone to the plane of occlusion in the posterior region and the incisal edge of the arch in question in the anterior region (Figure 10-31). In the anterior regions of the mouth, the presence of a vertical overbite means the CHS is larger in the maxilla than the space from the crest of the ridge to the opposing teeth incisal edge. In general, when the anterior teeth are in contact in centric occlusion, there is a vertical overbite. The anterior mandibular CHS is therefore usually measured from the crest of the ridge to the mandibular incisal edge. However, the anterior maxillary CHS is measured from the maxillary crestal bone to the maxillary incisal edge, not the occlusal contact position.

The ideal CHS needed for a fixed implant prosthesis should range between 8 and 12 mm. This measurement accounts for the "biological width," abutment height for cement retention or prosthesis screw fixation, occlusal material strength, esthetics, and hygiene considerations around the abutment crowns. Removable prostheses often require a CHS greater than 12 mm

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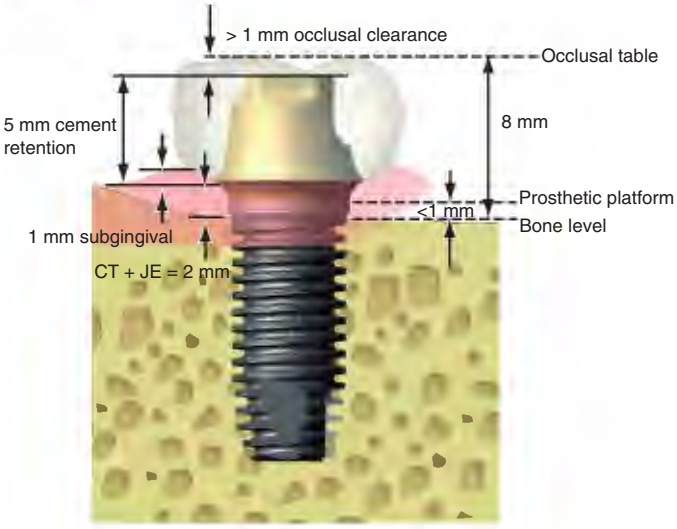


FIGURE 10-31. The crown height space is measured from the occlusal plane to the crest of the bone. The ideal space for a FP-1 prosthesis is between 8 mm and 12 mm. *CT,* Connective tissue attachment; *JE,* junctional epithelial attachment.

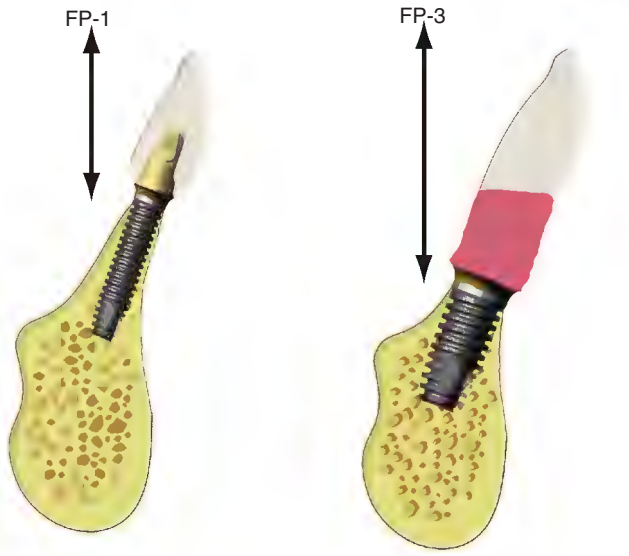


FIGURE 10-32. The crown height space is a vertical cantilever to any angled load or cantilever. The FP-3 on the *right* will deliver greater stresses to the implant compared with the implant on the *left*. Therefore, a wider-diameter implant is of benefit to support the implant restoration on the right.

BOX 10-8 Crown Height Space

The CHS is measured from the occlusal plane to the crest of the bone.

CHS does not have a specific ideal dimension. With fixed restorations, the acceptable range for CHS is between 8 and 12 mm.

Removable implant restorations often require a CHS of 12 mm or more, especially when a bar connects the individual implants.

An increase in prosthetic complications occurs with either limited or excessive CHS.

CHS, crown height space.

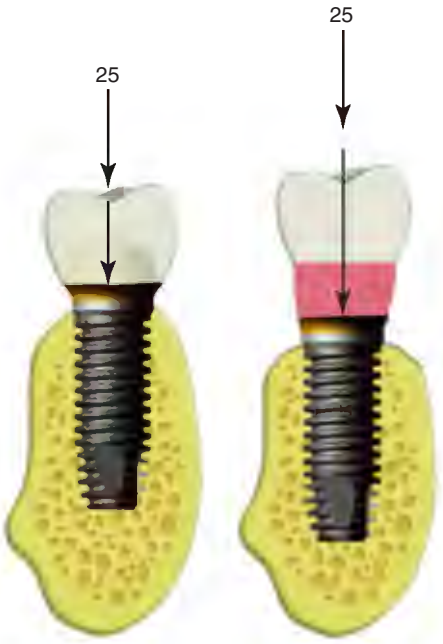


FIGURE 10-33. When a long axis load is applied to an implant, the crown height does not magnify the load. The implant on the *left* will have similar stress as the one on the *right* because the load is in the long axis.

for denture teeth and acrylic resin base strength, attachments, bars, and oral hygiene considerations[65,66] (Box 10-8).

Biomechanic Consequences of Excessive Crown Height Space

Force magnifiers are situations or devices that increase the amount of force applied to a system and include a screw, pulley, incline plane, and lever.[42] The biomechanics of CHS are related to lever mechanics. The properties of a lever have been appreciated since the time of Archimedes 2000 years ago ("give me a lever and a fulcrum and a place to stand and I can move the world"). The issues of cantilevers and implants were demonstrated in the edentulous mandible, where the length of the posterior cantilever directly related to complications or failure of the prosthesis.[1] Rather than a posterior cantilever, the CHS is a vertical cantilever when any lateral or cantilevered load is applied and therefore is also a force magnifier[42] (Figure 10-32). As a result, because CHS excess increases the amount of force, any of the mechanical-related complications related to implant prostheses may also increase, including uncemented prosthesis, screw loosening (prosthetic or abutment), overdenture attachment complications, and so on.

When the direction of a force is in the long axis of the implant, the stresses to the bone are not magnified in relation to the CHS (Figure 10-33). However, when the forces to the implant are on a cantilever or a lateral force is applied to the crown, the forces are magnified in direct relationship to the crown height. Bidez and Misch evaluated the effect of a cantilever on an implant and its relation to crown height.[42,43] When a cantilever is placed on an implant, there are six different potential rotation points (i.e., moments) on the implant body (Figure 10-34; Table 10-2). When the crown height is increased from 10 to 20 mm, two of six of these moments are increased 200%.

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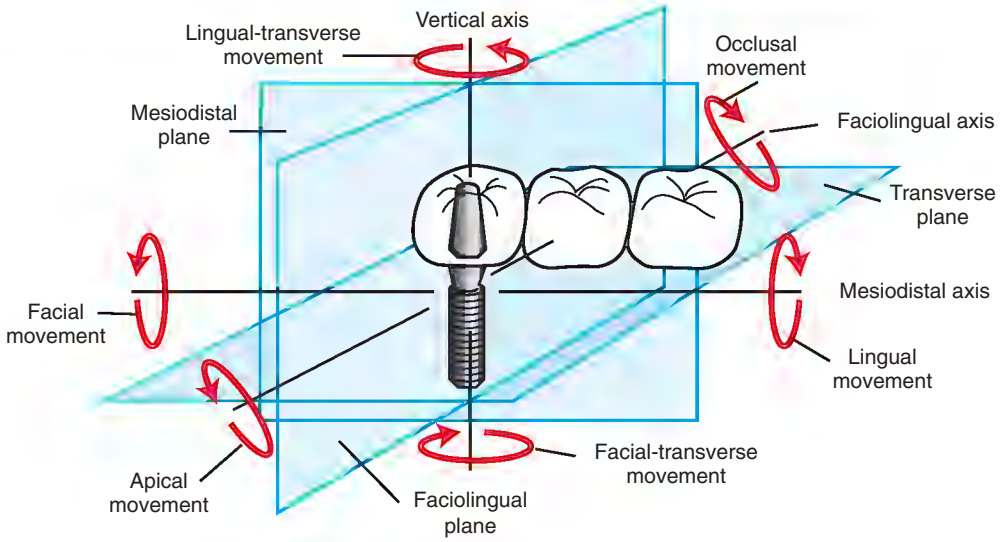


FIGURE 10-34. Moment loads tend to induce rotations in three planes. Clockwise and counterclockwise rotations in these three planes result in six moments: lingual-transverse, facial-transverse, occlusal, apical, facial, and lingual.

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TABLE 10-2
Moment Load at Crest, When Subjected to Forces Shown in Figure 10-34

Influences on Moment	Imposed Moments (N/mm) at Implant Crown-to-Crest Interface	Imposed Moments (N/mm) at Implant Crown-to-Crest Interface					
Occlusal Height (mm)	Cantilever Length (mm)	Lingual	Facial	Apical	Occlusal	Facial Transverse	Lingual Transverse
10	10	100	0	50	200	0	100
10	20	100	0	50	400	0	200
10	30	100	0	50	600	0	300
20	10	200	0	100	200	0	100
20	20	200	0	100	400	0	200
20	30	200	0	100	600	0	300

A cantilevered force may be in any direction: facial, lingual, mesial, or distal. Forces cantilevered to the facial and lingual direction are often called *offset loads.* The bone width decrease is primarily from the facial aspect of the edentulous ridge. As a result, implants are often placed more lingual than the center of the natural tooth root. This condition often results in a restoration cantilevered to the facial. When the crest of the ridge resorbs, available bone height is also decreased, and the CHS is increased. Therefore, the potential length of the implant is often reduced in excessive CHS conditions, and the more lingual implant position results in offset loads.

The vertical distance from the occlusal plane to the opposing landmark for implant insertion is typically a constant in an individual (with the exception of the posterior maxilla because the sinus cavity expands more rapid than crestal bone resorption in height). Therefore, as the bone resorbs, the crown height becomes larger, but the available bone height decreases (Figure 10-35). An indirect relationship is found between the crown and implant height. Moderate bone loss before implant placement may result in a crown height–bone height ratio greater than 1, with greater lateral forces applied to the crestal bone than in abundant bone (in which the crown height is less). A linear relationship exists between the applied load and internal stresses within the bone.[67,68] Therefore, the greater the load applied, the greater the tensile and compressive stresses transmitted at the bone interface and to the prosthetic components. And yet, many implant treatment plans are designed with more implants in abundant bone situations and fewer implants in atrophied bone volume. The opposite scenario should exist. The lesser the bone volume, the greater the crown height and the greater the number of implants indicated (Figure 10-36).

An angled load to a crown will also magnify the force applied to the implant. A 12-degree force to the implant will be increased by 20% compared with a long axis load. This increase in force is further magnified by the crown height. For example, a 12-degree angle with a force of 100 N will result in a force of 315 N-mm on a crown height of 15 mm.[60] In other words, the CHS force increase is even greater than the angled load increase.

Maxillary anterior teeth are usually at an angle of 12 degrees or more to the occlusal planes. Even implants placed in an ideal position are usually loaded at an angle. Maxillary anterior crowns are often longer than any other teeth in the arch, so the effects of crown height cause greater risk. The angled force to the implant also may occur during protrusive or lateral excursions because the incisal guide angle may be 20 degrees or more.[37] Anterior implant crowns will therefore be loaded at a

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FIGURE 10-35. In the past, treatment plans included more and longer implants in abundant bone *(top)* but fewer and shorter implants in less available bone *(bottom)*. However, crown height increases as bone height decreases, and this approach creates unfavorable mechanics when the bone height is reduced.



FIGURE 10-36. Crown height is a force magnifier to any lateral load or horizontal cantilever. Therefore, when available bone height decreases with a greater crown height, more implants should be inserted and cantilever length reduced.

considerable angle during excursions compared with the long axis position of the implant. As a result, an increase in the force to maxillary anterior implants should be compensated for in the treatment plan.

In most implant designs and bone density types, most forces applied to the osseointegrated implant body are concentrated in the crestal 7 to 9 mm of bone.[3] Therefore, implant body height is usually not an effective method to counter the effects of crown height. In other words, crown-to-root ratio is a prosthetic concept that may guide the restoring dentist when

BOX 10-9 Causes of Excessive Crown Height Space

Long-term edentulism and vertical bone loss
Genetics
Trauma
Implant failure

evaluating a natural tooth abutment. The longer the natural tooth root, the shorter the crown height, which acts as a lever to rotate the tooth around an axis located two thirds down the root. However, the crown height–implant ratio is not a direct comparison. Crown height is a vertical cantilever that magnifies any lateral or cantilever force in either a tooth- or an implant-supported restoration. However, this condition is not improved by increasing implant length to dissipate stresses. The implant does not rotate away from the force in relation to implant length. Instead, it captures the force at the crest of the ridge.

The greater the CHS, the greater number of implants usually required for the prosthesis, especially in the presence of other force factors. This is a complete paradigm shift to the concepts advocated originally, with many implants in greater available bone and small crown heights and fewer implants with greater crown heights in atrophied bone. The cantilever should also be reduced in greater CHS conditions and may need to be eliminated completely if other force conditions are present.

An increased CHS may increase the forces to the crestal bone around the implants and increase the risk of crestal bone loss. The CHS increases when crestal bone loss occurs around the implants. This in turn may further increase both the CHS and the moment forces to the entire support system, resulting in screw loosening, crestal bone loss, implant fracture, and implant failure.

Excessive Crown Height Space

Crown height space greater than 15 mm is considered excessive and is primarily the result of the vertical loss of alveolar bone from long-term edentulism.[65] Other causes may include genetics, trauma, and implant failure (Box 10-9). Treatment of excessive CHS before implant placement includes orthodontic and surgical methods. Orthodontics in partially edentulous patients (especially in the growth and development state) is the method of choice because other surgical or prosthetic methods are usually more costly and have greater risks of complications. Several surgical techniques may also be considered, including block onlay bone grafts, particulate bone grafts with titanium mesh or barrier membranes, interpositional bone grafts, and distraction osteogenesis. A staged approach to reconstruction of the jaws is often preferred to simultaneous implant placement, especially when large-volume gains are required. Significant vertical bone augmentation may even require multiple surgical procedures.

Distraction osteogenesis has several advantages over onlay bone grafting techniques for vertical bone growth. Vertical bone gains are not limited by factors such as graft size or expansion of the existing soft tissue volume. There is no donor site morbidity, and the surgery may be performed in an office setting. However, distraction osteogenesis requires patient compliance, and bone volume gains are often unidirectional. In addition, clinical studies found that secondary bone augmentation procedures are often required for dental implant placement.[69]

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Misch presented a unique approach combining vertical distraction and horizontal onlay bone grafting to reconstruct the deficiency three dimensionally. Osseous distraction is performed first to vertically increase the ridge and expand the soft tissue volume. Secondarily, an onlay bone graft is used to complete the repair of the defect (Figure 10-37).[65]

In case of excessive CHS, bone augmentation may be preferred to prosthetic replacement, especially in type C-h or D bone volumes. Surgical augmentation of the residual ridge height reduces the CHS and improves implant biomechanics by both position and number. Augmentation often permits the placement of wider-body implants with the associated benefit of increased surface area (Figure 10-38). Prosthetics is the most commonly used option to address excess CHS; however, it should be the last choice. Using gingival-colored prosthetic materials (pink porcelain or acrylic resin) on fixed restorations or changing the prosthetic design to a removable restoration should often be considered when the prosthesis is used to restore excessive CHS (Figure 10-39).

In the maxilla, a vertical loss of bone results in a more palatal ridge position. As a consequence, implants are often inserted more palatal than the natural tooth position. Removable restorations have several advantages under these clinical circumstances. The removable prosthesis does not require embrasures for hygiene. The removable restoration may be removed during sleep to decrease the effects of an increase in CHS on nocturnal parafunction. The removable restoration may improve the lip and facial support, which is deficient because of the advanced bone loss. The overdenture may have sufficient bulk of acrylic resin to decrease the risk of prosthesis fracture. The increase in CHS permits denture tooth placement without infringement of the implant–prosthetic substructure (Figure 10-40).

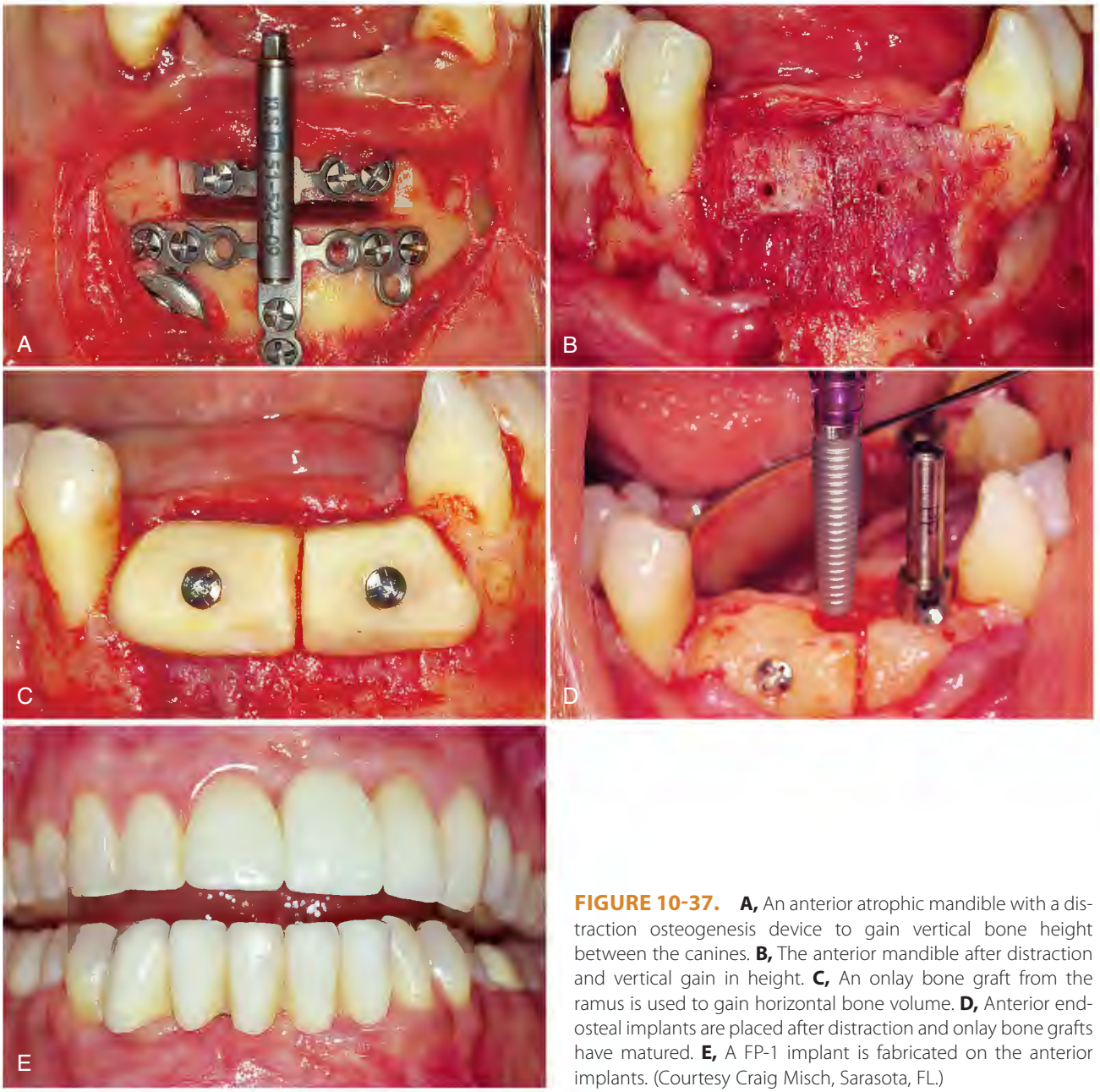


FIGURE 10-37. **A,** An anterior atrophic mandible with a distraction osteogenesis device to gain vertical bone height between the canines. **B,** The anterior mandible after distraction and vertical gain in height. **C,** An onlay bone graft from the ramus is used to gain horizontal bone volume. **D,** Anterior endosteal implants are placed after distraction and onlay bone grafts have matured. **E,** A FP-1 implant is fabricated on the anterior implants. (Courtesy Craig Misch, Sarasota, FL.)

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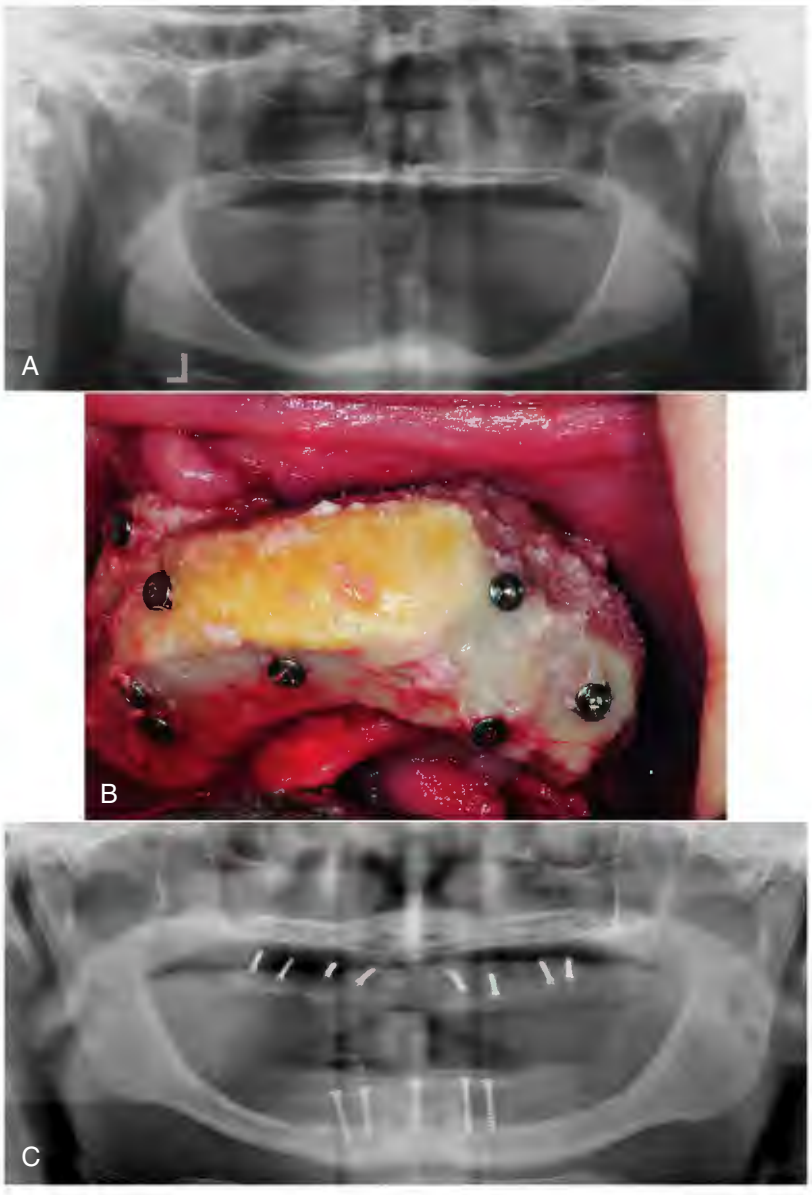


FIGURE 10-38. **A,** A panoramic radiograph of a severely resorbed maxilla and mandible. **B,** An autologous bone graft may be used to increase the available bone height and reduce the crown height in a division C or D bone volume. **C,** A panoramic radiograph after the iliac crest bone graft to the maxilla and mandible.

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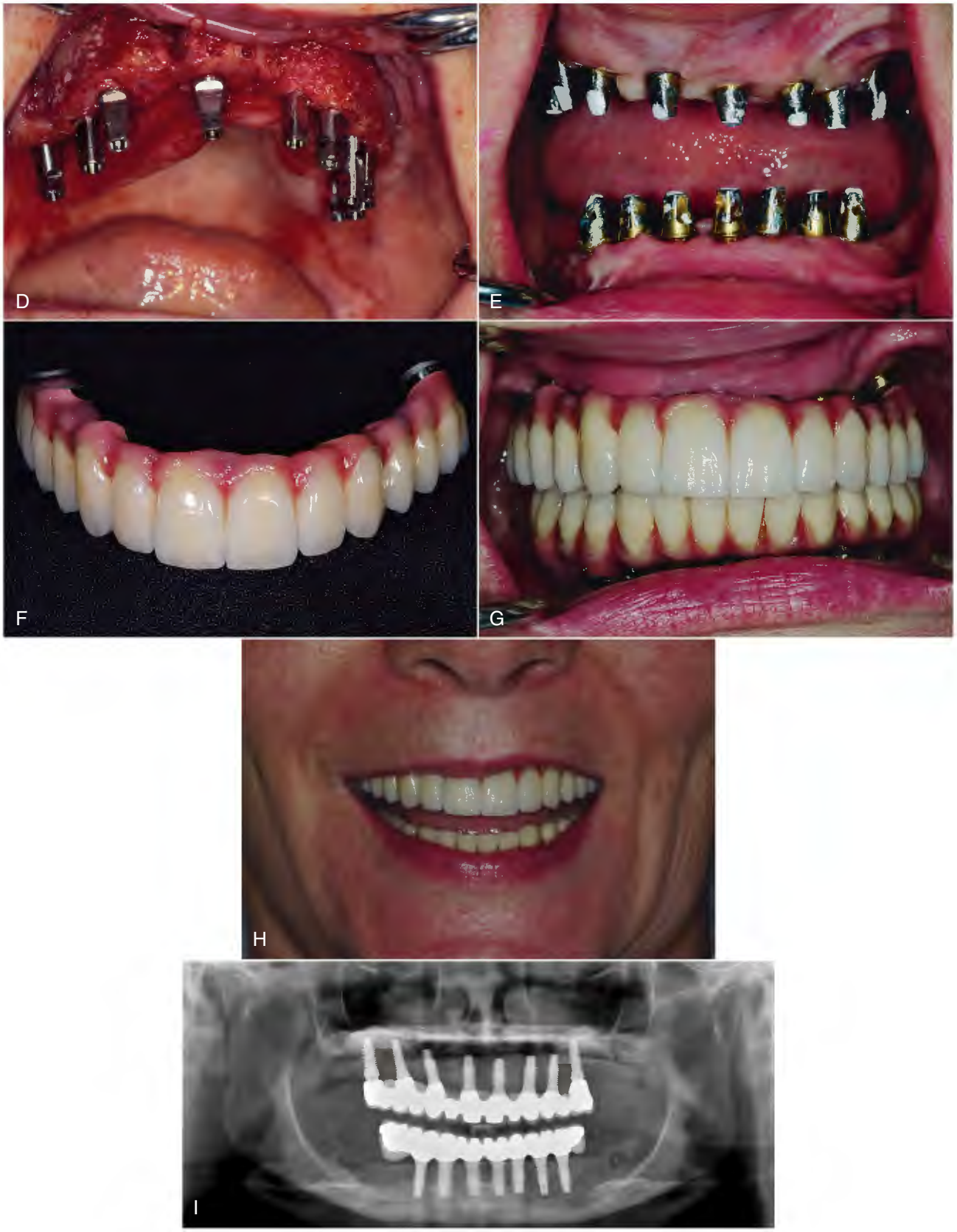


FIGURE 10-38, cont'd. **D,** Implants may be inserted into the bone graft after 6 months. **E,** The implants are prepared to support a cemented prosthesis. **F,** A FP-3 fixed restoration is fabricated. **G,** The maxillary and mandibular FP-3 prosthesis in place. **H,** The high smile line of the patient. **I,** A panoramic radiograph of the iliac crest, implants, and prostheses.

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Soft tissue support in addition to implant-supported removable implant restorations with an excessive CHS is recommended when it is not possible to overengineer the implant support system. A rigid overdenture has identical requirements for implant support in position and number as a fixed prosthesis because it is rigid during function. Misch describes the "hidden cantilever" beyond the cantilevered bar with a rigid implant overdenture.[70] When the overdenture has no movement during function, the cantilever does not stop at the end of the cantilevered substructure but ends at the last occlusal contact position on the prosthesis, often the distal of a second molar.

The position and type of overdenture attachments may render an overdenture rigid during function even in the absence of distal cantilevers on the bar. For example, when three anterior implants are splinted together and a Hader clip is used to retain the prosthesis, if the Hader clips are placed at angles to the midline, the attachments have limited movement and result in a rigid overdenture during function. Misch suggests the prosthesis movement, not the individual attachment movement, should be evaluated.[70] Excessive CHS with overdentures are situations that benefit from a prosthesis designed to have more than one direction of movement.

The excessive CHS on a RP-5 prosthesis often makes the restoration more unstable and often requires more soft tissue support. In RP-5 overdentures, there are two different components of the CHS: (1) the distance from the crest of the ridge to the height of the overdenture attachment and (2) the distance from the overdenture attachment to the occlusal plane. The greater the distance from the attachment to the occlusal plane, the more force on the prosthesis to move or rotate on the attachment and the greater the prosthesis mobility (and less the stability). Hence, more tissue support is required during function. This may cause more sore spots under the prosthesis and may accelerate the posterior bone loss (Figure 10-41).

The ideal CHS for a fixed prosthesis is between 8 and 12 mm, accounting for an ideal 3 mm of soft tissue, 2 mm of occlusal material thickness, and a 5 mm or greater abutment height. A CHS greater than 12 mm may be of concern in fixed restorations. The replacement teeth are elongated and often require the addition of gingival tone materials in esthetic regions. The greater impact force on implants compared with teeth, combined with the increased crown height, creates increased moment forces on implants and risks of uncemented or unretained prostheses, component, and material fracture. These problems are especially noted when associated with less favorable biomechanics on cantilevered sections of fixed restorations.[65]

Crown height space greater than 15 mm means a large amount of metal must be used in the substructure of a traditional fixed restoration to keep porcelain to its ideal 2-mm thickness. Fine-tuning techniques for traditional fixed restorations are required under these conditions.[66,71] Controlling surface porosities of metal substructures after casting as their different parts cool at different rates becomes increasingly difficult. Furthermore, when the casting is reinserted into the oven to bake the porcelain, the heat is maintained within the casting at different rates, so the porcelain cools in different regions at different rates.[72] If not controlled properly, both of these factors increase the risk of porcelain fracture after loading.[73] For excessive CHS, considerable weight of the prosthesis (approaching 3 oz of alloy) may affect maxillary trial placement appointments because the restoration does not remain in place without the use of adhesive. Noble metals must be used to control alloy's heat expansion or corrosion; therefore, the costs of such implant restorations have dramatically increased.[74] Proposed methods to produce hollow frames to alleviate these problems, including the use of special custom trays to achieve a passive fit, may double or triple the labor costs.



FIGURE 10-39. When the crown height space is greater than 12 mm, pink porcelain (or acrylic) is often used to replace the soft tissue drape in the prosthesis.

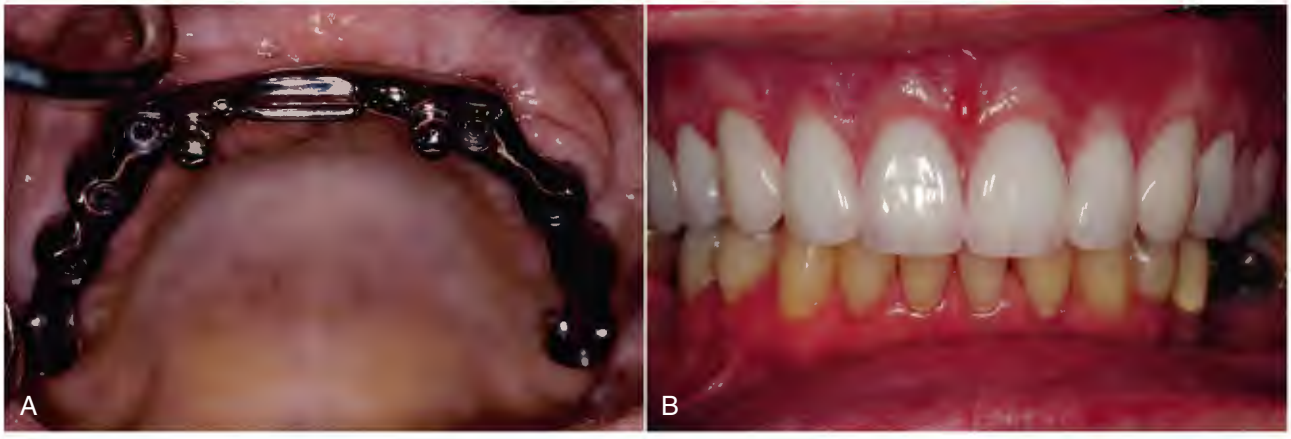


FIGURE 10-40. **A,** A maxillary overdenture may be used to restore a patient with a large crown height space (CHS). **B,** A maxillary overdenture may support the lip and face when the CHS is excessive.

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An alternative method of fabricating fixed prostheses in situations of CHS of 15 mm or greater is the fixed complete denture or hybrid prosthesis, with a smaller metal framework, denture teeth, and acrylic resin to join these elements together (Figure 10-42). The reduced metal framework compared with a porcelain-to-metal fixed prosthesis exhibits fewer dimensional changes and may more accurately fit the abutments, which is especially important for a screw-retained restoration. It is less expensive to fabricate than a porcelain-to-metal fixed prosthesis, is highly esthetic (premade denture teeth), easily replaces teeth and soft tissue in appearance, and is easier to repair if fracture occurs. Because resin acts as an intermediary between the teeth and metal substructure, the impact force during dynamic occlusal loading may also be reduced. Therefore, this type of fixed prosthesis is often indicated for implant restorations with a large CHS.

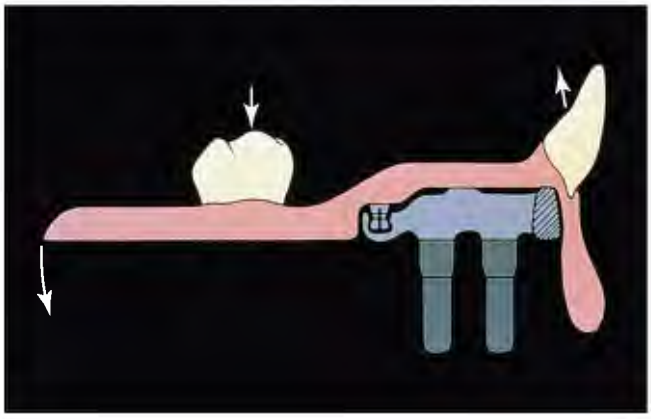


FIGURE 10-41. A RP-5 overdenture is usually less stable when the crown height space (CHS) is large. The CHS of the prosthesis is measured from the occlusal plane to the height of the overdenture attachments.

On occasion, undercontoured interproximal areas are designed by the laboratory in such restorations to assist oral hygiene and have been referred to as "high water" restorations. This is an excellent method in the mandible; however, it results in food entrapment, affects air flow patterns, and may contribute to speech problems in the anterior maxilla. Hence, the excessive CHS condition has several conditions that may alter the treatment plan (Box 10-10).

An increase in the biomechanical forces is in direct relationship to the increase in CHS. Therefore, the treatment plan of the implant restoration should consider stress-reducing options whenever the CHS is increased. Methods to decrease stress include[64–66]:

1. Shorten cantilever length.
2. Minimize offset loads to the buccal or lingual.
3. Increase the number of implants.
4. Increase the diameters of implants.
5. Design implants to maximize the surface area of implants.
6. Fabricate removable restorations that are less retentive and incorporate soft tissue support.



FIGURE 10-42. **A,** A metal framework for a hybrid prosthesis composed of metal, acrylic, and denture teeth presents several advantages for fixed prostheses with a crown height space greater than 15 mm. **B,** Denture teeth are connected to a metal substructure with an acrylic base in the maxillary prosthesis. **C,** A panoramic radiograph with the metal framework and denture teeth hybrid prosthesis in the maxilla and a FP-3 porcelain–metal restoration in the mandible.

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BOX 10-10 Excessive Crown Height Space

CHS is a vertical lever with any lateral force or cantilever.

Excessive CHS increases mechanical complications in fixed prostheses.

Overdentures may more often be required in completely edentulous patients.

The implant support for RP-4 overdentures should be as great as that for a FP.

In RP-5 overdentures, there may be two different components of the CHS: the distance from the crest of the bone to the height of the attachment and the distance from the attachment to the occlusal plane.

With RP-5 overdentures, there should be adequate soft tissue support.

The need for gingival replacement procedures (FP-3) should be evaluated before implant placement for fixed restorations.

Metal and porcelain shrinkage is more of a problem in FP-3 than traditional FP cases.

Hybrid FP-3 FPs with denture teeth, metal substructure, and acrylic resin may be indicated.

CHS, Crown height space; *FP,* fixed prosthesis; *RP,* removable prosthesis.



FIGURE 10-43. Masticatory dynamics are affected by the size of the patient. (Larger persons generally have greater bite forces.)

7. Remove the removable restoration during sleeping hours to reduce the noxious effects of nocturnal parafunction.
8. Splint implants together, whether they support a fixed or removable prosthesis.

Crown height space is a considerable force magnifier; therefore, the greater the crown height, the shorter the prosthetic cantilever that should extend from the implant support system. When the CHS is greater than 15 mm, no cantilever should be considered unless all other force factors are minimal. The occlusal contact intensity should be reduced on any offset load from the implant support system. Occlusal contacts in centric relation occlusion may even be eliminated on the most posterior aspect (or offset region) of a cantilever. In this way, a parafunction load may be reduced because the most cantilevered portion of the prosthesis is only loaded during functional activity (e.g., chewing).

Masticatory Dynamics

Masticatory muscle dynamics are responsible for the amount of force exerted on the implant system. Several criteria are included under this heading, including patient size, gender, age, skeletal position, and state of the dentition. The size of the patient can influence the amount of bite force. Large, athletic men can generate greater forces; patients of weak physical condition often develop less force than athletic patients[13] (Figure 10-43). Higher bite forces may be related to greater implant failure after loading, greater risk of occlusal material fracture, abutment screw loosening, and an increase in the amount of crestal bone loss.

In general, the forces recorded in women are 20 lb less than those in men. The affects of testosterone affects muscle size and strength. In a clinical report by van Steenberghe et al., partially edentulous men have a 13% implant failure rate compared with women.[75] In a report by Kinsel and Lin, men had a 13.1% porcelain fracture rate compared to 6.4% for women. The percentage of patients with restorations with fracture was 26.9% for men compared with 20% for women.[44]

Older patients record lower bite forces than young adults. In addition, younger patients will live longer and require the additional implant support for the prosthesis for a longer time (e.g., an 80-year-old patient will need implant support for far fewer years than a 20-year-old patient, all other factors being equal). In a report by Wyatt and Zarb, first-year radiograph bone loss was positively correlated with male gender, younger age, and implants supporting a distal extension prosthesis.[76] Hence, clinical reports substantiated the need to evaluate masticatory dynamics in the treatment plan.

The skeletal arch position may influence the amount of maximum bite force.[77] People with a brachiocephalic head shape (a stout head shape) may generate three times the bite force than those with a regular head shape[78] (Figure 10-44). This is especially noteworthy when accompanied by moderate to severe bruxism or clenching. Skeletal class III patients are primarily vertical chewers and generate vertical forces with little excursive movement. However, some patients appear as being "pseudo class III" as a result of anterior bone resorption or loss of posterior support and collapse of the vertical dimension with an anterior rotation of the mandible. The "pseudo class III" has an anterior cantilever on the final restoration when restored to a class I dentate position. These patients do exhibit lateral excursive movements when the incisal edge position is restored to its initial position. The angled force also increases the force magnitude on the anterior implants (Figure 10-45).

The maximum bite force decreases as muscle atrophy progresses throughout years of edentulism. A maximum occlusal force of less than 6 psi may be the result of 15 years without teeth.[79] This force may increase 300% in the 3 years after implant placement. As a general rule, the fewer the number of teeth in an arch, the less the maximum bite force.[80] Therefore, physical status, sex, age, muscle mass, skeletal position, and state of the dentition all influence muscle strength, masticatory dynamics, and maximum bite force (Box 10-11). The greater these factors, the greater the risk of biomechanical complications.

The implant treatment plan should reduce other force magnifiers when masticatory musculature dynamics increase. For example, a cantilever length should be reduced in cases of elevated masticatory dynamics. A crown height may be reduced by bone augmentation. The implant number, size, and design may also be increased to increase the surface area of load.

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Arch Position

The maximum biting force is greater in the molar region and decreases as measurements progress anteriorly. Maximum bite forces in the anterior incisor region correspond to approximately 35 to 50 psi, those in the canine region range from 47 to 100 psi, and those in the molar area vary from 127 to 250 psi[11] (Figure 10-46). Mansour et al. evaluated occlusal forces and moments mathematically using a class III lever arm, the condyles being the fulcrum and the masseter and temporalis muscles supplying the force.[81] Similar figures were obtained by mathematical calculation and by direct measurement. The forces at the second molar were 10% higher than at the first molar, indicative of a range from 140 to 275 psi.

In a study by Chung et al. with 339 implants in 69 patients in function for an average of 8.1 years (range, 3–24 years), the posterior implants (even with keratinized mucosa) showed a 3.5-fold greater average bone loss per year than anterior implants.[82] Hence, in the region of higher bite forces, greater bone loss may be evident.

The anterior biting force is decreased in the absence of posterior tooth contact and greater in the presence of posterior occlusion or eccentric contacts.[37,83] Therefore, besides the mechanical properties of a class III lever function, there also is a biological component to decrease bite force in the anterior regions. When the posterior teeth are in contact, the large masticatory muscles contract. When the posterior teeth are not in contact, two thirds of the temporalis and masseter muscles do not contract their fibers. As a consequence, the bite force is reduced.

In the anterior regions with less force, the anterior natural tooth roots are smaller in diameter and root surface area compared with posterior teeth. The greatest increase in natural tooth surface area occurs in the molar region, with a 200% increase compared with the premolars. Yet, in implant dentistry, we primarily determine the implant length by existing bone volume and place longer implants in the anterior region and shorter implants in the posterior regions (or cantilever off the anterior implants, which results in posterior bite forces magnified by the cantilever length). This approach should be corrected to conform to the biomechanical load similar to that observed with natural teeth. However, the length of an implant is less effective to dissipate force. Instead, implant width and design



FIGURE 10-44. A brachiocephalic skeletal patient has a greater bite force than the average patient. This is especially noteworthy when parafunction is present.

BOX 10-11 Masticatory Dynamics

Patient size
Gender
Age
Muscle mass
Skeletal position
State of the dentition

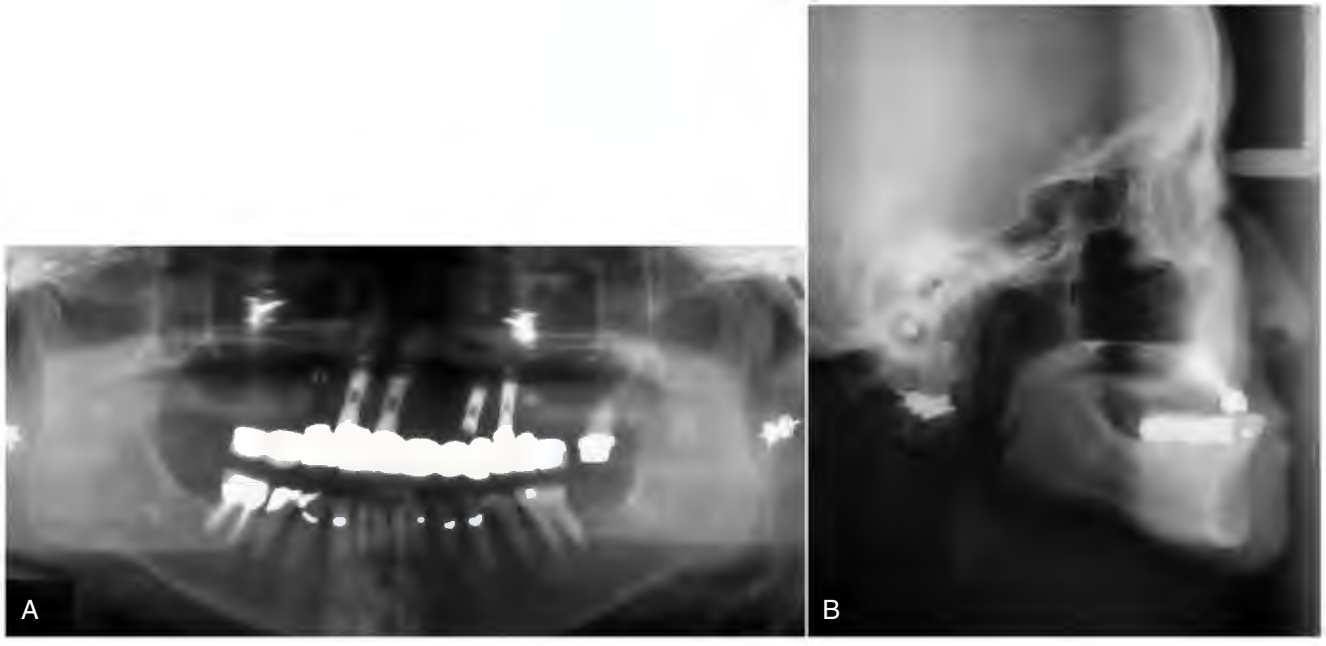


FIGURE 10-45. **A,** A panoramic radiograph of a failing implant prosthesis in the maxilla opposing natural teeth in an Angle class III patient. **B,** A lateral cephalogram of the Angle class III patient with mandibular teeth opposing the failed implant prosthesis.

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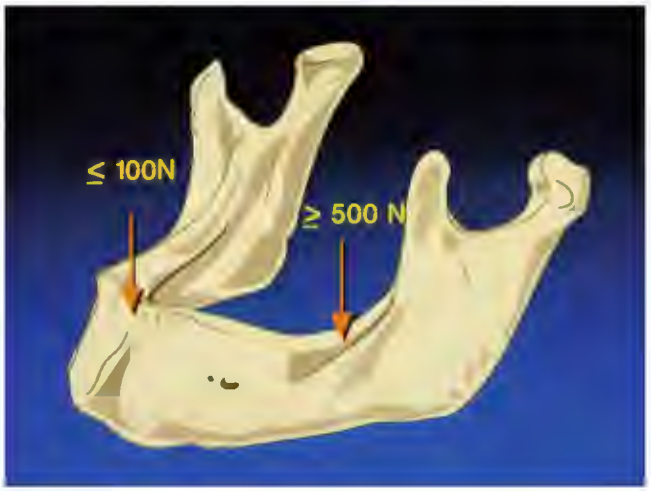


FIGURE 10-46. The maximum bite forces are greater in the posterior regions of the jaws compared with the anterior regions.



FIGURE 10-47. As a general rule, the greater the number of opposing teeth, the greater the bite force. When the opposing arch to the implant prosthesis is a denture (as depicted in this panoramic radiograph in the maxilla), the bite forces are less.

BOX 10-12 Arch Position: Posterior Regions

1. Maximum bite force in molar region
   a. Mechanical component: class III lever
   b. Biological component: amount of muscle mass contraction
2. Most long-term crestal bone loss of integrated implants
3. Bone density poorer than anterior regions of mouth
4. Posterior maxilla more risk than posterior mandible
5. Posterior maxilla has least bone volume
   a. Crestal bone loss
   b. Sinus expansion
6. Posterior mandible less bone height than anterior regions
   a. Position of mandibular canal and foramen

are more effective. The best option to decrease stress is to increase implant number. Therefore, implants in the posterior regions should often be of greater diameter or greater number (because molars have more roots), especially in the presence of additional force factors.

The natural teeth are surrounded by a thin cortical plate of bone and periodontal complex, which is similar for all teeth and arch positions. However, after the teeth are lost, the bone density in the edentulous site is reduced and is often different for each region of the mouth. The posterior regions, in general, form less bone density after tooth loss than the anterior regions, with the anterior maxilla less dense than the mandible. The mandibular anterior implant sites benefit from denser bone than the maxillary anterior implant sites. The denser the bone, the greater its resistance to stress applied at the implant–bone interface. In other words, the edentulous bone density is inversely related to the amount of force and surface area of the natural tooth roots generally applied in that arch position. As a result, the posterior maxilla is the most at-risk arch position followed by the posterior mandible and then the anterior maxilla. The most ideal region for implant stress transfer within the physiologic loading zone for bone is the mandibular anterior region.[84]

Arch position should also consider the anterior maxilla versus the anterior mandible. Not only is the bone generally more dense in the anterior mandible, but the direction of force is also more in the long axis for the lower anterior teeth. The angled load of 12 to 15 degrees in maxillary anterior implants increases the force by approximately 25%. Note that the maxillary anterior teeth are wider in diameter and have greater surface area compared with the smallest teeth in the mouth, the mandibular incisors. The amount of force is similar, but the direction of force places the maxillary teeth more at risk.

Arch position includes the maxillary arch versus the mandibular arch. As previously mentioned, the bone in the mandible is more often more dense than that of the maxilla, especially in the posterior regions. Hence, the edentulous maxilla with a poorer bone density requires more implants or larger widths compared with the edentulous mandible. It is interesting to note that the maxillary dentition has more roots and greater surface area roots than the mandibular counterparts (Box 10-12). Yet, in the edentulous maxilla, there is less available bone height than any region because the maxillary sinus quickly expands to decrease bone height.

Opposing Arch

Natural teeth transmit greater impact forces through occlusal contacts than soft tissue–borne complete dentures. In addition, the maximum occlusal force of patients with complete dentures is limited and may range from 5 to 26 psi.[79] The force is usually greater in recent denture wearers and decreases with time. Muscle atrophy, thinning of the oral tissues with age or disease, and bone atrophy often occur in edentulous patients as a function of time[85] (Figure 10-47). Some denture wearers may clench on their prosthesis constantly, which may maintain muscle mass. However, this condition usually accelerates bone loss. Implant overdentures improve the masticatory performance. The RP-5 overdenture has more force than a full denture.

The maximum force generated against an implant prosthesis is related to the number of teeth or implants supporting the prosthesis in the opposing arch.[86–88] Hence, partially edentulous dentate patients have less force than dentate patients with all of their teeth (Figure 10-48). Patients with partial dentures may have forces intermediate between those of natural teeth and complete dentures, depending on the location and condition of the remaining teeth, muscles, and joints.[80] In partially edentulous patients with implant-supported fixed prostheses, force ranges are more similar to those of natural dentition, but lack of proprioception may magnify the load amount during parafunctional and functional activity.

A complete implant fixed prosthesis does not benefit from proprioception as do natural teeth, and patients chew food with

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FIGURE 10-48. The opposing arch to the implant prosthesis consists of natural teeth in this panoramic radiograph. The cantilever length should be reduced or the number of implants increased compared with an edentulous opposing arch. This mandibular restoration became loose because the cantilever length and opposing arch increased the forces.



FIGURE 10-49. When the opposing arch has a fixed implant prosthesis, the bite forces are greatest. The decrease in proprioception results in higher forces during function and parafunction. In this patient, the cantilever on the mandibular prosthesis should be reduced significantly, especially because the crown height space is also large.

BOX 10-13 Opposing Arch: Least to Most Force Effects

Soft tissue–borne denture
RP-5 overdenture
Partially edentulous arch
Dentate arch
RP-4 overdenture
Fixed implant prosthesis

RP, Removable prosthesis.

a force four times greater than with natural teeth.[89] Thus, the highest forces are created with implant prostheses in the opposing arch. A RP-4 overdenture may have some movement compared with a fixed prosthesis and is more likely to have acrylic or resin teeth. Hence, the bite force is slightly less than for a full arch fixed implant prosthesis (Figure 10-49). In addition, premature contacts in occlusal patterns or during parafunction on the implant prostheses do not alter the pathway of closure because occlusal awareness is decreased with implant prostheses compared with natural teeth.[18] Therefore, continued stress increases can be expected to occur with the implant restoration (Box 10-13).

The opposing arch is not as major a factor to alter an implant treatment plan as parafunction, masticatory dynamics, or excessive CHS, but is a major factor for the risk of porcelain fracture. In a report by Kinsel and Lin, the opposing dentition varies the incidence of porcelain fracture to an implant crown.[44] When the opposing arch was a denture, 0% fracture of the implant crowns in the opposing arch was found. The opposing dentition of a natural tooth found 3.2% fracture of implant crowns. The opposing dentition of a crown on a natural tooth found a 5.7% fracture of the opposing implant crown. A 16.2% fracture was observed when an implant crown opposed an implant crown. When the percentage of patients with major fractures of porcelain were compared with no fractures, the incidence of patients with porcelain fractures of implant crowns was 19.4% for natural teeth and 69.5% of patients with implant crowns in the opposing arch. Hence, the opposing dentition may increase the impact force, and the greater the force, the higher the risk of porcelain fracture (Box 10-14).

BOX 10-14 Implant Crown Porcelain Fracture Related to Opposing Arch: Least to Most Risk

Complete denture (0%)
Natural teeth (3.2%) (19.4% of patients)
Crown on a natural tooth (5.7%)
Implant crown (16.2%) (69.5% of patients)

As a consequence of the opposing arch affecting the intensity of forces applied to an implant prosthesis, the treatment plan may be modified to reduce the risk of fatigue fracture and overload. Rarely should the opposing arch be maintained in a traditional denture as a method to decrease the stress to the implant arch. Unfortunately, many edentulous patients opt to remain in a denture for the maxillary arch as a consequence of the increased costs associated with implant prostheses. However, the patient should be aware of the continued bone loss in the maxillary edentulous arch, and a preferred treatment is an implant-supported prosthesis in both arches in order to maintain the existing bone volume.

Summary

Patient force factors are highly variable from one person to another. An implant foundation should be designed to support the load and resist the stresses while the restoration is in service. An ideal treatment plan may be established relative to the number and position of missing teeth. The treatment plan is then modified dependent on the force factors of the individual patient. It is far better to overengineer the amount of support necessary for a prosthesis. If just one too few or too small an implant is used, implant bone loss, fracture, or failure may occur. As a general rule, the best way to reduce the risk of biomechanical overload to the implant foundation is to add additional implants.

The five most important force factors related to patient conditions were presented in this chapter. Of these, parafunction is the predominant element to account for in the treatment plan. On a scale of 1 to 10 of significance, severe bruxism is a 10, moderate bruxism is a 7, and mild bruxism a 4. Severe clenching on this scale is a 9, moderate clenching a 5, and mild clenching habits a 3. An excessive CHS can double a force and therefore is a 7 on the importance scale. Whereas severe masticatory dynamics can also double a force component and result in a 7 on this scale, mild masticatory increases are more of a 3. The

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BOX 10-15 Force Factor Risks: Scale 1 to 10

1. Parafunction
   - A. Bruxism
     1. Severe: 10
     2. Moderate: 7
     3. Mild: 4
   - B. Clenching
     1. Severe: 9
     2. Moderate: 5
     3. Mild: 3
2. Crown height space
   - A. Excessive: 7
3. Masticatory dynamics
   - A. Severe: 7
   - B. Mild: 3
4. Arch position
   - A. Maxilla
     1. Posterior: 5
     2. Anterior: 3
   - B. Mandible
     1. Posterior: 5
     2. Anterior: 0
5. Opposing arch
   - A. Complete implants: 4
   - B. Natural teeth: 2

position of the abutment in the arch determines the magnitude of force and is a 1 when in the mandibular anterior region, a 3 in the maxillary anterior, a 5 in the posterior mandible, and a 7 in the posterior maxilla (because bone density is most ideal in the anterior mandible and least biomechanically favorable in the posterior maxilla). The opposing arch under typical treatment conditions is the least important force component modifier. A complete implant restoration may be a factor of 4, natural teeth a 2, and an opposing soft tissue–supported denture a 1 (Box 10-15).

The greater the number of risk factors in the patient conditions related to force, the more implants, wider implants, or more surface design implants should be designed in the foundation. Biomaterial choices in high-risk factors should favor metal occlusals in the prosthesis and titanium alloy for the implant bodies. Implant-protective occlusal aspects also become more important, especially cantilevers on the prosthesis, as the patient force factor risks increase.

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CHAPTER 11

Bone Density: A Key Determinant for Treatment Planning

Carl E. Misch

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Available bone is particularly important in implant dentistry and describes the external architecture or volume of the edentulous area considered for implants.[1] Historically, the available bone was not modified in the implant candidate. Instead, the existing bone volume was the primary factor used to develop a treatment plan. Short implants and fewer implants were used in less available bone, and long implants in greater numbers were inserted in larger bone volumes.[2] Today, the treatment plan should first consider the final prosthesis options and determine the prosthesis type indicated for the specific patient in question. The key implant positions for the prosthesis may then be determined by a biomechanical perspective. The additional number of implants required to support the specific restoration may then be established related to the amount of force generated by the patient (patient force factors) because stress equals force divided by area. The next consideration to determine the additional implant number and size to support the restoration is the bone density in the sites of the implant abutments.[3]

The external (cortical) and internal (trabecular) structure of bone may be described in terms of quality or density, which reflects a number of biomechanical properties, such as strength, modulus of elasticity, bone–implant contact (BIC) percent, and stress distribution around a loaded endosteal implant (Box 11-1). In other words, the external and internal architecture of bone controls virtually every facet of the practice of implant dentistry. The density of available bone in an edentulous site is a determining factor in treatment planning, surgical approach, implant design, healing time, and the need for initial progressive bone loading during prosthetic reconstruction.[4-7] This chapter presents the aspects of bone density related to overall planning of an implant prosthesis.

Influence of Bone Density on Implant Success Rates

The quality of bone often depends on the arch position.[4,8,9] The most dense bone is usually observed in the anterior mandible followed by the anterior maxilla and posterior mandible, and the least dense bone is typically found in the posterior maxilla (Box 11-2). A range of implant survival has been found relative to arch location. Following a standard surgical and prosthetic protocol, Adell et al.[2] reported an approximate 10% greater success rate in the anterior mandible as compared with the anterior maxilla. In a 15-year follow-up study, Snauwaert et al.[10] reported that early annual and late failures were also more frequently found in the maxilla.

In addition to arch location, several independent groups have reported different failure rates related to the quality of the bone. In fact, reduced implant survival most often is more related to bone density than arch location. Engquist et al.[11] observed that 78% of all reported implant failures were in soft bone types when they supported overdentures. Friberg et al.[12] observed that 66% of their group's implant failures occurred in the resorbed maxilla with soft bone. Jaffin and Berman,[13] in a 5-year study, reported a 44% implant failure when poor-density bone was observed in the maxilla and 35% implant loss in any region of the mouth when bone density was poor, with 55% of all implant failures in the soft bone type. Johns et al.[14] reported 3% failure of implants in moderate bone densities but a 28% implant failure in the poorest bone type. Smedberg et al.[15] reported a 36% failure rate in the poorest bone density. Herrmann et al.[16] found that implant failures were strongly correlated to patient factors, including bone quality, especially when coupled with poor bone volume (65% of these patients experienced failure). These reported failures are not primarily related to surgical healing but instead occur after prosthetic loading. Therefore, over the years, many independent clinical groups, following a standardized surgical and prosthetic protocol, documented the indisputable influence of bone density on clinical success[17-19] (Figure 11-1).

A protocol established by the author in 1988, which adapts the treatment plan, implant selection, surgical approach, healing regimen, and initial prosthetic loading, has resulted in similar implant success rates in all bone densities and all arch

BOX 11-1 Bone Quality Reflects:

- Strength
- Modulus of elasticity
- Bone–implant contact percent
- Stress contours around a loaded endosteal implant

BOX 11-2 Bone Quality Locations: Most to Least Dense

- Anterior mandible
- Anterior maxilla
- Posterior mandible
- Posterior maxilla

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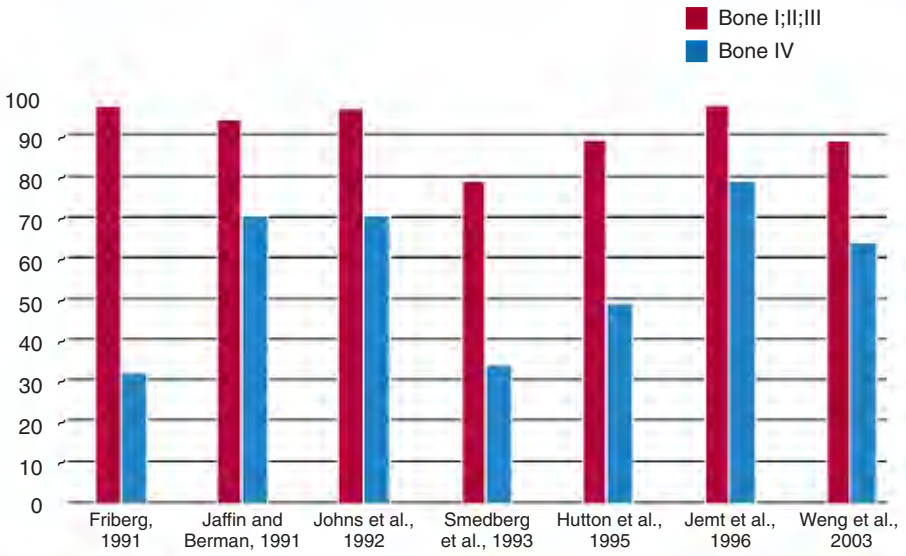


FIGURE 11-1. Over the years, several clinical reports observed higher success rates in better bone quality *(red)* and lower survival rates in poor bone quality *(blue)*.



FIGURE 11-2. A 5-year radiograph of a fixed implant prosthesis in D4 bone in the posterior maxilla. Implant survival and crestal bone loss may be similar in all bone densities and arch locations when the implant treatment plan, surgery, healing time, and prosthodontic protocol are related to the bone quality.



FIGURE 11-3. The proximal head of the femur has trabecular bone aligned along stress pathways, similar to beams for a bridge or tower.

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positions.[4] Multicenter clinical reports by Misch et al. and Kline et al. confirm implant success rates with this protocol may be similar in all bone density types and arch locations[20-23] (Figure 11-2). This chapter proposes a scientific rationale for the modification of a treatment plan in function of bone density to achieve comparable success rates in all bone types.

Etiology of Variable Bone Density

Bone is an organ that is able to change in relation to a number of factors, including hormones, vitamins, and mechanical influences. However, biomechanical parameters, such as the amount of strain transmitted to bone, are predominant.[24] Awareness of this adaptability in the skeletal system has been reported for more than a century. In 1887, Meier qualitatively described the architecture of trabecular bone in the femur.[25] In 1888, Kulmann noticed the similarity between the pattern of trabecular bone in the femur and tension trajectories in construction beam concepts used by Eiffel[26] (Figure 11-3). Wolff, in 1892, further elaborated on these concepts and published: "Every change in the form and function of bone or of its function alone is followed by certain definite changes in the internal architecture, and equally definite alteration in its external conformation, in accordance with mathematical laws."[27] The modified function of bone and the definite changes in the internal and external formation of the vertebral skeleton as influenced by mechanical load were also reported more recently by Murry.[28] Therefore, it has been widely reported in the structural skeleton that the external architecture of bone (cortical bone) changes in relation to function, and the internal bony structure (trabecular bone) is also modified.

The structural changes in bone as a consequence of mechanical influences have also been noted in the jaws. As an example, both MacMillan and Parfitt have reported on the structural characteristics and variation of trabeculae in the alveolar regions of the jaws.[29,30] The maxilla and mandible have different biomechanical functions (Figure 11-4). The mandible, as an independent structure, is designed as a force absorption unit. Therefore, when teeth are present, the outer cortical bone is denser and thicker, and the trabecular bone is more coarse and dense (Figure 11-5). On the other hand, the maxilla is a force

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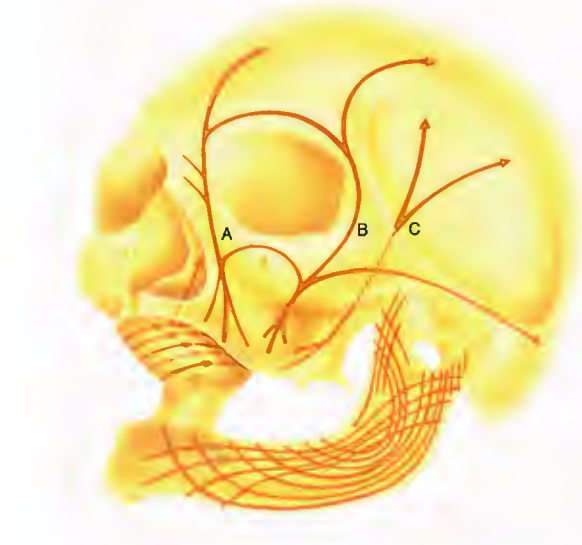


FIGURE 11-4. The maxilla is a force distribution unit, and the mandible is a force absorption unit. As a consequence, the cortical and trabecular bone are different.



FIGURE 11-5. The trabecular bone in a dentate mandible is more coarse than the maxilla. The cortical bone is thick and dense. The mandible, as an independent structure, is a force-absorbing element.

distribution unit. Stresses to the maxilla are transferred by the zygomatic arch and palate away from the brain and orbit. As a consequence, the maxilla has a thin cortical plate and fine trabecular bone surrounding the teeth (Figure 11-6). Neufeld noted that the bone is most dense around the teeth (cribriform plate) and more dense around the teeth at the crest compared with the regions around the apices[31] (Figure 11-7) Alveolar bone resorption associated with orthodontic therapy also illustrates the biomechanical sensitivity of the alveolar processes.[32]

Orban demonstrated a decrease in the trabecular bone pattern around a maxillary molar with no opposing occlusion compared with a tooth with occlusal contacts on the contralateral side[33] (Figure 11-8). Bone density in the jaws also decreases after tooth loss. This loss is primarily related to the length of time the region has been edentulous and not loaded appropriately, the initial density of the bone, flexure and torsion in the mandible, and parafunction before and after tooth loss.[34-37] In general, the density change after tooth loss is greatest in the posterior maxilla and least in the anterior mandible.

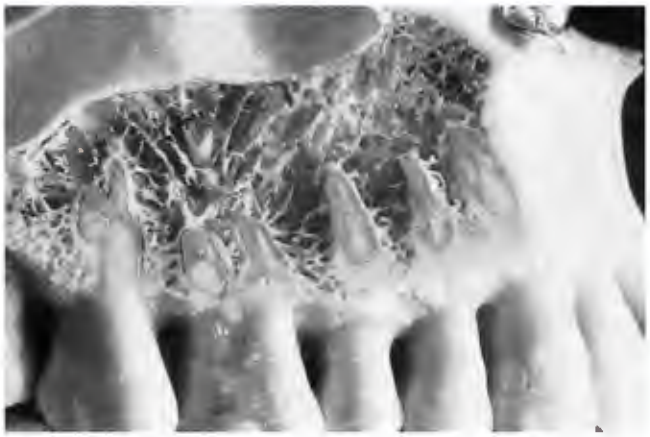


FIGURE 11-6. The dentate maxilla has a finer trabecular pattern compared with the mandible. The cortical bone is more thin and porous. The maxilla is a force distribution unit and is designed to protect the orbit and brain.



FIGURE 11-7. The trabecular bone of each jaw has structural variations. The trabecular bone is most dense next to the teeth, where it forms the cribriform plate. Between the teeth, the bone is usually most dense near the crest and least dense at the apex.

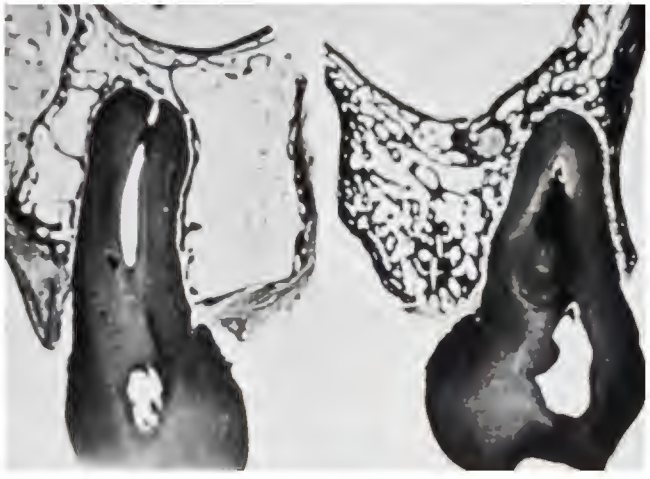


FIGURE 11-8. On the left, the opposing mandibular tooth was removed. A lack of occlusal contact resulted in loss of trabecular bone around the maxillary tooth. The tooth on the *right* is from the same monkey, with the opposing mandibular tooth in place. The trabecular bone is much more dense around the tooth. The disuse atrophy observed on the *left* is from inadequate microstrain conditions to maintain the bone. (From Orban B: *Oral histology and embryology,* ed 3, St Louis, 1953, Mosby.)

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Cortical and trabecular bone throughout the body are constantly modified by either modeling or remodeling.[38] Modeling has independent sites of formation and resorption and results in the change of the shape or size of bone. Remodeling is a process of resorption and formation at the same site that replaces previously existing bone and primarily affects the internal turnover of bone, including that region where teeth are lost or the bone next to an endosteal implant. These adaptive phenomena have been associated with the alteration of the mechanical stress and strain environment within the host bone.[39]

Stress is determined by the magnitude of force divided by the functional area over which it is applied. Strain is defined as the change in length of a material divided by the original length. The greater the magnitude of stress applied to the bone, the greater the strain observed in the bone.[40] Bone modeling and remodeling are primarily controlled, in part or whole, by the mechanical environment of strain. Overall, the density of alveolar bone evolves as a result of mechanical deformation from microstrain.

Frost proposed a model of modeling/remodeling patterns for compact bone as it relates to mechanical adaptation to strain.[41] Spontaneous fracture, the pathologic overload zone, mild overload zone, adapted window, and acute disuse window were described for bone in relation to the amount of the microstrain experienced (Box 11-3). These categories also may be used to describe the trabecular bone response next to a dental implant in the jaws.[42-44]

BOX 11-3 Categories of Mechanical Adaption of Bone

Spontaneous fracture
Pathologic overload zone
Mild overload zone
Adapted window
Acute disuse window

The bone in the acute disuse window loses mineral density, and disuse atrophy occurs because modeling for new bone is inhibited and remodeling is stimulated, with a gradual net loss of bone (Figure 11-9). The microstrain of bone for trivial loading is reported to be 0 to 50 microstrain.[41] This phenomenon may occur throughout the skeletal system, as evidenced by a 15% decrease in the cortical plate and extensive trabecular bone loss consequent to immobilized limbs for 3 months.[45] A cortical bone density decrease of 40% and a trabecular bone density decrease of 12% also have been reported with disuse of bone.[46,47] Interestingly, bone loss similar to disuse atrophy has been associated with microgravity environments in outer space because the microstrain in bone resulting from the earth's gravity is not present in the "weightless" environment of space.[48] In fact, an astronaut aboard the Russian Mir space station for 111 days lost nearly 12% of his bone minerals.[49,50]

The adapted window (50–500 microstrain) represents an equilibrium of modeling and remodeling, and bone conditions are maintained at this level.[41] Bone in this strain environment remains in a steady state, and this may be considered the homeostatic window of health. The histologic description of this bone is primarily lamellar or load-bearing bone. Approximately 18% of trabecular bone and 2% to 5% of cortical bone is remodeled each year in the physiologic loading zone, which corresponds to the adapted window.[24] This is the range of strain ideally desired around an endosteal implant after a stress equilibrium has been established. Bone turnover is required in the adapted window; Mori and Burr provide evidence of remodeling in regions of bone microfracture from fatigue damage within the physiologic range.[51]

The mild overload zone (1500–3000 microstrain) causes a greater rate of fatigue microfracture and increase in the cellular turnover rate of bone.[41] As a result, the bone strength and density decrease. The histologic description of bone in this

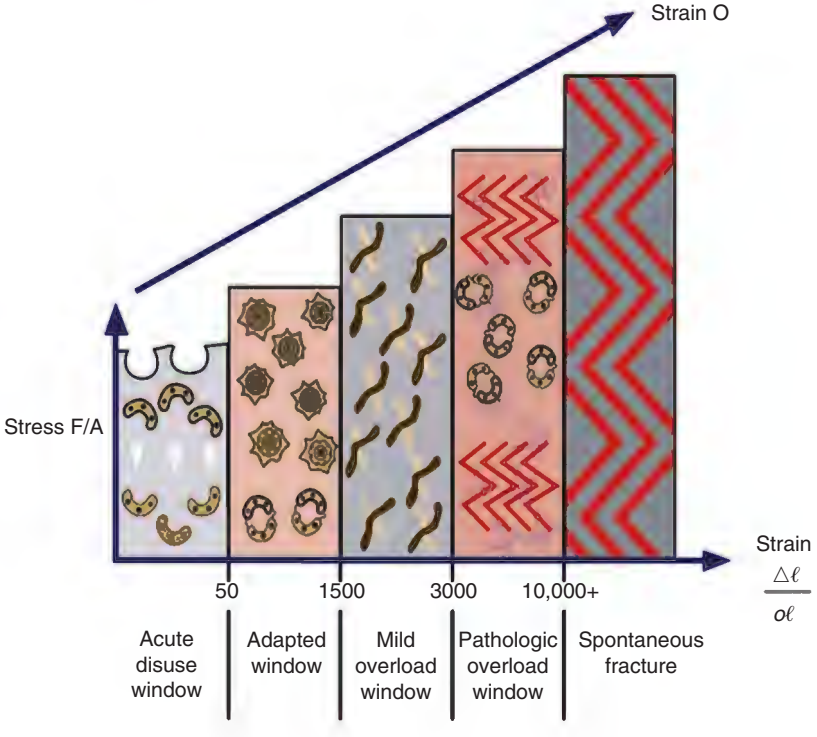


FIGURE 11-9. Four zones for bone related to mechanical adaption to strain before spontaneous fracture. The acute disuse window is the lowest microstrain amount. The adapted window is an ideal physiologic loading zone. The mild overload zone causes microfracture and triggers an increase in bone remodeling, which produces more woven bone. The pathologic overload zone causes increase in fatigue fractures, remodeling, and bone resorption.

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range is usually woven or repair bone. Woven bone is able to form faster but is less mineralized and less organized than lamellar bone. This may be the state for bone when an endosteal implant is overloaded and the bone interface attempts to adapt to the greater strain environment.[44] During the repair process, the woven bone is weaker than the more mature, mineralized lamellar bone.[42] Therefore, although bone is loaded in the mild overload zone, care must be taken because the "safety range" for bone strength is reduced during the repair.

Pathologic overload zones are reached when microstrains are greater than 3000 units.[41] Cortical bone fractures occur at 10,000 to 20,000 microstrain (1%–2% deformation). But pathologic overload may begin at microstrain levels of only 20% to 40% of the ultimate strength or physical fracture of cortical bone. The bone may resorb and form fibrous tissue or, when present, repair woven bone is observed in this zone because a sustained turnover rate is necessary. The marginal bone loss evidenced during implant overloading may be a result of the bone in the pathologic overload zone. Implant failure from overload may also be a result of bone in the pathologic overload zone.

Bone Classification Schemes Related to Implant Dentistry

An appreciation of bone density and its relation to oral implantology has existed for more than 25 years. Linkow, in 1970, classified bone density into three categories[52]:

Class I bone structure: This ideal bone type consists of evenly spaced trabeculae with small cancellated spaces.

Class II bone structure: The bone has slightly larger cancellated spaces with less uniformity of the osseous pattern.

Class III bone structure: Large, marrow-filled spaces exist between bone trabeculae.

Linkow stated that class III bone results in a loose fitting implant, class II bone was satisfactory for implants, and class I bone was the most ideal foundation for implant prostheses.

In 1985, Lekholm and Zarb listed four bone qualities found in the anterior regions of the jawbone[53] (Figure 11-10). Quality 1 was composed of homogeneous compact bone. Quality 2 had a thick layer of compact bone surrounding a core of dense trabecular bone. Quality 3 had a thin layer of cortical bone surrounding dense trabecular bone of favorable strength. Quality 4 had a thin layer of cortical bone surrounding a core of low-density trabecular bone. Irrespective of the different bone qualities, all bone was treated with the same implant design and standard surgical and prosthetic protocol.[2] Following this protocol, Schnitman et al. and others observed a 10% difference in implant survival between quality 2 and quality 3 bone and a 22% lower survival rate in the poorest bone density.[54] As previously presented, many authors also experienced a greater failure in soft bone.[11-19,54-56] It is obvious that a standardized surgical, prosthetic, and implant design protocol does not yield similar results in all bone densities. In addition, these reports are for implant survival, not the quality of health of surviving implants. The amount of crestal bone loss also has been related to bone density and further supports a different protocol for soft bone.[57-59]

In 1988, Misch proposed four bone density groups independent of the regions of the jaws based on macroscopic cortical and trabecular bone characteristics.[4,5] The different anterior and posterior regions of the jaws often had densities related from one patient to another, but ranges of bone density may be found in any location. Suggested treatment plans, implant design, surgical protocol, healing, and progressive loading time spans have been described for each bone density type.[3,6] Following this regimen, similar implant survival rates have been observed for all bone densities.[20-23]

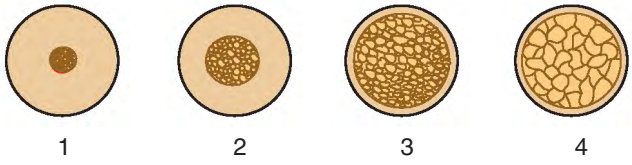


FIGURE 11-10. Lekholm and Zarb described four bone qualities for the anterior region of the jaws. Quality 1 is composed of homogenous compact bone. Quality 2 has a thick layer of cortical bone surrounding dense trabecular bone. Quality 3 has a thin layer of cortical bone surrounded by dense trabecular bone of favorable strength. Quality 4 has a thin layer of cortical bone surrounding a core of low-density trabecular bone. (From Lekholm U, Zarb GA: Patient selection and preparation. In Brånemark P-I, Zarb GA, Albrektsson T, editors: *Tissue integrated prostheses: osseointegration in clinical dentistry,* Chicago, 1985, Quintessence.)

Misch Bone Density Classification

Dense or porous cortical bone is found on the outer surfaces of bone and includes the crest of an edentulous ridge. Coarse and fine trabecular bone types are found within the outer shell of cortical bone and occasionally on the crestal surface of an edentulous residual ridge. These four macroscopic structures of bone may be arranged from the most dense to the least dense, as first described by Frost and by Roberts: dense cortical bone, porous cortical bone, coarse trabecular bone, and fine trabecular bone[41,42] (Figure 11-11).

In combination, these four macroscopic densities constitute the four bone categories described by Misch (D1, D2, D3, and D4) located in the edentulous areas of the maxilla and mandible (Table 11-1; Figure 11-12). The regional locations of the different densities of cortical bone are more consistent than the highly variable trabecular bone.

D1 bone is primarily dense cortical bone. D2 bone has dense to porous cortical bone on the crest and lateral to the implant



FIGURE 11-11. The macroscopic structure of bone may be described, from the least dense to the most dense, as (1) fine trabecular, (2) coarse trabecular, (3) porous cortical, and (4) dense cortical. (From E. Roberts.)

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TABLE 11-1
Misch Bone Density Classification Scheme

Bone Density	Description	Tactile Analog	Typical Anatomical Location
D1	Dense cortical	Oak or maple wood	Anterior mandible
D2	Porous cortical and coarse trabecular	White pine or spruce wood	Anterior mandible Posterior mandible Anterior maxilla
D3	Porous cortical (thin) and fine trabecular	Balsa wood	Anterior maxilla Posterior maxilla Posterior mandible
D4	Fine trabecular	Styrofoam	Posterior maxilla

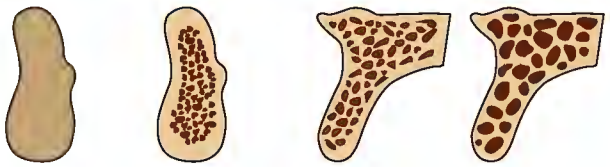


FIGURE 11-12. Misch described four bone densities found in the anterior and posterior edentulous regions of the maxilla and mandible. D1 bone is primarily dense cortical bone, D2 bone has dense to thick porous cortical bone on the crest and coarse trabecular bone underneath, D3 bone has a thinner porous cortical crest and fine trabecular bone within, and D4 bone has almost no crestal cortical bone. The fine trabecular bone composes almost all of the total volume of bone.



FIGURE 11-13. A cross-section of a D2 mandible in the region of the midline. A dense to porous cortical plate exists on the crest and lateral borders, and a coarse trabecular bone pattern exists within.

site. The bone within this cortical housing has coarse trabecular bone (Figure 11-13). D3 bone types have a thinner porous cortical crest and facial/lingual regions, with fine trabecular bone in the region next to the implant (Figure 11-14). D4 bone has almost no crestal cortical bone and porous cortical lateral



FIGURE 11-14. A posterior mandible with D3 bone. A thin porous cortical bone is at the crest and fine trabecular bone is in the body of the mandible.

plates. The fine trabecular bone comprises almost all of the total volume of bone next to the implant (Figure 11-15). A very soft bone, with incomplete mineralization and large intratrabecular spaces, may be addressed as D5 bone (Figure 11-16). This bone type is found often in the immature bone of a developing bone graft site. The bone density may be determined by the general location, tactile sense during surgery, or computerized radiographic evaluation.

Bone Density: Location

A review of the literature and a survey of completely and partially edentulous patients postsurgery indicated that the location of different bone densities often may be superimposed on the different regions of the mouth.[9-17,19,54,55,60-62] As a result, implant success, arch location, and bone density are often related to each other. For example, Schnitman et al. found the highest implant success in the anterior mandible followed by the anterior maxilla and the posterior mandible and the highest failure in the posterior maxilla when a similar surgical protocol was used in all regions[54] (Figure 11-17). D1 bone is almost never observed in the maxilla and is rarely observed in

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most mandibles. In the mandible, D1 bone is observed approximately 6% of the time in the division A anterior mandible and 3% of the time in the posterior mandible, primarily when the implant is engaging the lingual cortical plate of bone. In a C–h bone volume (moderate atrophy) in the anterior mandible, the prevalence of D1 bone approaches 15% in men. The C–h mandible often exhibits an increase in torsion, flexure, or both in the anterior segment between the foramina during function. This increased strain may cause the bone to increase in density. D1 bone also may be encountered in the anterior division A mandible of a Kennedy class IV partially edentulous patient with a history of parafunction and recent extractions. It may also be observed in the anterior or posterior mandible when the angulation of the implant may require the engagement of the lingual cortical plate.

Single- or two-tooth, partially edentulous spans in either arch almost always have D2 bone. The bone density D2 is the most common bone density observed in the mandible (see Figure 11-13). The anterior mandible consists of D2 bone approximately two thirds of the time. Note that the anterior mandible extends between the mental foramina, hence from first premolar to first premolar (Figure 11-18). Almost half of patients have D2 bone in the posterior mandible. The maxilla presents D2 bone less often than the mandible. Approximately one fourth of patients have D2 bone, and this is more likely in the partially edentulous patient's anterior and premolar region rather than the completely edentulous posterior molar areas.

Bone density D3 is very common in the maxilla. More than half the patients have D3 bone in the upper arch. Whereas the anterior edentulous maxilla has D3 bone about 75% of the time, almost half the patients have posterior maxillae with D3 bone (more often in the premolar region). Note that the anterior maxilla extends from the regions anterior to the maxillary sinus and most often from first premolar to first premolar.



FIGURE 11-15. An anterior maxilla demonstrating D3 bone with a thin porous cortical plate on the crest with fine trabecular bone underneath.

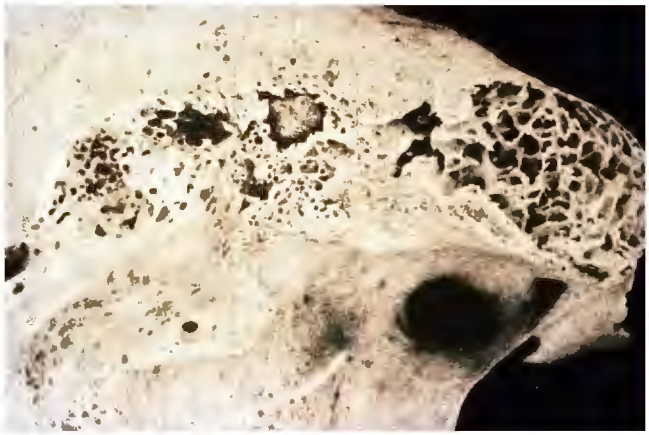


FIGURE 11-16. In a D4 posterior maxilla, the posterior crestal region has little to no cortical bone on the crest and is composed primarily of fine trabecular bone.

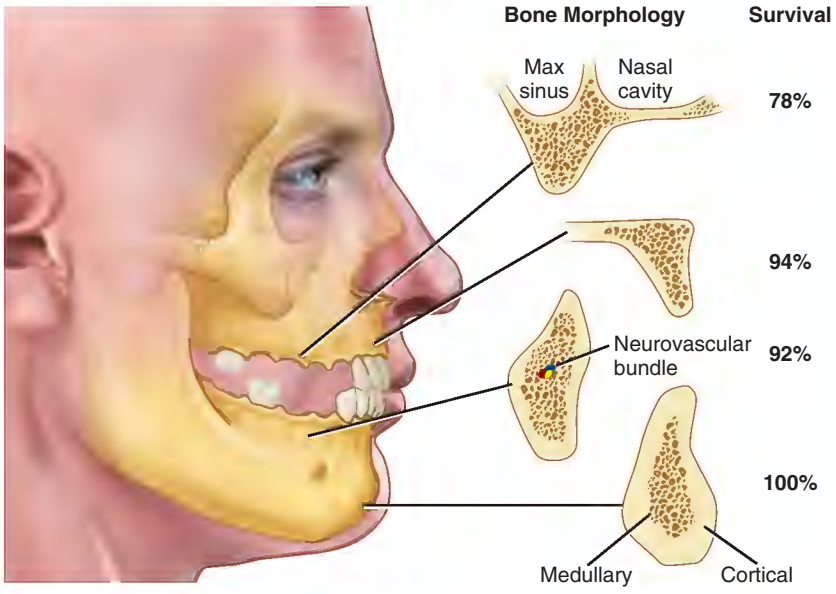


FIGURE 11-17. Schnitman et al found implant survival may be directly related to bone density with highest success in the anterior mandible followed by the anterior maxilla and the posterior mandible and the least in the posterior maxilla.[54] (Redrawn from Schnitman PA, Rubenstein JE, Whorle PS, et al: Implants for partial edentulism, *J Dent Educ* 52:725–736, 1988, Fig. 9, p. 731.)

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Almost half of the posterior mandibles also present with D3 bone, but approximately 25% of the anterior edentulous mandibles have D3 bone. The posterior mandible extends from second premolar to the molar region.

The softest bone, D4, is most often found in the posterior maxilla (≈40%), especially in the molar regions or after a sinus graft augmentation (where almost two thirds of the patients have D4 bone). The posterior maxilla is the second premolar and molar region. The anterior maxilla has D4 bone less than 10% of the time—more often after an onlay iliac crest bone graft. The mandible presents with D4 bone in fewer than 3% of patients. When observed, it is usually division A bone in a long-term, completely edentulous patient after an osteoplasty to remove the crestal bone.



FIGURE 11-18. The anterior mandible extends from first premolar to first premolar and usually is D2 bone. This section is through the mental foramen and has dense cortical bone on the crest and coarse trabecular within.

The bone density in a particular region of the mouth is often similar, yet the local strain history also is related to the bone density in the region. For example, the range of bone density in a particular patient may be most any of the bone density groups (Figure 11-19). However, generalizations for treatment planning can be made prudently, based on location. The bone density by location method is the first way the dentist can estimate the bone density in the implant sites to develop an initial treatment plan. It is safer to err on the side of less dense bone during treatment planning, so the prosthesis will be designed with slightly more, rather than less, support. Therefore, the initial treatment plan before computed tomographic (CT) radiographic scans or surgery suggests the anterior maxilla is treated as D3 bone, the posterior maxilla as D4 bone, the anterior mandible as D2 bone, and the posterior mandible as D3 bone[3] (Box 11-4). A more accurate determination of bone density is made with CT before surgery or tactilely during implant surgery.

Radiographic Bone Density

Periapical or panoramic radiographs are not very beneficial to determine bone density because the lateral cortical plates often obscure the trabecular bone density. In addition, the more subtle changes of D2 to D3 cannot be quantified by these radiographs. Therefore, the initial treatment plan, which often begins with these radiographs, follows the bone density by location method.

Bone density may be more precisely determined by tomographic radiographs, especially CT.[63-66] CT produces axial images of the patient's anatomy, perpendicular to the long axis of the body. Each CT axial image has 260,000 pixels, and each pixel has a CT number (Hounsfield unit) related to the density of the tissues within the pixel. In general, the higher the CT number, the denser the tissue.

BOX 11-4 Generalized Bone Density Location

Anterior mandible	D2
Posterior mandible	D3
Anterior maxilla	D3
Posterior maxilla	D4

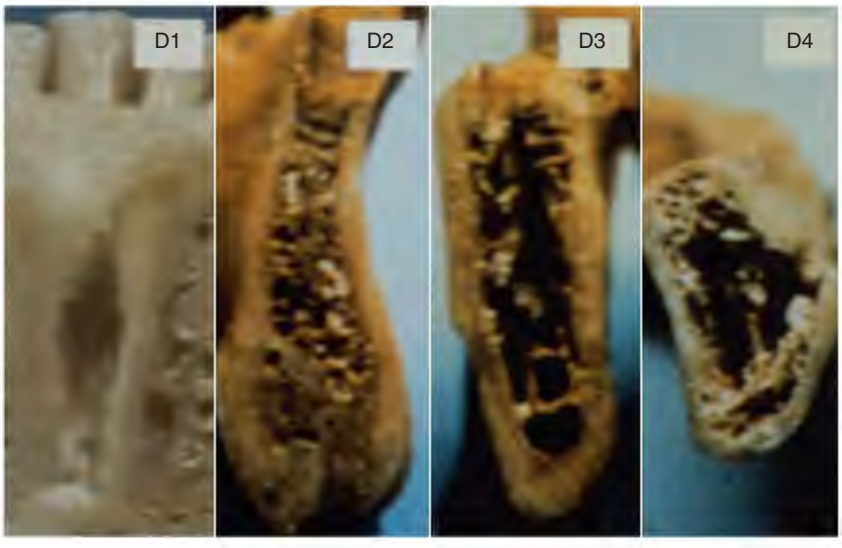


FIGURE 11-19. The density of bone is influenced by its local strain history. These four posterior mandibles have a range of bone densities.

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BOX 11-5 Computed Tomography Determination of Bone Density

D1:	>1250 Hounsfield units
D2:	850–1250 Hounsfield units
D3:	350–850 Hounsfield units
D4:	150–350 Hounsfield units
D5:	<150 Hounsfield units

BOX 11-6 Tactile Analog of Bone Density

DENSITY	ANALOG
D1	Oak or maple wood
D2	White pine or spruce wood
D3	Compressed balsa wood
D4	Compressed Styrofoam or light balsa wood
D5	Styrofoam

Modern CT scanners can resolve objects less than 0.5 mm apart. In addition, software is available to electronically position the implant on the CT scan and evaluate to Hounsfield numbers in contact with the implant. In a retrospective study of CT scan images from implant patients, Kirkos and Misch established a correlation between CT Hounsfield units and the Misch bone density classification at the time of surgery.[67] (Box 11-5). D1 bone has Hounsfield units greater than 1250. D2 bone has 850 to 1250 Hounsfield units next to the implant–bone interface. D3 bone has 350 to 850 Hounsfield units in the implant site, and D4 bone has 150 to 350 Hounsfield units at the site. D5 bone has less than 150 Hounsfield units. The very soft bone observed after some immature bone grafts may be a negative number to 200 units, suggestive of fat tissue, and has been observed within the cortical plates of some jaws, including the anterior mandible.[68]

Norton and Gamble also found an overall correlation between subjective bone density scores of Lekholm and Zarb and the CT values.[69] Studies correlating torque forces at implant insertion with preoperative bone density values from CTs have reported similar conclusions.[70,71] Preoperative CT scan data of areas that lead to successful and unsuccessful implant placement have also been reported. In the mandible, failed sites exhibited higher Hounsfield numbers than usual. This was correlated with failure in dense bone, possibly because of the lack of vascularization or overheating during surgery. By contrast, in the maxilla, the bone density was low for the failed sites.

Cone-beam CT radiographs do not relate Hounsfield values to the digital system to develop the bone images.[72] As a result, the bone density classification cannot be determined. However, the presence of cortical bone and trabecular bone can be observed and coupled with location within the arch and does provide some valuable information.

The bone density may be different near the crest where the implant placement is planned compared with the apical region.[71] The most critical region of bone density is the crestal 7 to 10 mm of bone for D1, D2, or D3 bone because this is where most stresses are applied to an osseointegrated bone–implant interface. Therefore, when the bone density varies from the most crestal to apical region around the implant, the crestal 7 to 10 mm determines the treatment plan protocol.

Bone Density—Tactile Sense

There is a great difference in the tactile sensation during osteotomy preparation in different bone densities because the density is directly related to its strength.[73] To communicate more broadly to the profession relative to the tactile sense of different bone densities, Misch proposed the different densities of his classification be compared with materials of varying densities.[4,5] Site preparation and implant placement in D1 bone is similar to the resistance on a drill preparing an osteotomy in oak or maple wood. D2 bone is similar to the tactile sensation of drilling into white pine or spruce wood. D3 bone is similar to drilling into a compressed balsa wood. D4 bone is similar to pushing a drill into a compressed Styrofoam or a light balsa wood. D5 bone is similar to pushing an implant into Styrofoam (Box 11-6). This clinical observation may be correlated to different histomorphometric bone density determinations.[74]

When an implant drill operates at 2000 to 2500 rpm, it may be difficult for the surgeon to feel the difference between D3 and D4 bone. In D4 bone, the drill may be inserted to the full desired depth without the drill rotating. In other words, a bone compression rather than extraction process may be used with the drill. D3 bone is very easy to prepare but requires the drill to rotate while it is pressed into position.[3] When the tactile sense is the primary method to determine bone density, the surgeon should know how to modify the treatment plan if the bone density is different than estimated when developing the treatment plan.

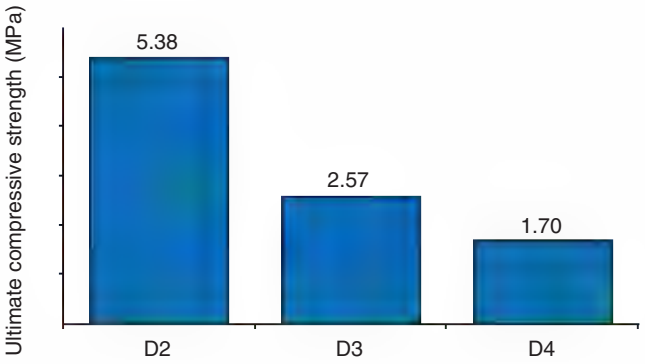


FIGURE 11-20. The strength of bone is related directly to the density of bone.

Scientific Rationale of a Bone Density–Based Treatment Plan

Bone Strength and Density

Bone density is directly related to the strength of bone before microfracture.[73] Misch et al. reported on the mechanical properties of trabecular bone in the mandible using the Misch density classification.[75] A 10-fold difference in bone strength may be observed from D1 to D4 bone (Figure 11-20). D2 bone exhibited a 47% to 68% greater ultimate compressive strength compared with D3 bone (Figure 11-21). In other words, on a scale of 1 to 10, D1 bone is a 9 to 10 relative to strength, D2 bone is a 7 to 8 on this scale, D3 bone is 50% weaker than D2 bone

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and is a 3 or 4 on the strength scale, and D4 bone is a 1 to 2 and up to 10 times weaker than D1 bone (Box 11-7). It should be noted that the strength of bone studies were performed on mature bone types. Bone is 60% mineralized at 4 months after implant surgery, and the strength of bone is related to the amount of mineralization. Hence, it is rational to wait longer before loading an implant, when the bone density is D3 or D4. A period of 3 to 4 months is adequate for D1 and D2 bone. A healing period of 5 to 6 months is beneficial in D3 to D4 bone. The bone densities that originally relied on clinical impression are now fully correlated to quantitative objective values obtained from CT scans and bone strength measurements. These values can help prevent failure in specific situations of weak densities.

BOX 11-7 Bone Density: Scale 1 to 10*

DENSITY	SCALE 1–10
D1	9, 10
D2	7, 8
D3	3, 4
D4	1, 2

*10 = most dense.

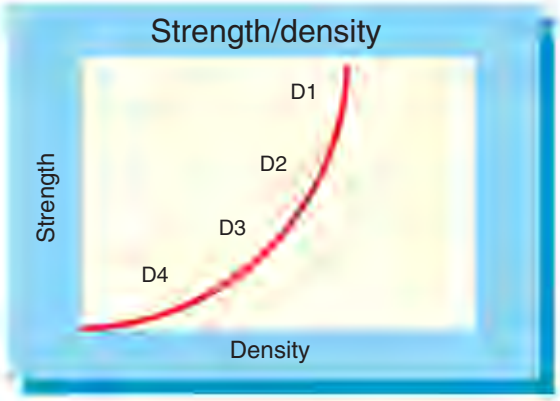


FIGURE 11-21. The ultimate compressive strength of D2 trabecular bone is greater than D3 trabecular bone, and D4 trabecular bone is the weakest.

Elastic Modulus and Density

The elastic modulus describes the amount of strain (changes in length divided by the original length) as a result of a particular amount of stress. It is directly related to the apparent density of bone.[76] The elastic modulus of a material is a value that relates to the stiffness of the material. The elastic modulus of bone is more flexible than titanium. When higher stresses are applied to an implant prosthesis, the titanium has lower strain (change in shape) compared with the bone. The difference between the two materials may create microstrain conditions of pathologic overload and cause implant failure. When the stresses applied to the implant are low, the microstrain difference between titanium and bone is minimized and remains in the adapted window zone, maintaining load-bearing lamellar bone at the interface.[44]

Misch et al. found the elastic modulus of the trabecular bone in the human jaw to be different for each bone density[75] (Figure 11-22). As a result, when a stress is applied to an implant prosthesis in D1 bone, the titanium–D1 bone interface exhibits very small microstrain difference. In comparison, when the same amount of stress is applied to an implant in D4 bone, the microstrain difference between titanium and D4 bone is greater and may be in the pathologic overload zone (Figure 11-23). As a result, D4 bone is more likely to cause implant mobility and failure.[77] Conclusions agree with prior reports and show the

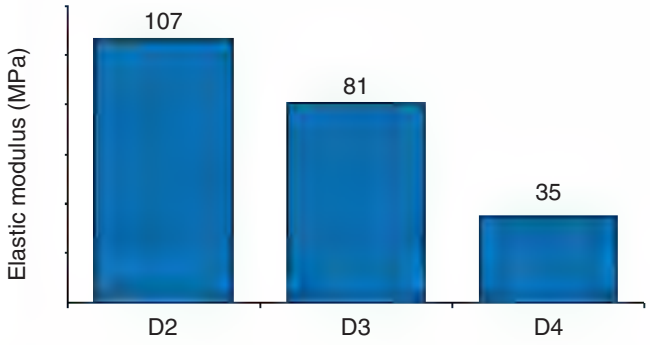


FIGURE 11-22. The elastic modulus for D2 trabecular bone is greater than D3 trabecular bone, and D4 trabecular bone has the lowest elastic modulus.

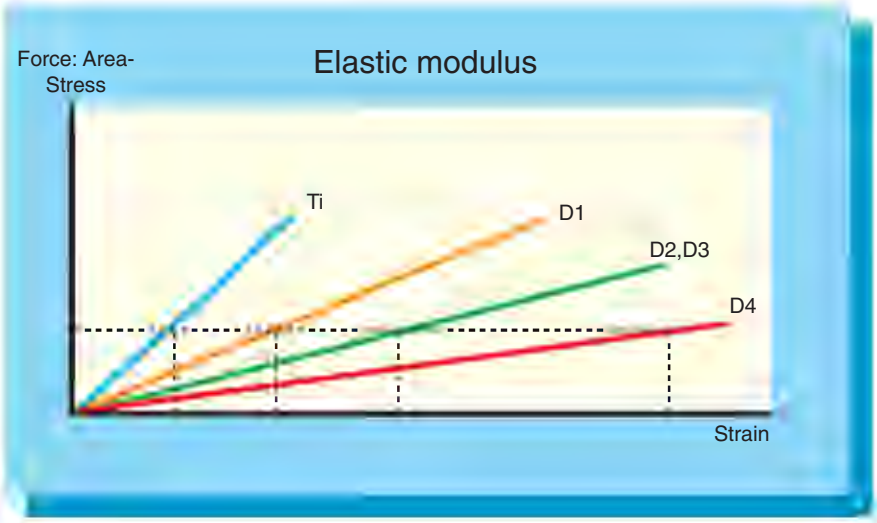


FIGURE 11-23. The microstrain difference between titanium and D4 bone is great and may be in the pathologic overload zone, whereas at the same stress level, the microstrain difference between titanium and D2 bone may be within the ideal adapted window zone.

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importance of bone quality in the treatment planning phase for long-term prognosis.

Bone Density and Bone–Implant Contact Percentage

The initial bone density not only provides mechanical immobilization of the implant during healing but after healing also permits distribution and transmission of stresses from the prosthesis to the implant–bone interface. The mechanical distribution of stress occurs primarily where bone is in contact with the implant. Open marrow spaces or zones of unorganized fibrous tissue do not permit controlled force dissipation or microstrain conditions to the local bone cells. Because stress equals force divided by the area over which the force is applied, the less the area of bone contacting the implant body, the greater the overall stress, other factors being equal. Therefore, the BIC percent may influence the amount of stress and strain at the interface.

In 1990, Misch noted that the bone density influences the amount of bone in contact with the implant surface, not only at first-stage surgery but also at the second-stage uncovery and early prosthetic loading.[5] The BIC percentage is significantly greater in cortical bone than in trabecular bone. The very dense D1 bone of a C–h resorbed anterior mandible or of the lingual cortical plate of a division A anterior or posterior mandible provides the highest percentage of bone in contact with an endosteal implant and may approximate more than 85% BIC (Figure 11-24). D2 bone, after initial healing, usually has 65% to 75% BIC (Figure 11-25). D3 bone typically has 40% to 50% BIC after initial healing (Box 11-8). The sparse trabeculae of the bone often found in the posterior maxilla (D4) offer fewer areas of contact with the body of the implant. With a machined-surface implant, this may approximate less than 30% BIC and is most related to the implant design and surface condition (Figure 11-26). Consequently, greater implant surface area is required to obtain a similar amount of BIC in soft bone compared with a denser bone quality. As a result, many anterior mandibles with more dense bone have less importance of implant number, size, or design compared with posterior maxillae with less dense bone.

It has been reported that the BIC is related to the bone density and the healing time. For example, in a study by Carr et al., the BIC was greater in the mandible than the maxilla (the mandible is usually more dense). In addition, the BIC was greater at 6 months compared with 3 months in both jaws (Figure 11-27). Thus, the healing time before implant loading may be related to the density of bone because the strength of bone increases and the BIC increases with a longer time period. Hence, 3 to 4 months of healing for D1 to D2 bone and 5 to 6 months for D3 to D4 bone has less risk than a shorter time period for all bone types.

BOX 11-8 Initial Bone–Implant Contact Percent (BIC%)

DENSITY	BIC %
D1	85%
D2	65%–75%
D3	40%–50%
D4	<30%

Bone Density and Stress Transfer

Crestal bone loss and early implant failure after loading results may occur from excess stress at the implant–bone interface.[78-80] A range of bone loss has been observed in implants in different bone densities with similar load conditions.[58] Bidez and Misch noted in 1990 that part of this phenomenon may be explained by the evaluation of finite element analysis (FEA) stress contours in the different volumes of bone for each bone density.[5,81] Each model reproduced the cortical and trabecular bone material properties of the four densities described. Clinical failure was mathematically predicted in D4 bone and some D3 densities under occlusal loads (Figure 11-28). Other studies using FEA models with various implant designs and bone quality have

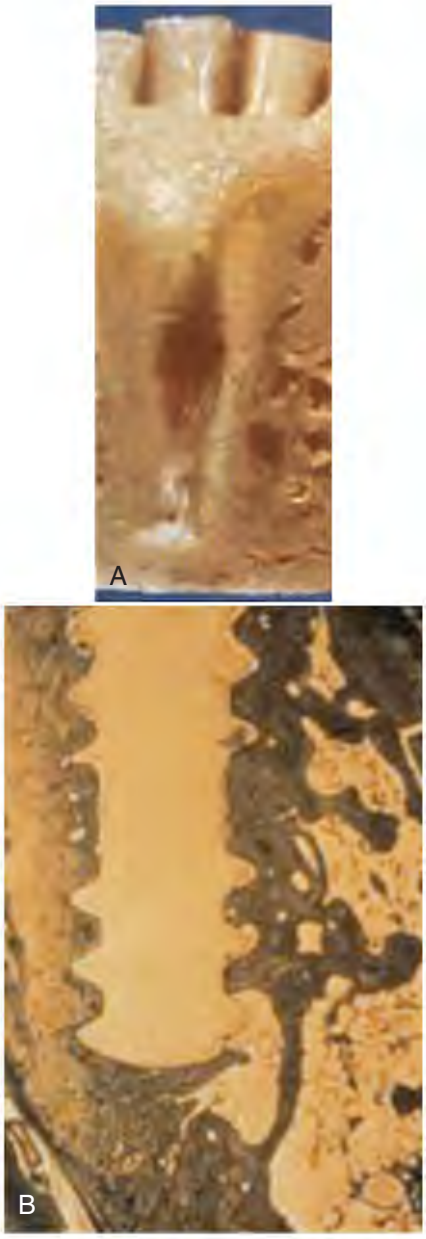


FIGURE 11-24. D1 bone density has the greatest amount of bone–implant contact. Because stress equals force divided by area, the increase in the area of contact results in a decreased amount of stress.

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FIGURE 11-25. In D2 bone density, one finds primarily coarse trabecular bone next to the implant. The bone–implant contact is greater than D3 bone but less than D1 bone.



FIGURE 11-26. D4 bone has the least bone–implant contact. As a result, the stress is greatest for the D4 bone–implant interface. Trabecular bone is fine, the strength is poor, and the modulus of elasticity microstrain difference is greatest. The microstrain difference for each bone density is not the same. Whereas D4 bone is most at risk, D1 bone is least at risk after loading.

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also evaluated the stress–strain distribution in the bone around the implants.[82] For example, Tada et al. evaluated the three-dimensional changes around different-length implants in different bone qualities[83] (Figure 11-29). The type 3 and 4 bone categories had four to six times more strain around all implants, with the highest strains around the shortest implants. As a result of the correlation of bone density to the elastic modulus, bone strength, and BIC percent, when a load is placed on an implant, the stress contours in the bone are different for each bone density.[84] In D1 bone, the highest strains are concentrated around the implant near the crest, and the stress in the region is of lesser magnitude. D2 bone, with the same load, sustains a slightly greater crestal strain, and the intensity of the stress extends farther apically along the implant body. D4 bone exhibits the greatest crestal strains, and the magnitude of the stress on the implant proceeds farthest apically along the implant body.

As a consequence of different strain regions found around implants with different bone densities, the magnitude of a prosthetic load may remain similar and yet give one of the following three different clinical situations at the bone–implant interface based on the bone density around the implant: (1) physiologic bone loads in the adapted window zone and no marginal bone loss, (2) mild overload to pathologic overload bone loads and crestal bone loss, or (3) generalized pathologic overload and implant failure. Therefore, to obtain a similar clinical result in each implant prosthesis, the variables in each patient must be either eliminated or accounted for in the treatment plan. Because the myriad of variables cannot be eliminated relative to bone density, the treatment plans (including implant number, size, and design) should be modified.

Treatment Planning

When a patient is first examined, the most common radiographic evaluation is with a panoramic radiograph. The initial treatment plan is presented to the patient using the anatomical location as an index of the bone density: anterior mandible and single tooth replacement is D2, anterior maxilla and posterior mandible is D3, and posterior maxilla is D4. After the initial treatment steps are taken into consideration (e.g., prosthesis type and design, implant key position, and patient force factors), a more complete treatment plan relative to bone density is obtained by a CT scan or modified during the surgical procedure using the tactile method to determine bone density.

Four facts support the basis for treatment plan modification in function of the bone quality: (1) each bone density has a different strength, (2) bone density affects the elastic modulus, (3) bone density differences result in different amounts of BIC

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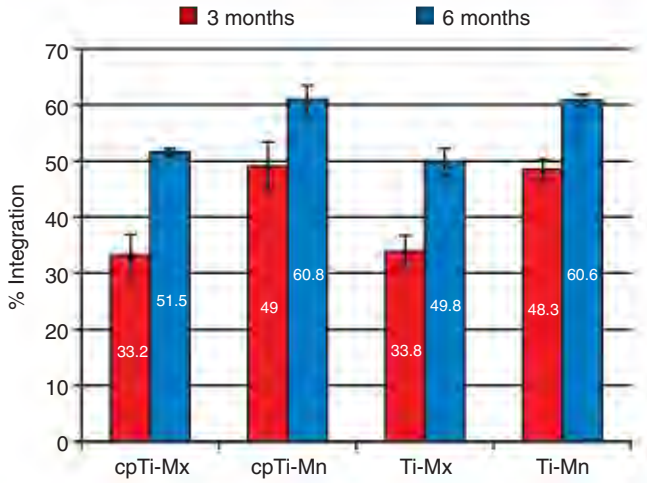


FIGURE 11-27. The percentage of bone contact after initial healing and before any occlusal load may be related to bone density (e.g., mandible vs. maxilla) and healing time. Longer healing periods may increase bone–implant contact.

BOX 11-9 Treatment Plan Modifiers

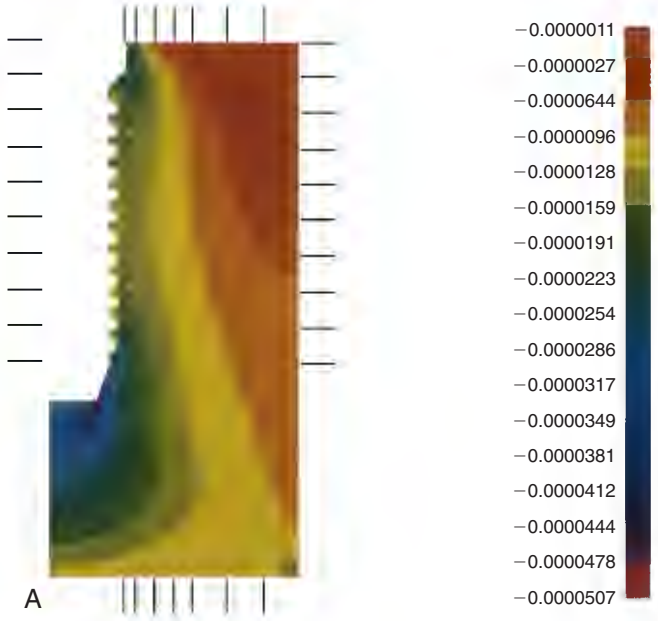
↓Bone density = ↑ Implant area
↑ Implant number
↑ Implant width
↓ Cantilevers
↑ Implant body surface area
↑ Implant length (D4 bone)
↑ Implant surface condition

percent, and (4) bone density differences result with a different stress–strain distribution at the implant-–bone interface. Bone density is an implant treatment plan modifier in several ways—prosthetic factors, implant number, implant size, implant design, implant surface condition, and the need or method of progressive loading (Box 11-9).

As the bone density decreases, the strength of the bone also decreases. To decrease the incidence of microfracture of bone, the strain to the bone should be reduced. Strain is directly related to stress. Consequently, the stress to the implant system should be reduced as the bone density decreases.

Stress may be reduced by increasing the functional area over which the force is applied. Increasing implant number is an excellent way to reduce stress by increasing functional loading area. Three implants rather than two may decrease applied implant moments in half and bone reaction forces by two thirds, depending on implant position and size.[40] An implant prosthesis with normal patient forces in D4 bone should have at least one implant per tooth. In the molar region, two implants for each missing molar may even be appropriate. In D3 bone, one implant per tooth is often appropriate in the posterior region, where less implants are required in the anterior location. In D2 bone with normal patient forces, a pontic(s) may replace a tooth between two implants in both posterior and anterior regions.

The surface area of the implant macrogeometry may be increased to decrease stress to the implant–bone interface.[44,85] The width of the implant may decrease stress by increasing the surface area.[86] This may also reduce the length requirement. For every 0.5-mm increase in width, there is an increased surface



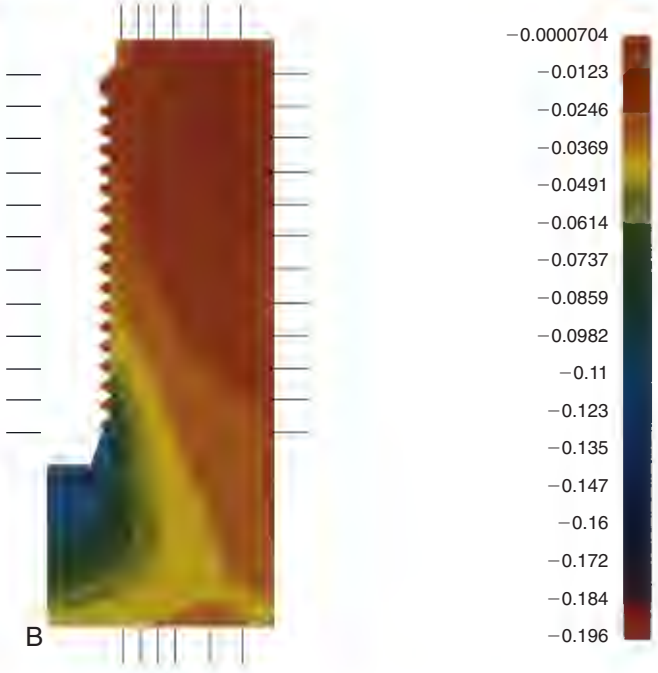


FIGURE 11-28. **A,** Stress transfer around the implant interface is different for each bone density. In this two-dimensional finite element analysis, D2 bone has an intermediate stress intensity around the implant. **B,** A two-dimensional finite element analysis demonstrates that D4 bone has a higher stress intensity around the implant, and the higher intensity even extends to the zone around the apical threads.

area between 10% and 15% for a cylinder implant, and even more difference is found with threaded implant body designs. Because the greatest stresses are concentrated at the crestal region of the implant in good bone types, width is more significant than length for an implant design after adequate length has been established. D4 bone should often require wider implants compared with D1 or D2 bone. This may require onlay grafts or bone spreading to increase the width of bone when other stress factors are high.

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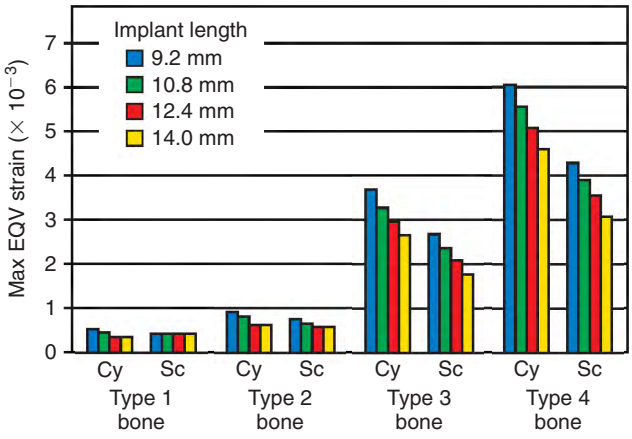


FIGURE 11-29. The softer bone types (types 3 and 4) have higher strain values around implants regardless of their length compared with harder bone types (types 1 and 2).[83]

Based on long-term clinical experience of V-shaped threaded implant bodies, the minimum bone height for initial fixation and early loading for D1 bone is 7 mm; for D2 bone, 9 mm; and for D3 bone, 12 mm using the classic V-thread screw implant design and titanium surface condition.[87] Because the crestal region is where pathologic overload of bone most often occurs after prosthetic loading, after initial healing is complete, the length of the implant is not as effective to solve crestal bone loss (and the quality of implant health) as other factors (e.g., implant design, implant width). D4 bone benefits from relatively longer implants for initial fixation and early loading compared with other bone densities, not only for initial fixation but also because the stress–strain transfer of occlusal forces extends farther down the implant body. As a consequence, 12- to 15-mm long implants are suggested. This implant length requirement may require sinus grafts in the posterior maxilla.[88]

The macro implant body design affects the magnitude of stresses and their impact on the bone–implant interface[44,86] and can dramatically change the amount and contour of the bone strains concentrated at the interface. Different implant design criteria respond to different bone densities. Bone densities exhibit a 10-fold difference in strength, and the elastic modulus is significantly different between D1 and D4. Implants designed for D4 bone should have the greatest surface area. For example, a classic V-thread screw design has 30% more surface area than a cylinder implant. A thread design with more threads has more surface area than one with fewer threads. The depth of the thread is also a variable that may be controlled based on the surface area desired. The deeper the thread depth in the implant body, the more functional surface area for the BIC. An implant body designed for the soft bone should have more and deeper threads than an implant body designed for hard bone. A D1 implant, on the other hand, may be designed for easy surgical placement because the strains under load are minimized, but the surgical failure rates are greater.

Coatings or the surface condition on an implant body can increase the BIC percentage and therefore the functional surface area. A rougher surface is strongly suggested in soft bone and has resulted in improved survival rates compared with machined titanium.[10] However, after 1 to 2 years, the mechanical load on the overall implant design is more critical to the amount and type of bone contact compared with the surface condition on the implant body. Rough surface conditions also may have some disadvantages. Plaque retention when exposed above the bone, contamination, and increased cost are a few of the concerns with roughened surfaces. The benefit and risk of surface conditions suggests that the roughest surfaces are most often used in only softer bone types.

Another way to reduce the biomechanical loads on implants is by prosthesis design to decrease force. For example, cantilever length may be shortened or eliminated, narrower occlusal tables designed, and offset loads minimized, all of which reduce the amount of load.[40,89] Removable prostheses (RP-4) restorations, rather than fixed prostheses, permit the patient to remove the restorations at night and reduce nocturnal parafunctional forces. RP-5 prostheses permit the soft tissue to share the occlusal force and reduce the stress on the implants. Night guards and acrylic occlusal surfaces distribute and dissipate parafunctional forces on an implant system. As the bone density decreases, these prosthetic factors become more important.

The load on the implant may also be influenced by the direction of force to the implant body.[89] A load directed along the long axis of the implant body decreases the amount of stress in the crestal bone region compared with an angled load. Therefore, as the bone density decreases, axial loads on the implant body become more critical. Bone grafting or bone spreading to increase the width of bone and to better position the implant relative to the intended load is considered for soft bone types.

Progressive bone loading provides for a gradual increase in occlusal loads, separated by a time interval to allow the bone to mature and accommodate to the local strain environment.[6] Over time, progressive loading changes the amount and density of the implant–bone contact. The increased density of bone at the implant interface improves the overall support system mechanism. The softer the bone, the more important the need for progressive loading.

Summary

A key determinant for clinical success is the diagnosis of the bone density in a potential implant site. The strength of bone is directly related to bone density.

The modulus of elasticity is related to bone density. The percentage of BIC is related to bone density, and the axial stress contours around an implant are affected by the density of bone. As a consequence, past clinical reports that did not alter the protocol of treatment related to bone density had variable survival rates. To the contrary, altering the treatment plan to compensate for soft bone types has provided similar survival rates in all bone densities. After the prosthetic option, key implant position, and patient force factors have been determined, the bone density in the implant sites should be evaluated to modify the treatment plan. The treatment plan may be modified by reducing the force on the prosthesis or increasing the area of load by increasing implant number, implant size, implant design, or implant body surface condition. Of these choices, the number of implants is often the most effective method to decrease the stress to the implant system.

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CHAPTER 12

Treatment Plans Related to Key Implant Positions and Implant Number

Carl E. Misch

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Treatment plan options for abutments in partially edentulous patients are more often related to clinical experience and the art form of dentistry rather than science or clinical studies. The periodontal, endodontic, and structural health of the teeth adjacent to the edentulous space(s) is variable. As a result, there are more than 100,000 combinations of missing teeth and available bone in one dental arch.[1] The dentist uses past experiences and art to splint together the best abutment teeth available to replace the missing teeth. Hence, several different options may be present from one patient or doctor to another to replace the same missing teeth in an arch.

Implant dentistry has become the most predictable method to replace missing teeth. However, the doctor and the patient often have an incentive to do treatment that is faster, easier, and less expensive. As a consequence, treatment planning for implant dentistry is often driven by the existing bone volume in the edentulous sites. Faster, easier, and cheaper are only justified if the clinical outcome is as predictable and has fewer complications than other options. For example, in the mid 1980s, the most common treatment plan in the literature of completely edentulous patients was to place implants between the mental foramen in the mandible and anterior to the maxillary sinuses in the maxilla (with the number of implants related to the existing bone volume).[2] Full-arch fixed restorations were then cantilevered to the posterior regions of the jaws (Figure 12-1). This treatment plan is still popular today because bone grafting is often not required and the fees are lower than many other options. Yet often this treatment option has significant complications, especially when the opposing arch is natural teeth or implants and the existing bone volume is limited (Figure 12-2).

Placing implants in existing bone volumes is often problematic. In partially edentulous patients, more than 6 mm of bone height is found in fewer than 40% of posterior maxillae and 50% of posterior mandibles.[3] This percentage is further reduced in the posterior regions to fewer than 20% of completely edentulous patients in either arch. Therefore, the treatment plan without bone grafting often presented to the patient uses cantilevers from anterior implants or short implants in the posterior region. However, the posterior regions of the jaws have the greatest bite forces (which are generated on the cantilever), and the existing bone (to support short implants) in the posterior regions is less dense than the anterior regions.

Treatment Plan Rationale

When implants are inserted into abundant bone volume and allowed to integrate for 4 or more months before loading, the *surgical success* rate is over 98%. This success rate is not related to implant number, size, or design. However, when the implant is *occlusal loaded* with the prosthesis, the failure rate may be greater than three to six times the surgical failure rate. For example, a meta-analysis reveals 15% failure rates (with several reports above 30% failure) when the implant prosthesis is occlusal loaded with implants shorter than 10 mm or when they are placed in softer bone.[4] This failure most often occurs during the first 18 months of loading and is called *early loading failure*. The primary cause of this complication in implant dentistry is related to biomechanical factors, with too much biomechanical stress applied to the implant support system or bone too weak to support the load.[5] The biomechanical stress can be reduced by several methods (e.g., eliminating cantilevers and splinting together additional implants of adequate size).

Mechanical complications of the implant components or prosthesis outnumber *surgical failures,* and many reports are more frequent than *early loading failures*. Mechanical complications include abutment screw loosening, uncemented prostheses, and porcelain fracture.[4] These complications are found more often in bruxism patients, in men, when the implant restoration is opposing another implant prosthesis, and with group function occlusion.[6] All of these factors increase the amount of stress on the implant system (occlusal porcelain, cement, implant abutment screw, and implant–bone interface). Hence, mechanical complications are also related to biomechanical factors.

Biomechanical stress may also cause marginal crestal bone loss.[7] Because the implant does not have a periodontal membrane as a tooth does, the stress to the implant–bone interface is mostly to the crestal marginal bone. When the stress is beyond the bone physiologic limit, resorption may occur. The bone loss may increase the risk of anaerobic bacteria and periimplantitis, or the surrounding soft tissues may shrink and result in poor cervical esthetics. Hence, biomechanical factors can lead to early loading failure, mechanical complications, marginal bone loss, or periimplantitis around an implant. As a consequence, a primary objective to develop a treatment plan in implant dentistry should be to reduce biomechanical stress in the system.

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FIGURE 12-1. **A,** In the 1980s, the most common treatment plan for completely edentulous patients inserted four to six implants in the anterior region (depending on the existing bone volume). **B,** A full-arch cantilevered fixed restoration was then secured to the anterior implants.



FIGURE 12-2. A recent treatment in which three anterior implants and a cantilevered fixed prosthesis were inserted into a severely resorbed mandible, opposing natural dentition in the maxilla.

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Treatment Fees and Economics

The doctor and patient are motivated to place implants without bone grafting because the cost is greater and the procedure is more difficult (and may be less predictable) than placing shorter or angled implants into existing bone volume. The discomfort after bone augmentation is usually more than what occurs after implant surgery. An extended healing time of 4 to 9 months may be necessary for the bone graft to mature compared with implant healing in native bone. The costs associated with bone augmentation are often greater than the fees related to implant insertion. In addition, there are usually more implants and more teeth replaced after bone augmentation compared with situations when implants are inserted into existing volumes of the bone and teeth are cantilevered to the posterior regions. More implants and more teeth replacements further increase the cost to the patient. As a consequence of these considerations, the doctor and the patient are both motivated to use existing bone volumes for implants and restore fewer posterior teeth in the prosthesis. In addition, the patient undergoes one surgery and therefore experiences less discomfort.

An example of the patient and doctor having an economic incentive to perform procedures with higher biomechanical risks is when a patient has four teeth missing in a posterior maxillary quadrant (two premolars and two molars), with a pneumatized maxillary sinus cavity. There are typically two treatment options. The first is to place two implants anterior to the sinus, which supports a three-unit prosthesis (with a first molar cantilever) (Figure 12-3). A second option is to perform a sinus bone graft and the insertion of three implants (in the first premolar, first molar, and second molar positions) and to fabricate a four-unit restoration.

The first treatment option in this example is half the fee of the second option because it does not require a sinus graft and

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FIGURE 12-3. Two implants are inserted in front of the maxillary sinus and supports a cantilevered three-unit fixed partial denture. Note the bone loss to the third thread on the distal implant and bone loss to the second thread in the anterior implant.

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has fewer implants and fewer teeth replaced. The typical fees associated with treatment in implant dentistry are related to the number of implants and teeth replaced. Hence, a three-unit fixed partial denture (FPD) supported by two implants is half the fee of a six-unit FPD supported by four implants. As a result, in a posterior maxilla, instead of posterior bone grafts and additional implants supporting a four-unit FPD, a three-unit FPD with a distal cantilever is often extended from two anterior implants, anterior to the maxillary sinus. The first option is also faster and easier because a bone augmentation is not required.

Although the first treatment option is less expensive and has less discomfort, treatment is not equivalent to the four-unit FPD with more implants. The second treatment option has three to four times better chance for long-term success because it does not cantilever a pontic in the molar region and has more implant support. Cantilevers increase the biomechanical force to the anterior implants. Therefore, there is an increased risk of an unretained prosthesis on the first premolar (because of a tensile force to the retainer and cement is 20 times weaker to tension compared with compression). This results with one implant (the second premolar) supporting all three teeth and the risk of overload and failure. In addition, the first option more often has more bone loss from occlusal overload related to the increased biomechanical stress as a result of the cantilever. In addition, the opposing mandibular second molar may erupt past the plane of occlusion with the first option (because it only has one molar), and each protrusive mandibular movement would result in a lateral premature contact on the maxillary prosthesis. This force direction increases the shear force and may even trigger parafunction. All of these increased risks of complications are related to the increased biomechanical stress.

Biomechanical-related complications often occur within the first few years of function. As a result, the patient expects the dentist to repeat the treatment for no charge. When the first option fails, the second treatment option may be selected, often from a different dentist, which is associated with a greater cost. As a result, the patient is more likely to bring litigation against the first treatment team in order to pay for the additional costs of the second treatment option.

Treatment Fees and Risk Factors

As a consequence of an increased risk of complications in the first treatment option (cantilevered prosthesis), the fees for this option should be more than the second treatment option. In other words, the fee for services rendered should not only be based on the sum of the number of implants and teeth in the prosthesis; it should also include the amount of risk associated with the treatment.[8]

A more basic example of charging for risk factors is the treatment for a crown on a maxillary central incisor implant compared with a mandibular molar implant. The time and technique for an anterior tooth soft tissue drape development, preparation, impression, and transitional prosthesis is greater than to restore a mandibular posterior implant. The risk that an anterior maxillary crown has to be redone because of gingival recession, shade selection, and so on is greater than the mandibular crown. Yet most dentists charge the same fee for both procedures. The maxillary anterior crown has more risk; therefore, the fee should be greater.

In conclusion, the treatment plan in implant dentistry should have a biomechanical rationale to decrease stress to the implant system. The fees for an implant treatment plan that has fewer implants or cantilevers should be greater than restorations supported by more implants or without cantilevers. The risks in dentistry are factors that should be included in the cost of most all procedures that are associated with greater complications. The implant and associated restoration is not a commodity in which the cost is solely related to the number of implants and prosthetic units.

Treatment Plan Sequence

Because the primary causes of complications in implant dentistry are related to biomechanics, Misch developed a treatment plan sequence to decrease the risk of biomechanical overload, consisting of the following steps[9]:

1. Prosthesis design
2. Patient force factors
3. Bone density in the edentulous sites
4. Key implant positions
5. Implant number
6. Implant size
7. Available bone in the edentulous sites
8. Implant design

This chapter considers the key implant positions for a prosthesis followed by the overall number of implants to support the restoration.

Abutment Options

Several treatment options are available for the adequate restoration of an edentulous segment. As a general rule, in a partially edentulous patient, implant-supported prostheses should be independent from natural adjacent teeth. There are biological and biomechanical factors that favor independent implant prostheses, and the greatest benefits are biological factors of less decay and endodontic risks. The incidence of decay when teeth are splinted together in a FPD accounts for 22% of the complications within 10 years (because the pontic acts as a plaque reservoir), whereas individual crowns have a less than 1% risk of decay within this time frame.[10–12] When the adjacent tooth to the edentulous site is a natural tooth and an independent

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implant prosthesis is fabricated, there is less risk of decay on the tooth, and implants do not decay. A second common complication of teeth-supported fixed prosthetic restorations is endodontic-related factors that occur in approximately 15% of cases within 10 years. When independent prostheses are designed, implant abutments do not require endodontic procedures, and unsplinted natural teeth have less endodontic procedures, especially if they are not prepared for crowns. Therefore, the unprepared tooth has less risk of endodontic failure or fracture (Figure 12-4).

There are also biomechanical advantages for implant-supported independent prostheses.[13] The tooth has physiologic movement of 28 microns apically and 56 to 108 microns in the horizontal dimension.[14] Hence, a tooth joined to the implant (with much less movement) may act as a cantilever on the implant and increase biomechanical complications (Figure 12-5). As a consequence, when an implant restoration is joined to a natural tooth, an increased risk of abutment screw loosening, implant marginal bone loss, and unretained restoration may occur (Figure 12-6). In addition, independent implant prostheses may reduce or eliminate pontics between the tooth and the implant (by adding an additional implant next to the tooth). This simultaneously increases the number of abutments and distributes forces more effectively. The increase in abutment number decreases the risk of an unretained restoration, which is the third most common fixed prosthesis complication supported by natural teeth.[10,11] Therefore, independent implant prostheses cause fewer complications and exhibit greater long-term success rates of the prosthesis and greater survival rates of the adjacent teeth.

In addition, the distribution of occlusal forces is optimized when independent implant prostheses are designed. This distribution of forces also decrease the risk of abutment screw loosening, unretained restorations, and marginal bone loss. As a result, the ideal treatment plan for a partially edentulous patient includes an independent implant restoration (Box 12-1).



FIGURE 12-4. When an implant is joined to a natural tooth (in this x-ray, the first premolar implant is connected to the second molar), the pontic acts as a plaque reservoir, and the natural tooth is at increased risk of decay. There is also an increased risk of endodontic complications (e.g., failure or fracture) of the tooth because it is prepared for a crown and has a higher caries risk.

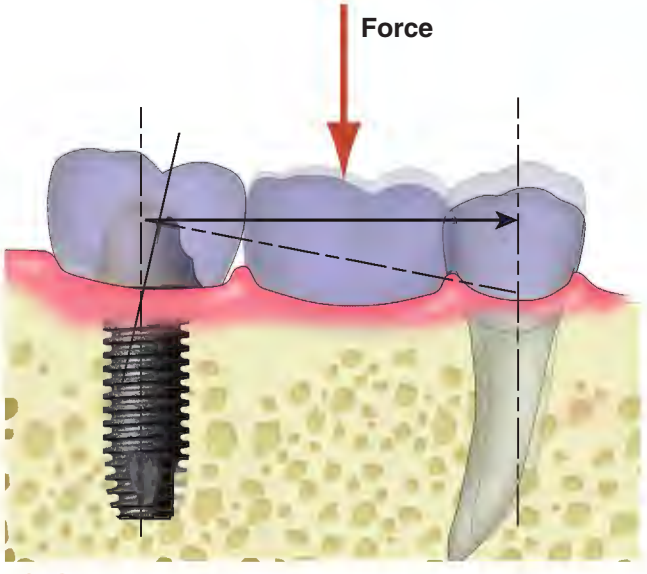


FIGURE 12-5. When an implant is joined to a natural tooth, the physiologic movement of the tooth may cause the prosthesis to act as a cantilever on the implant.

Key Implant Positions

Implant dentistry may use implants that have ideal qualities of health. Rather than using a compromised tooth for support, the implant more often has an ideal clinical condition. However, some implant positions are more critical than others in regard to force reduction to the implant system. The maximum number of potential implants that may be used in a fixed prosthesis is usually determined by allowing 1.5 mm or more from each natural tooth and a 3-mm space between each implant and adding the diameter of the implant (Figure 12-7). This results with dividing the length of the span by 7 mm for the maximum number of implants (when the implants are 4 mm in diameter). Hence, a 21- to 27-mm span may have three implants, and a 28- to 34-mm span may have four implants. The key implant positions are implant sites that are more important than the



FIGURE 12-6. An implant joined to a tooth for a three-unit fixed prostheses may act as a cantilever and increase the risk of crestal bone loss around the implant. In this periapical radiograph, the implant has lost two thirds of the supporting bone.

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BOX 12-1 Independent Implant Prosthesis from Natural Teeth

1. Biological factors (most important)
   a. Less decay of natural tooth abutment (interproximal hygiene)
   b. Less endodontic factors (unprepared teeth have less endodontic complications)
2. Biomechanical factors
   a. Abutment screw loosening risk
   b. Unretained prosthesis (risk from implant)
   c. Marginal bone loss risk (around implant)
   d. More implants used as abutments (no pontic next to natural tooth)
      1. Increase surface area load
      2. Increased retention of prosthesis
      3. Less risk of abutment screw loosening

BOX 12-2 No Limitations to Ideal Treatment

Abutment-available bone
No financial limitation
Time of treatment is not a factor
The necessary skill exists of the treatment team for ideal treatment

BOX 12-3 Guidelines for Key Implant Positions for Fixed Prostheses

No prosthetic cantilevers
No three adjacent pontics in the prosthesis
Canine rule
First molar rule (for all partially edentulous patients and complete arch maxillae)

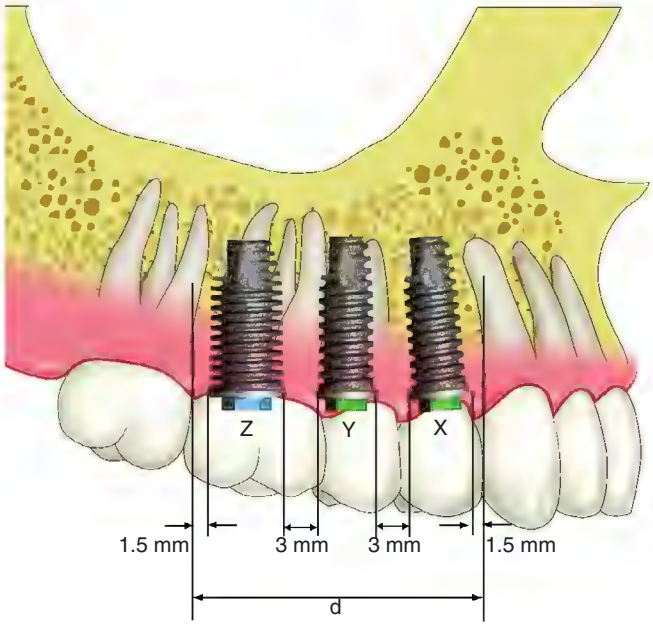


FIGURE 12-7. The maximum number of implants in an edentulous span may be determined by allowing 1.5 mm or more from an adjacent tooth and 3 mm between each implant and adding the diameter of the implants.

others to reduce biomechanical forces. The key implant abutment locations mean that biomechanical complications will be increased when an abutment is not positioned in the site.[15] Hence, even if a bone graft before implant placement is necessary, the additional training, surgery, costs, and time are warranted. After the final prosthesis is determined, the key implant positions for the prosthesis may be established.

The key implant positions are determined with no limitations. In other words, the radiograph is used for diagnosis to determine the prosthesis and pathology but not the available bone and implant position. Rather, the dentist "pretends" the patient has all the available bone necessary to place the implant in the key sites, the patient has no financial limitations to do the ideal treatment, time is not an issue related to treatment, and the skill necessary to place (or augment and place) an implant in the key sites is present by the dentist or the referring team (Box 12-2).

There are four general guidelines to determine key implant positions for a fixed prosthesis in the edentulous site with multiple adjacent teeth missing[15]:

1. Cantilevers on prostheses designed for partially edentulous patients or complete edentulous maxillae should preferably be eliminated; therefore, the terminal abutments in the restoration are key positions.
2. Three adjacent pontics should not be designed in the prosthesis, especially in the posterior regions of the mouth.
3. When the canine is missing, the canine site is a key position, especially when other adjacent teeth are missing.
4. When the first molar is missing, the first molar site is a key implant position for all partially edentulous patients and completely edentulous maxillae (Box 12-3).

No Cantilevers

The first rule for ideal key implant positions is that no cantilever should be designed in the fixed prosthesis for partially edentulous patients or full-arch maxillary fixed restorations. Cantilevers are significant force magnifiers to the cement or prosthesis screws, prosthesis superstructure, abutment screws, implant–bone interface, and the implants.[16,17]

Cantilevers on FPDs supported by teeth have a higher complication rate than prostheses with terminal abutments.[9,12,18] The primary causes of traditional three-unit FPD failure with natural tooth abutments are caries and endodontic complications (often related to the tooth preparation or decay). The 5-year survival rate of the traditional FPD is often above 95%.[11] However, when a cantilevered three-unit FPD supported by two teeth is used to replace a missing tooth, the failure rate is over 25% within the first 5 years, and the complication rate increases to 40% by 10 years; the primary cause of failure is biomechanics.[12,18]

When a load is placed on the cantilever portion of a prosthesis, the abutment farthest from the cantilevered pontic has a tensile and shear force applied to the cement seal because the tooth adjacent to the pontic acts as a fulcrum (Figure 12-8). Cements are 20 times weaker to tension and shear compared with forces in compression.[19] Hence, with a cantilevered prosthesis, the cement seal breaks on the most distal abutment, and

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then the abutment often decays. The abutment closest to the cantilever becomes mobile or fractures (especially when endodontics was performed) because it is the only retained abutment for the prosthesis. These biomechanical-related complications usually occur in a relatively shorter period of time compared with biological complications (e.g., decay or periodontal disease).

The maximum bite force in the anterior region approaches 25 lb, is increased to 100 lb in the region of the canine to premolar area, and further increases to 250 lb in the molar region. Cantilevers on the prosthesis are stress magnifiers to the implant system and may double the bite force.[16] When cantilevers are used in the posterior molar regions, the greater bite force (up to five times greater than the anterior region) is further magnified by the cantilever and may increase the force on the implant system severalfold. For example, a bite force of 100 lb may exist on a premolar implant with no cantilever. When a cantilever is used to replace the molar, this force may be magnified by a 250-lb force on a cantilevered posterior molar pontic, which results in a 500-lb force on the anterior premolar abutment. Instead of 100-lb force on the premolar, the force may be five times greater (Figure 12-9).

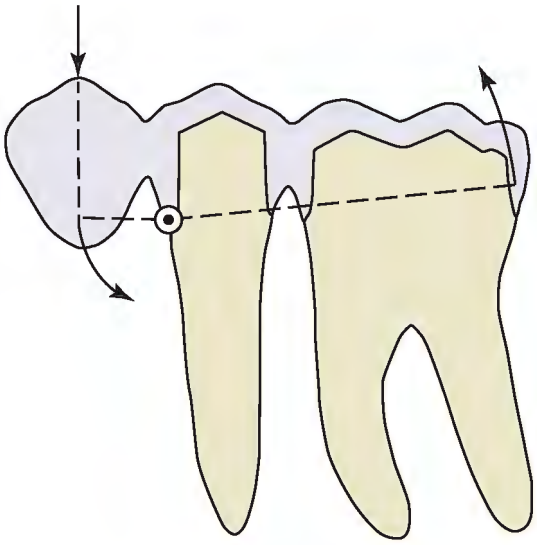


FIGURE 12-8. When a compressive force is placed on a cantilever from two (or more) natural teeth, the closest tooth acts as a fulcrum, and the distal tooth from the cantilever has a shear and tensile load applied to the cement seal. In this example, the compressive load is applied to a first premolar, the second premolar acts as a fulcrum, and the shear and tensile load is applied to the first molar.

Teeth have more physiologic movement than an implant. The physiologic movement absorbs some of the tensile and shear force on the cement seal. In fact, cantilevered fixed prostheses survive best when the teeth are mobile because the cement seal less often breaks. Implant abutments have higher stresses applied to the implant system than the tooth system. Hence, the biomechanical risk factors of a cantilever are worse on implants than on teeth (Figure 12-10). Cement seal breakage, prosthesis screw loosening, and abutment screw loosening are at greater risk with implants. Bone loss is more often observed from biomechanical stress on implants than teeth. Teeth may become mobile, but when the force is reduced, the mobility decreases. The fulcrum implant may even fail or fracture as a consequence of the uncemented prosthesis.

The length of the cantilever is directly related to the amount of the additional force placed on the abutments of the prosthesis.[16,20] When a 25-lb force is placed along the long axis of an implant, the implant system (i.e., crown, cement, abutment, abutment screw, implant body, implant marginal bone, and implant–bone interface) receives a 25-lb load. When a force of the same magnitude (25 lb) is applied on a 5-mm cantilever, the moment force on the abutment is increased to a 125-lb mm force (Figure 12-11).

One Missing Tooth

When one tooth is replaced with an implant, the implant should be inserted into the mesiodistal center of the site. As a general rule, the implant should be 1.5 to 2 mm from an adjacent tooth. Hence, a 4-mm implant requires 7 mm of space. When a molar (10–12 mm) is replaced, the implant should be larger in diameter to decrease the mesial and distal cantilever and placed in the mesiodistal center of the edentulous site. This decreases the biomechanical-related risks to the implant system (Figures 12-12 and 12-13).



FIGURE 12-9. **A,** A cantilever prosthesis to the anterior from premolar and molar implants, replacing a first premolar. The bite force is magnified to the implant system because of the cantilever (both anterior and lateral) *(left)*. **B,** The bone loss on the second premolar implant is greater because it is the fulcrum implant *(right)*.

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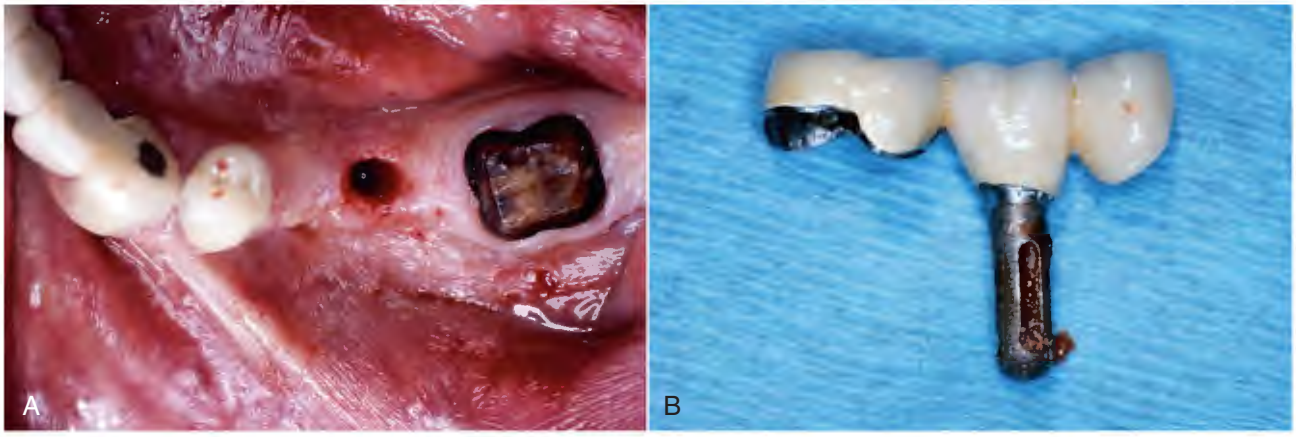


FIGURE 12-10. **A,** A three-unit fixed cantilever prosthesis (replacing a first premolar) was attached to a second premolar implant and a natural tooth first molar. The cement seal on the molar broke, and the molar has decay. **B,** The rigid implant has more biomechanical stress than a tooth and places more tensile and shear load on the cement seal of the distal abutment than the tooth, so it is more likely to become unretained. The implant then bears the entire load of the three-unit prosthesis, and the overloaded implant abutment lost bone, became mobile, and was lost.

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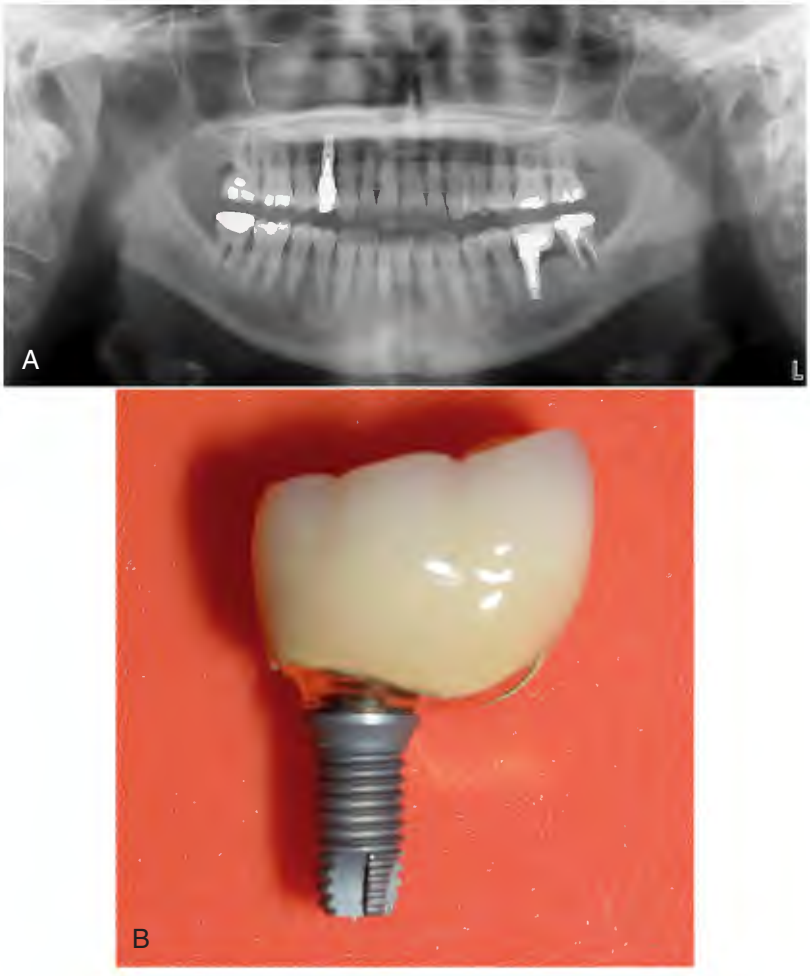


FIGURE 12-11. **A,** An implant was placed in the mesial root position to replace a first molar with a distal cantilever on the crown. **B,** An occlusal load to the cantilevered crown is increased to the implant. The implant failed within a few years.

Two Missing Teeth

When two adjacent teeth are missing, two implants should support the implant restoration. A trend in implant dentistry related to soft tissue esthetics is to have an ovate pontic cantilevered off one implant whenever two adjacent teeth are missing in the esthetic zone[21] (Figure 12-14). The reason most often cited is that it is difficult to obtain an interdental papilla between adjacent implants.[22] However, the biomechanical complications of uncemented prostheses, screw loosening, and increased force also increase the risk of marginal bone loss and implant fracture or failure (Figure 12-15). As a consequence, the soft tissue may be significantly affected (Figure 12-16). Interimplant papilla

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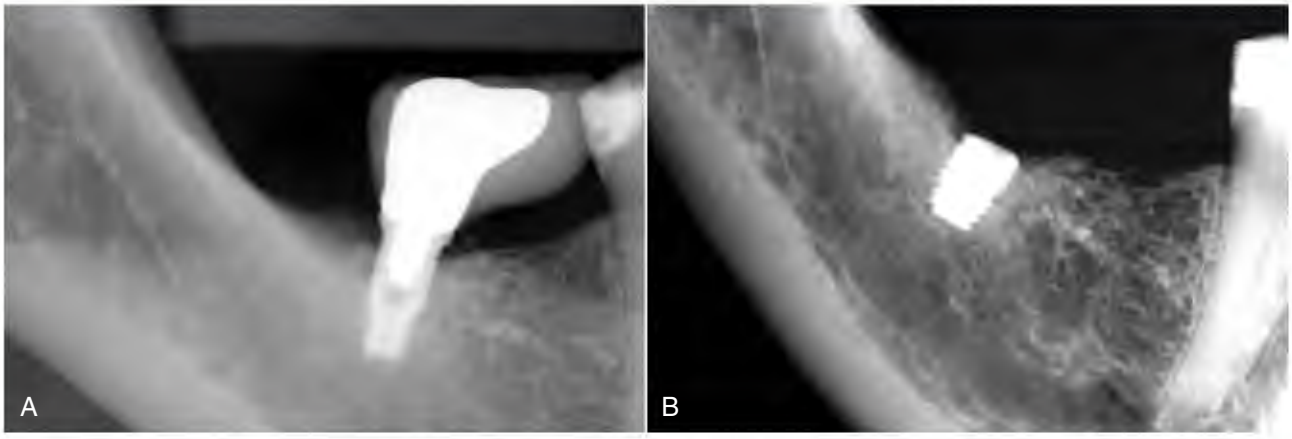


FIGURE 12-12. **A,** An implant was placed in the distal position to restore a first molar. A mesial 7-mm cantilever was used to restore the crown. **B,** The first molar implant fractured within a few years. Two implants should have been used to replace a molar tooth this large.

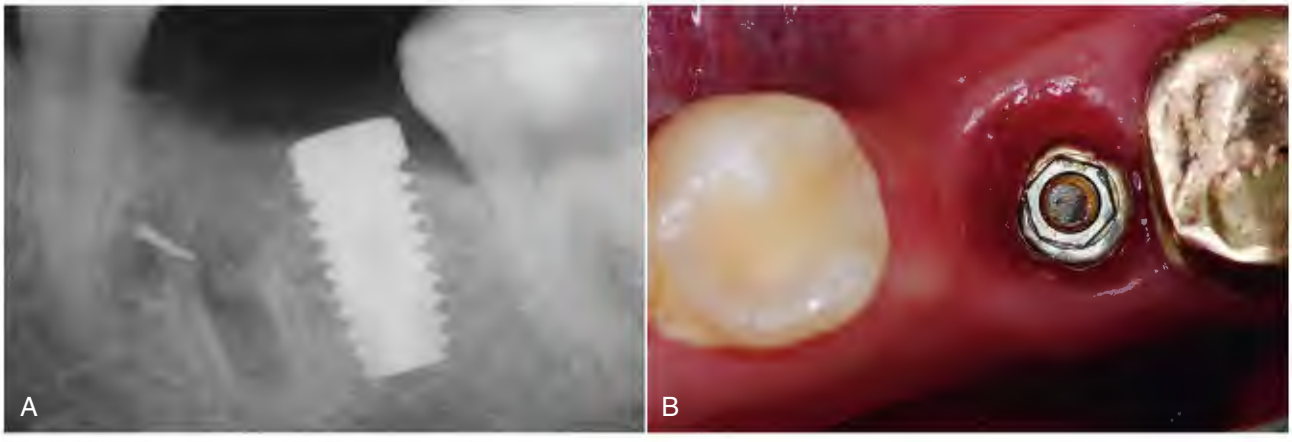


FIGURE 12-13. **A,** An implant was placed in a distal root position, and the crown was restored with a mesial cantilever. **B,** The abutment screw fractured three times within the first year. A larger-diameter implant should have been used in the mid mesiodistal position to restore this tooth.



FIGURE 12-14. A two-unit cantilever from one implant has been suggested in the anterior esthetic zone to improve the soft tissue interimplant region.[21]

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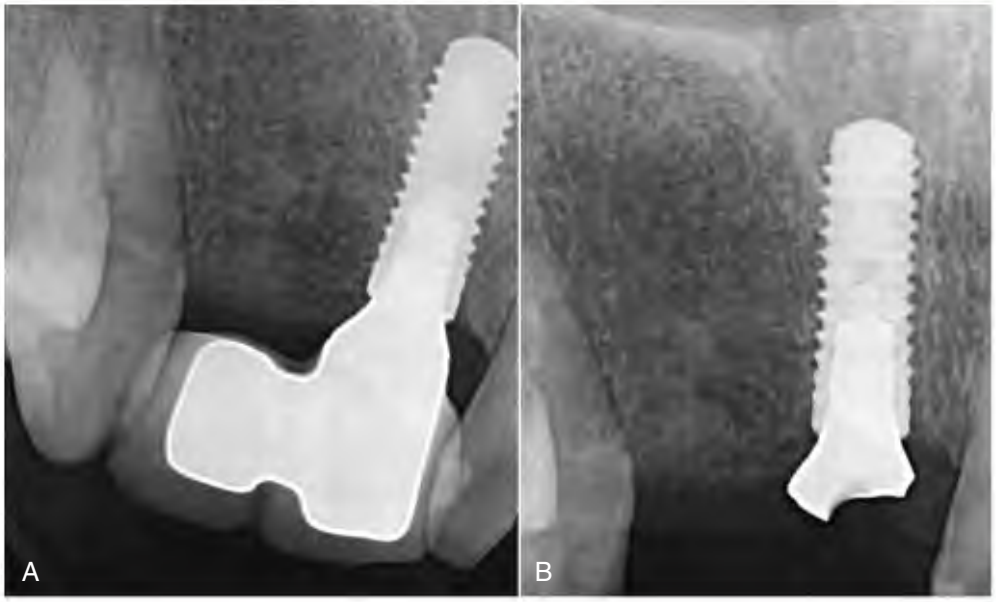


FIGURE 12-15. **A,** A two-unit fixed partial denture cantilever from a central incisor implant. **B,** The abutment fractured after the first year.

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FIGURE 12-16. **A,** A two-unit cantilever from a central incisor implant. Note the bone loss on the distal aspect of the implant. **B,** The soft tissue receded and the soft tissue drape is compromised.

may be generated between two implants as long as the space between the implants is 3 mm or more and 1½ mm from adjacent teeth (Figure 12-17).[23,24] As a result, whenever two adjacent teeth are missing and the space is 12 mm or more, two adjacent implants should be inserted even in the esthetic zone.

To enforce the rule of no cantilever, the key implant positions indicate one implant per tooth when one or two adjacent teeth are missing with a span of more than 12 mm (when the implant diameter is 3 mm), 13 mm (when one implant is 3 mm and the other 4 mm), and so on (Figure 12-18). However, if the cervical region is not in the esthetic zone (high smile line in the maxilla or low lip line during speech in the mandible), it is more advantageous to place two implants in limited mesiodistal spaces (e.g., 10–11 mm) to avoid the increased biomechanical complications. The interimplant papilla will not be ideal under these conditions, but the biomechanical risks are greater than the esthetic risks when the region is out of the soft tissue esthetic zone (Figure 12-19).

When one of the two (or more) missing teeth include a molar, one of the terminal implants should be positioned 1.5 mm from the anterior adjacent tooth and the other terminal implant at the distal of the last molar, not in the middle of the molar. In this fashion, the 3-mm cantilever from the midmolar to the marginal ridge is eliminated when the implants are splinted together (Figure 12-20). When the implant is not positioned in the distal molar position, the size of the last molar

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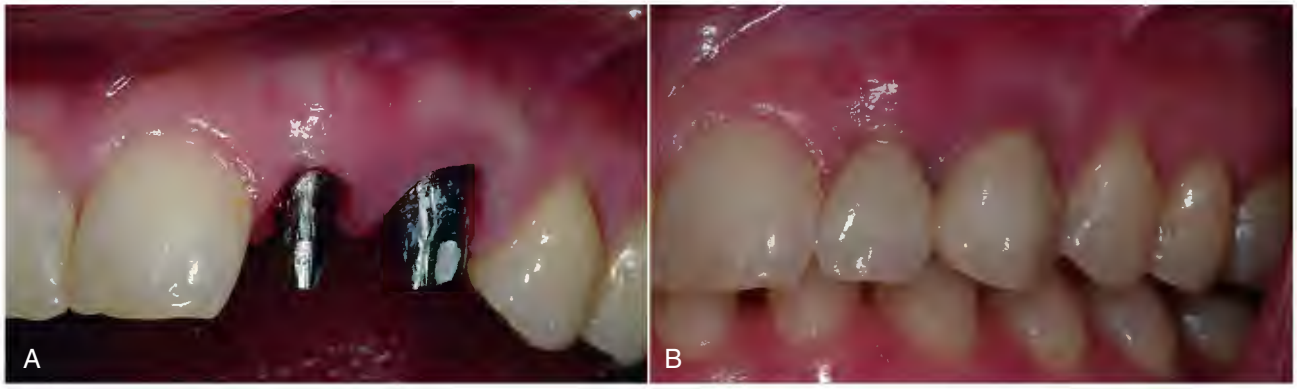


FIGURE 12-17. **A,** Two adjacent implants are placed in the esthetic zone to replace a canine and lateral incisor. The implants are 1.5 mm from each tooth and 3 mm apart. **B,** The two-unit prosthesis has fewer complications than a cantilever, and the soft tissue drape is within normal limits, when the base of the papilla is at least 3 mm wide.

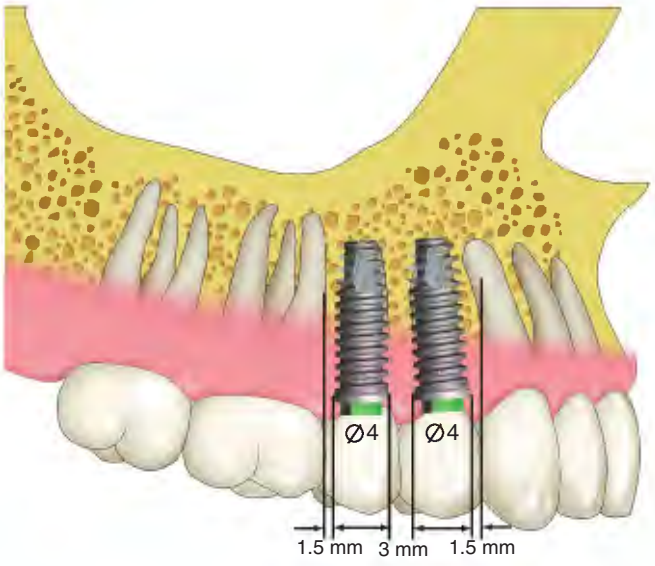


FIGURE 12-18. When two adjacent teeth are missing in the esthetic zone, the implants should be 1.5 mm from the teeth and 3 mm (or more) apart. This means a 12-mm space is required when the implants are 3 mm in diameter, and 14 mm is required for two 4-mm-diameter implants. A-P, anteroposterior.

should be reduced to eliminate the cantilever (Figure 12-21). The dental laboratory technician and dentist should be aware the last molar should be a premolar-size crown when the distal implant is positioned in the mesial to midmolar position.

Cantilever Option. When two adjacent teeth are missing in the esthetic zone anterior to the canines and the intratooth space is less than 12 mm, a cantilever may be an acceptable option. The most common time this clinical condition occurs is two adjacent incisors in the anterior mandible. When the cantilever on the prosthesis is represented by only a mandibular lateral incisor pontic, the ideal implant positions may not include the lateral incisor site. When a pontic replaces the lateral incisor, the soft tissue drape may be improved compared with an implant with less than 3 mm of space from the adjacent implant. The mandibular lateral incisor is the smallest tooth in the arch, so the cantilever is limited. When the mesiodistal space is less than 12 mm, the lateral incisor cantilever should be 5 mm or less. The anterior bite forces are lowest in the central and lateral incisor region. The occlusal force is in the long axis of a mandibular incisor tooth. The occlusal contact on the lateral incisor pontic should be eliminated to further reduce the risk of overload. As a result, the ideal implant position based on force and esthetics may be a larger-diameter implant in the central position (i.e., 4 mm diameter vs. 3 mm) and a cantilevered pontic to replace the mandibular lateral incisor. It should be noted that the cervical region of the mandibular incisors is rarely in the esthetic zone. Hence, a lack of interdental papilla is usually not a consequence.

When a maxillary lateral incisor and central incisor is missing, the intratooth space is almost always greater than 12 mm because a central incisor is usually 8 mm or more wide. Hence, two implants can almost always be inserted. Note: A two-unit cantilever should not be used from a canine implant because the force magnitude increases and the direction of force in the excursion also increases the force to the canine implant.

The fact that, on occasion, a cantilever may be acceptable when force factors are low and bone density is favorable does not negate the ideal goal that no cantilever should be designed in the prosthesis, especially in the posterior regions. Therefore, whenever the intratooth space is 12 mm or more, the terminal abutments at each end of the prosthesis are first designed in the treatment plan. When this option is not readily available, a larger-diameter implant size or greater implant surface area designs are indicated. In addition, the occlusal forces to the cantilevered portion of the prosthesis should most often be reduced or even eliminated.

Three Missing Teeth

When three adjacent teeth are missing, the key implant positions include the two terminal abutments, one on each end of the prosthesis (Figure 12-22). A three-unit prosthesis may be fabricated with only these abutments when most of the force factors are low to moderate and the bone density is favorable. A cantilevered restoration on multiple splinted implants may be compared to a class I lever.[16] The extension of the prosthesis from the last abutment is the *effort arm* of the lever. The last abutment next to the cantilever acts as a fulcrum when a load is applied to the lever. The distance between the last abutment and the farthest abutment from the end of the cantilever represents the *resistance arm*, and the distance between the implants may be called the anteroposterior distance or A-P spread.

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FIGURE 12-19. **A,** Two adjacent implants less than 3 mm apart, replacing two mandibular incisors out of the soft tissue esthetic zone. **B,** The two-unit prosthesis has a depressed interimplant papilla; however, the biomechanical risk complications are reduced.

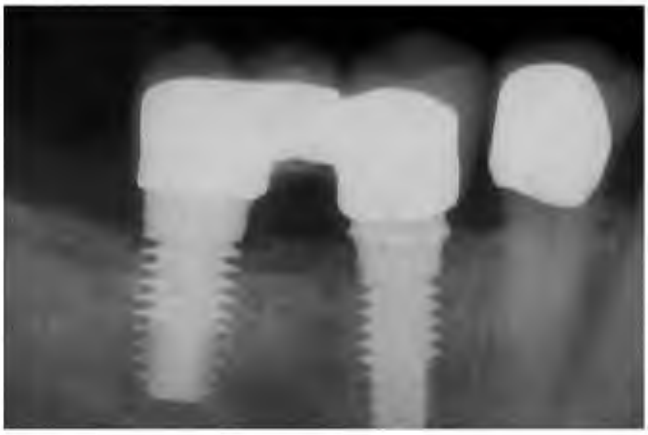


FIGURE 12-20. When two or more adjacent teeth missing include a molar, the distal implant is positioned in the distal of the molar (not the center). This eliminates the posterior cantilever when the implants are splinted together.



FIGURE 12-21. The full contour of the last molar should not be restored when the implant is placed in the mesial to midmolar position because the distal portion of the molar crown acts as a cantilever to the implant system. The last implant in this radiograph should have a premolar-size crown.

The length (usually in millimeters) of the cantilever (effort arm) divided by the resistance arm represents the *mechanical advantage*. Therefore, when two implants are 10 mm apart with a cantilever or extension of 20 mm, the mechanical advantage is 2 (20 mm/10 mm). In this example, a 25-lb force on the cantilever results with a 50-lb tensile force on the farthest abutment from the cantilever (25 lb × 2 = 50 lb). The abutment closest to the cantilever (fulcrum) receives a compressive force equal to the sum of the other two forces, or, in this example, 75 lb (25 lb + 50 lb). In other words, the force on the cantilever increases the force on the implants by two to three times (Figure 12-23). Therefore, cantilevers magnify forces to all the abutments supporting the prosthesis.

As important as the increase in force magnitude, the greater load to the implant farthest from the cantilever is a tensile or shear type of force. As a result, any part of the implant system is at an increased risk of biomechanical failure (e.g., porcelain fracture, uncemented prosthesis, abutment screw loosening, crestal bone loss, implant failure, implant component or body fracture) (Figure 12-24). This is especially observed when parafunction or increased crown height space (CHS) exists[25] (Figure 12-25).

To eliminate posterior cantilevers, a bone augmentation is often indicated. Most bone augmentation procedures are not as predictable as implant integration in existing bone volumes. Bone augmentation often requires an additional surgery before implant placement. Additional training is required to learn bone augmentation procedures, and the learning curve is longer and more difficult to become accomplished in these techniques. Complications related to bone augmentation are more common than implant surgery in existing bone volumes and may be more extensive and even debilitating to the patient. However, cantilevered implant prostheses have a more frequently observed biomechanical risk than the surgical risks of augmentation, and these risks can cause the loss of the entire implant support and

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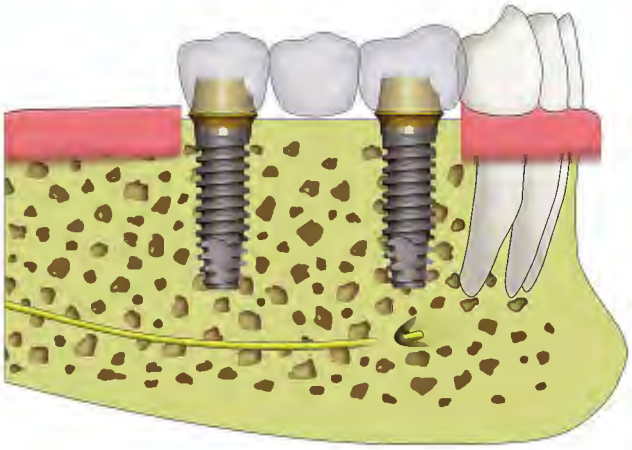


FIGURE 12-22. A three-unit prosthesis has key implant positions at each terminal end of the restoration.

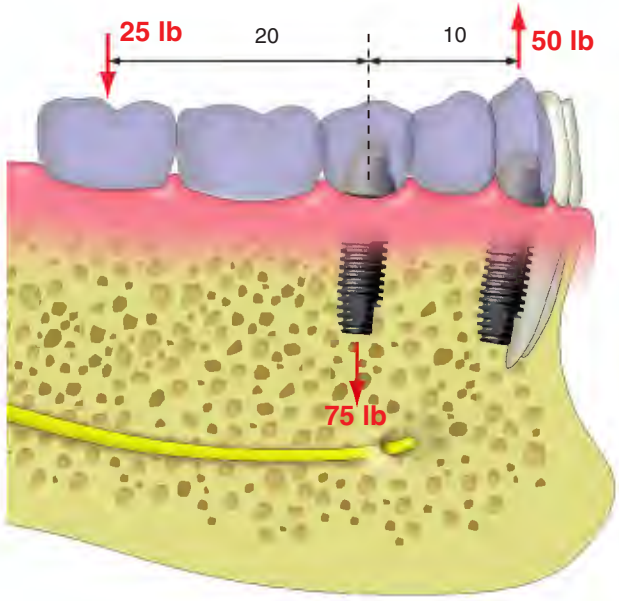


FIGURE 12-23. A cantilever on two implants may be considered a class I lever. When the implants are 10 mm apart, with a 20-mm cantilever, a mechanical advantage of 2 is created. Therefore, a load on the cantilever will be multiplied by 2 on the most distal implant, and the implant close to the cantilever receives the sum total stress of the two other loads.

prosthesis. In addition, bone loss from the implant failure may make the following bone augmentation procedures even more difficult to perform than when treatment was rendered in the original condition.

Four or More Adjacent Teeth Missing

When four adjacent teeth are missing, the terminal abutments are the key implant positions (Figure 12-26). Most often, an additional implant is required, especially when the missing teeth include a canine or posterior teeth or when the bone density is poor (Figure 12-27). Restorations of five to 14 units require the key terminal positions plus additional abutments regardless of force factors or bone density. The other guidelines to the key implant positions determine the most important additional sites for the implant placement.



FIGURE 12-24. Cantilevers increase the force to the implant system. As a consequence, implant failure, fracture, abutment screw loosening, and unretained prosthesis may occur more often. (All of these cantilever-related failures were observed in one office over a 1-year period.)

Cantilever Options. The ideal treatment plan should eliminate cantilevers in partially edentulous patients and in complete arch maxillae. However, in completely edentulous mandibles, a cantilever is often the most prudent treatment option. For example, in a completely edentulous mandible, available bone in the posterior regions may be insufficient for root form implant placement without advanced procedures (e.g., nerve repositioning, iliac crest bone grafts).

In addition, the dynamics of bone movement during opening and function is different for a mandible and maxilla. Upon opening, the mandible flexes distal to the mental foramen toward the midline. During heavy biting on the side of the jaw, the bottom of the mandible rotates to the buccal, and the crest slightly rolls toward the lingual, again, distal to the mental foramen[26,27] (Figure 12-28). As a consequence, splinting a molar implant across the arch to the contralateral molar may cause discomfort and lateral forces on the implant sites. With implant prostheses, uncemented restorations, bone loss, and even implant failure have been observed when there was cross-arch splinting of molars.

An alternative treatment plan for a completely edentulous mandible may be to cantilever pontics from anterior implants. The biomechanics of an arch is more favorable, the bone density in the anterior mandible is adequate, and the direction of force to these anterior implants is along their long axis in centric occlusion[2] (see Figure 12-1). However, when terminal abutments are not designed in the treatment plan and a cantilever is planned, other force factors should be moderate to low, and implant surface area factors of the implant number, size, and design should be high to compensate for the increase in force. When this option is considered, the force factors of parafunction, CHS, masticatory dynamics, implant location, and opposing arch are closely scrutinized.[26] When the force factors are less favorable, the cantilever length should be reduced or eliminated or the implant number increased, the implant size increased, or the implant design surface areas increased.

In addition to patient force modifiers, the A-P distance (or A-P spread) of the most distal and most anterior implants in a full-arch mandible is also a factor. The A-P distance is determined by first drawing a line from the distal aspect of the most

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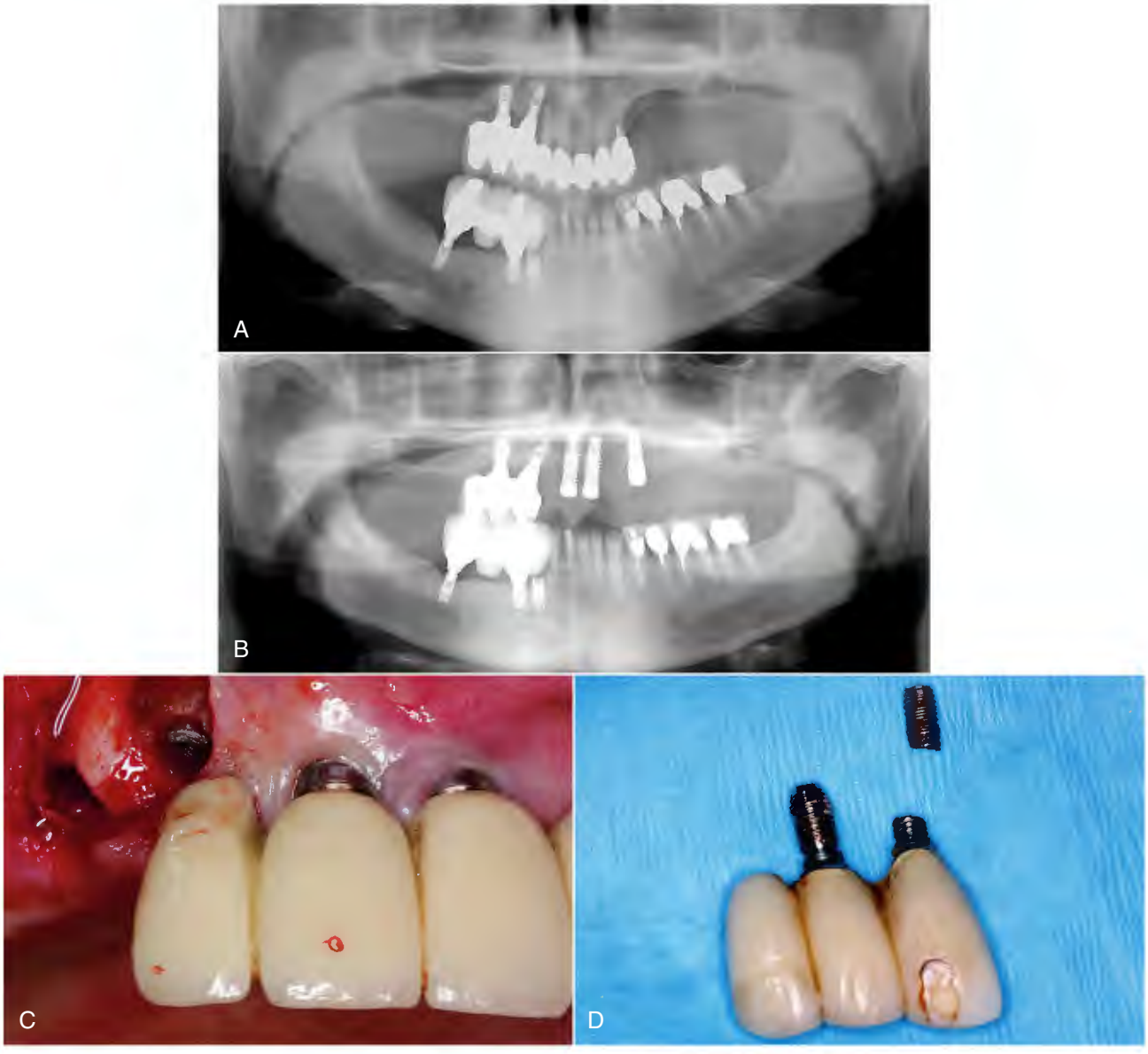


FIGURE 12-25. **A,** A panoramic radiograph of a maxillary and mandibular implant fixed partial denture (FPD) with cantilevers. **B,** A panoramic radiograph demonstrating the maxillary anterior teeth were extracted and replaced with 3 implants. **C,** The maxillary right cantilevered FPD fractured both supporting implants. **D,** The three-unit cantilever FPD and fractured implants.

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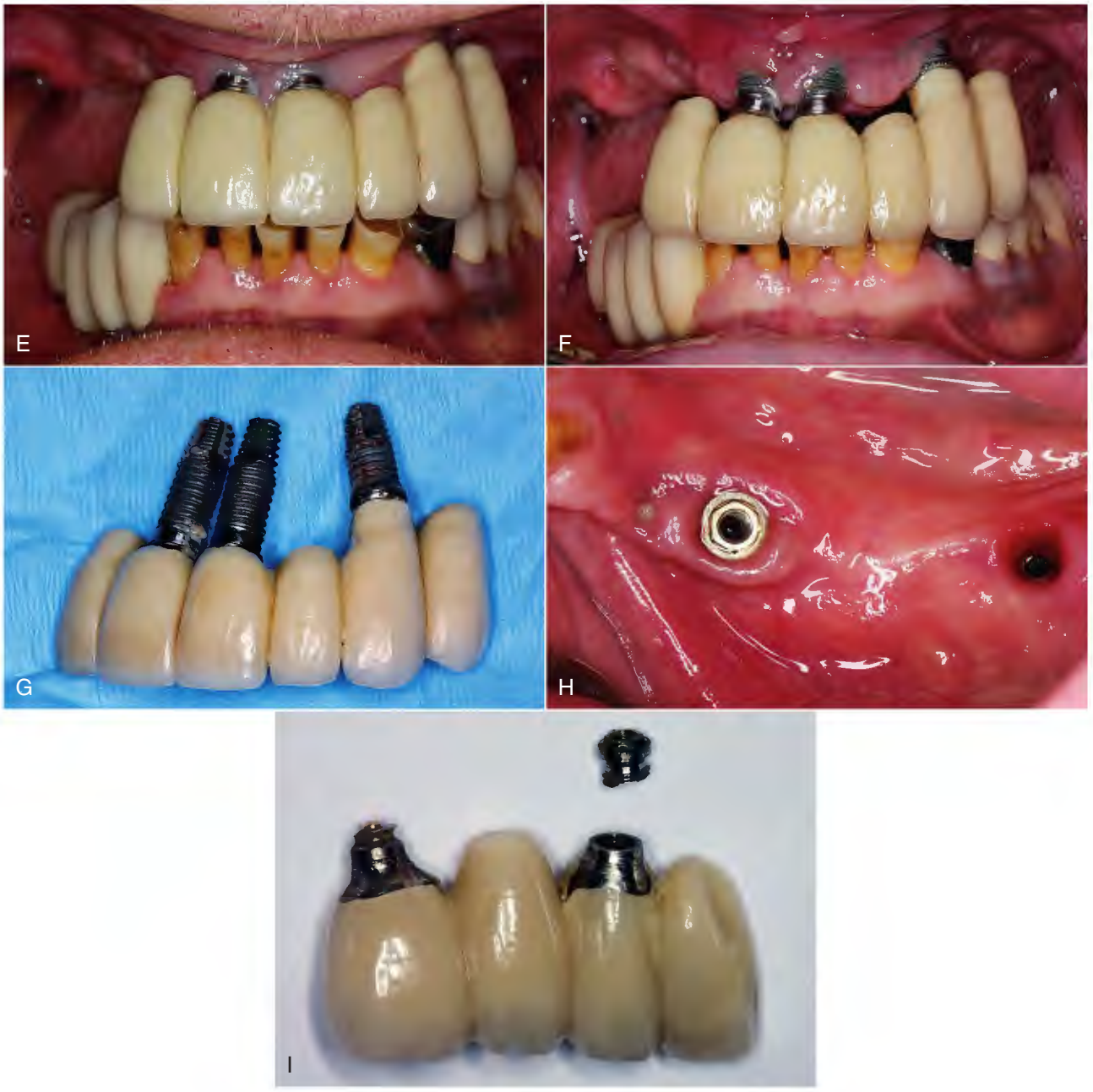


FIGURE 12-25, cont'd. **E,** The anterior implants support a bilateral cantilevered six-unit FPD with a larger crown height. **F,** Bone loss started occurring on the implants. **G,** The three implants and six-unit cantilevered FPD failed. **H,** The four-unit cantilevered mandibular prosthesis fractured the two supporting implants (same patient). **I,** The four-unit cantilevered FPD with the two fractured implants.

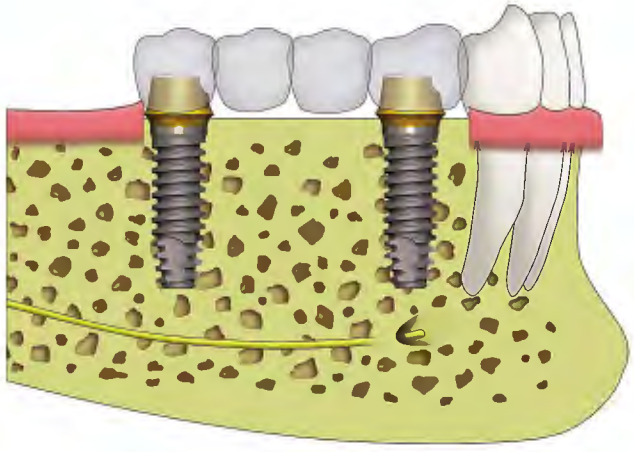


FIGURE 12-26. When four adjacent teeth are missing, the two terminal abutments are the key implant positions. Most often, an additional implant(s) is required.

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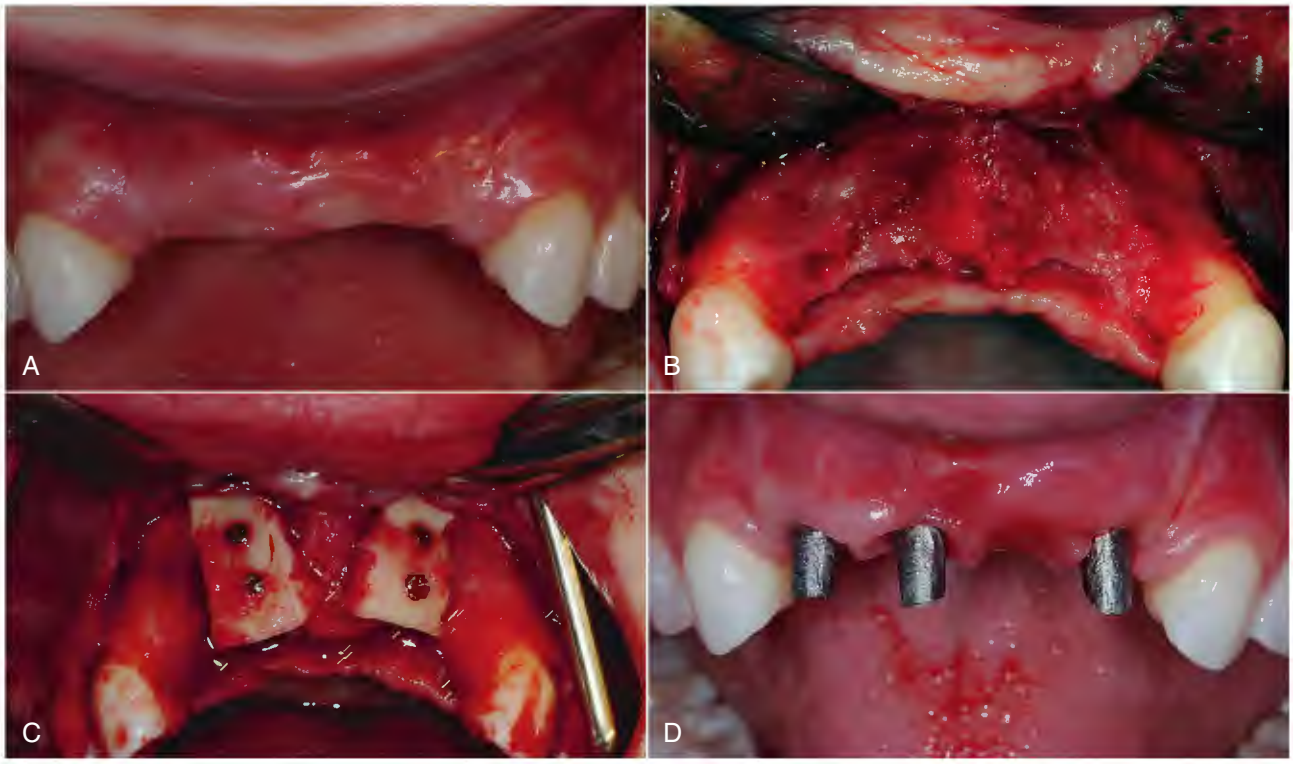


FIGURE 12-27. **A,** A young patient missing four anterior teeth, opposing natural teeth. **B,** The inadequate bone requires a bone augmentation for the key implant positions. **C,** The block bone grafts in situ. **D,** After healing, three implants are inserted. The two terminal implant positions (lateral incisors) are the keys. An additional implant is often required. Note the interimplant papilla is similar to the papilla around the ovate pontic.

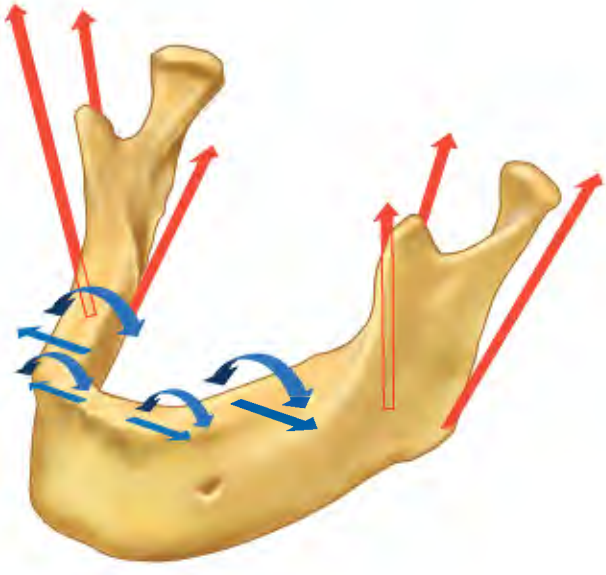


FIGURE 12-28. The mandibular bone has dynamic movement during function. Upon opening, it moves toward the midline. Heavy biting on one posterior side results with a torsion of the mandible with the inferior border rolling buccal and the crest moving toward the tongue.

posterior implant on each side of the arch. A second line (parallel to the first) is then drawn through the middle of the most anterior implant. The distance between these two lines is called the A-P spread (or A-P distance). When the implants are in one plane (a square arch form) and the A-P spread is less than 5 mm, the cantilever option should rarely be used regardless of how low the patient force factors. When five or more implants are positioned around an ovoid or tapered arch and the A-P distance is greater than 7 mm, five different planes exist (central to laterals, bilateral canines, and bilateral premolar-molar) because of the arch form of the splinted implants (Figure 12-29). The posterior cantilever under these conditions may extend as far as two times the A-P distance when all five patient force factors are low and bone density is favorable (Figure 12-30). However, more than two pontics are rarely indicated on a posterior cantilever even under ideal conditions of a full-arch splinted prosthesis. Chapter 15 presents five different implant locations and number options for a fixed prosthesis in an edentulous mandible.

No Three Adjacent Pontics

In most prostheses designs, three adjacent pontics are contraindicated on natural tooth abutments in the posterior regions of the mouth[19,28–30] (Figure 12-31). The adjacent abutments are subjected to considerable additional force when they must support three missing teeth, especially in the posterior regions of the mouth. When three adjacent posterior teeth are missing between remaining teeth (and the third molar is absent), the terminal abutments are the second molar and the canine. The forces in the posterior regions are three to four times greater

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FIGURE 12-29. The mandible may have a square, ovoid, or tapering shape. The anteroposterior distance between the most distal implant on each side and most anterior implant is variable and directly related to the shape of the arch.

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than the anterior region, and the force on the canine is two times greater than the anterior region. In addition, the canine receives a lateral load in most all excursions. The lateral load increases the intensity of the force and places the cement seal and porcelain under more tensile and shear loads.

In addition to the greater loads applied to the abutment teeth, all pontic spans between abutments flex under load.[31] The greater the span between abutments, the greater the flexibility of the metal in the prosthesis. A one-pontic span exhibits little flexure (8 microns or less with precious metal under a 25-lb load). A two-pontic span flexes eight times more than a one-pontic span, all other variables being equal. Although the metal flexure is more for the two-pontic prosthesis, the failure rate of three- or four-unit prosthesis supported by natural teeth is similar for the first 5 years because the cause of failure is mostly biological (e.g., caries) (Figure 12-32).

The metal between abutments for a three-pontic span flexes 27 times more than a one-pontic span if all other factors are equal[28] (Figure 12-33). In addition, the greater the load, the greater the flexure. Hence, in parafunction patients, the flexure is even greater. Metal flexure places shear and tensile loads on the abutments.[32] The greater the flexure, the greater the risk of porcelain fracture, uncemented prostheses, and abutment screw loosening. As a result, not only is the magnitude of the force increased to the adjacent abutments when the prosthesis has three pontics (because they are supporting two abutments and three pontics), but the flexure of the metal also increases to a point that the incidence of complications makes the treatment plan contraindicated, especially when forces are greater (as in the posterior region) (Figure 12-34). As a result, a three-adjacent-pontic prosthesis has an increased failure rate compared with a one- or two-pontic fixed prosthesis. The increased failure rate of long span fixed prostheses is due largely to the increase in biomechanical complications (e.g., unretained restorations and fracture). As a consequence, many authors have stated that three pontics in the posterior regions are contraindicated for natural teeth[18,26,28,29] (Figure 12-35).

The flexure of materials in a long span is more of a problem for implants than natural teeth.[32] Because natural roots have some mobility both apically and laterally, the tooth acts as a stress absorber, and the amount of material flexure may be reduced. Because an implant is more rigid than a tooth (and has a greater modulus of elasticity than a natural tooth), the risk for complications of increased load and material flexure are greater for an implant prosthesis. Because three posterior pontics are contraindicated in a natural tooth–fixed prosthesis, it is even more important not to have three pontics in an implant restoration[15] (Figure 12-36).

The span of the pontics in the ideal treatment plan should be limited to the size of two premolars, which is 13 to 16 mm.[15] When a molar is one of the teeth missing between existing teeth, the missing molar space alone may be 10 to 13 mm long. As a result, when a large second premolar and first molar are missing, this edentulous span is often treatment planned to replace three teeth, rather than two, and an additional implant is warranted in this span. This is especially appropriate for greater patient forces (i.e., moderate to severe parafunction) or softer bone types (i.e., D3 and D4). As a result of these guidelines, a maxillary edentulous arch missing 14 natural teeth may have as many as 18 potential implant sites if each molar is greater than 12 mm in width. Rarely are second molars replaced in the mandible; therefore, when 12 natural teeth are considered in a mandibular edentulous arch, 14 potential implant sites may be present.

To limit the effect of the complications of three adjacent premolar-size pontics, additional intraimplant key positions are indicated in prostheses missing five or more adjacent teeth. Therefore, when five to 14 missing adjacent teeth are to be replaced, key implant positions are located in the terminal abutments, and additional pier or intermediary abutments are indicated to limit the pontic spans to two premolar-size pontics. Following this rule, a five to seven premolar-size unit prosthesis has three key abutments (two terminal and one pier) (Figure 12-37).

An eight to 10 premolar-size unit prosthesis has four key implant positions (two terminal and two pier). An 11- to 13-unit prosthesis has five key abutments (two terminal and three pier), and a 14-unit prosthesis has six key abutment positions. In addition to these key abutments, additional abutments may be required to address patient force factors and bone density. Rarely is the force factor situation favorable and bone density ideal enough in a maxilla to be fulfilled with solely key abutments for a fixed prosthesis replacing more than five teeth.

Three-Pontic Options

Angled forces to the premaxilla magnify the amount of the force to the implant system in both centric and excursive occlusal forces. Therefore, most maxillary anterior prostheses should also limit the number of pontics in the restoration. The exception to the *no three-pontic rule* is most often the anterior

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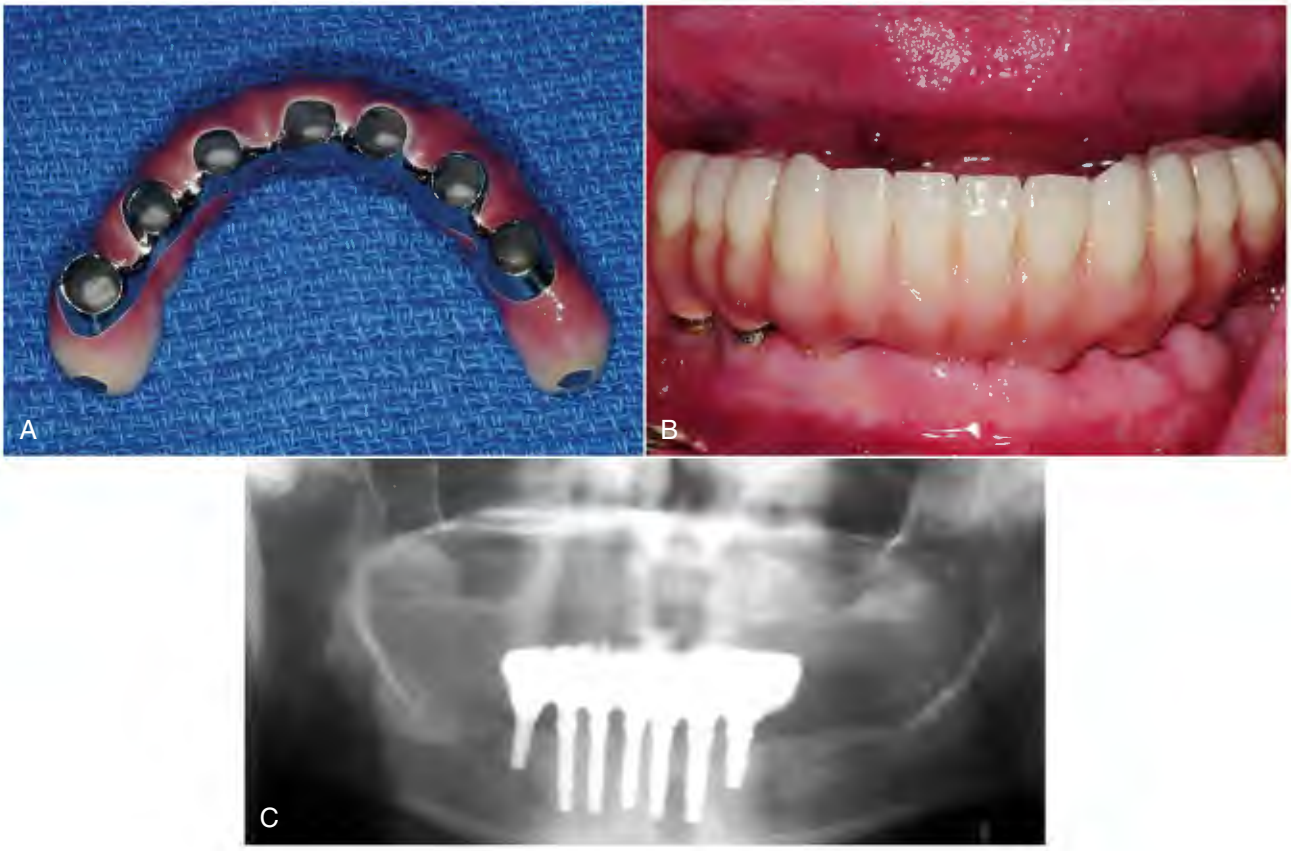


FIGURE 12-30. **A,** A tapering mandible with seven implants placed from mental foramen to mental foramen, with a limited posterior cantilever. **B,** The FP-3 fixed prosthesis in situ. **C,** A panoramic radiograph of the FP-3 prosthesis and implants in place.

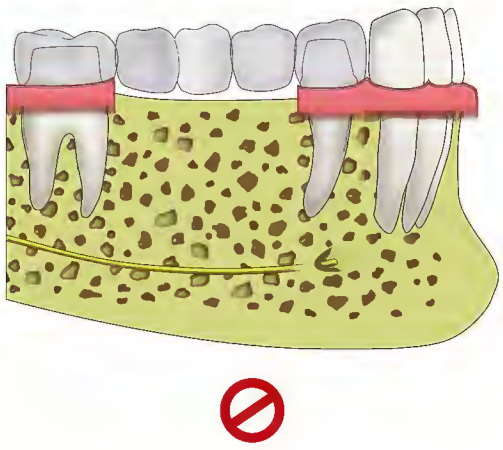


FIGURE 12-31. A posterior fixed prosthesis with three (or more) pontics is contraindicated with natural teeth abutments.

mandible, when the three adjacent missing teeth are mandibular incisors. As long as implants are placed in the canine position, the number of pontics may be increased because of the long axis angle of force, the reduced bite force, and the good bone quality. However, when the dentate arch position is tapered and the three anterior pontics are cantilevered to the facial, an additional implant is indicated even in the anterior mandible.

Canine Rule

In any arch, certain positions are more important sites than others. In the dental arch, these more important positions are represented by the canine and the first molar[33,34] (Figure 12-38). The canine root has more surface area in either arch compared with any other anterior tooth, and the molar has more root surface area than any posterior teeth[35] (Figure 12-39). The canine is a particularly interesting tooth. When a lateral force is placed on the natural canine and no posterior teeth are in contact, two thirds of the masseter and temporalis muscles do not contract, and the resultant force on the anterior teeth is less.[36] In addition, because the mandible acts as a class III lever, with the temporomandibular joint behind the muscles of mastication, the force applied to the anterior teeth is less when the posterior teeth do not occlude.[37] In other words, both biological and biomechanical factors make the canine position an important site in the dental arch.

A fixed restoration replacing a canine is at greater risk than nearly any other restoration in the mouth. The maxillary or mandibular adjacent incisor is one of the weakest teeth in the mouth, and the first premolar is often one of the weakest posterior teeth. As a consequence, when a canine is missing, a single tooth implant replacing the canine is the treatment of choice (Figure 12-40; Box 12-4).

When two adjacent teeth are missing and include a canine, two implants are required. Even when a canine and lateral incisor are in the esthetic zone, it is better to reduce the size of the implants and place two implants with no cantilever rather

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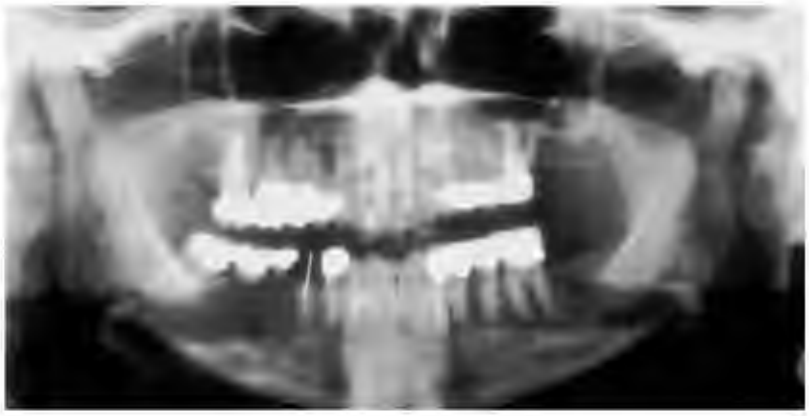


FIGURE 12-32. The most common cause of failure of a four-unit fixed partial denture on natural teeth is caries to an abutment. The second premolar is decayed as a consequence of the plaque reservoir found from the pontics of the restoration.

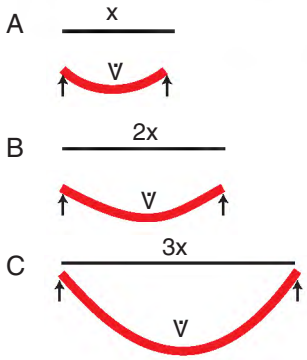


FIGURE 12-33. **A,** A one-pontic fixed partial denture (FPD) has minimal flexure of the metal. **B,** A two-pontic FPD flexes eight times more than one pontic span. **C,** A three-pontic FPD has 27 times more flexure than a one-pontic span.

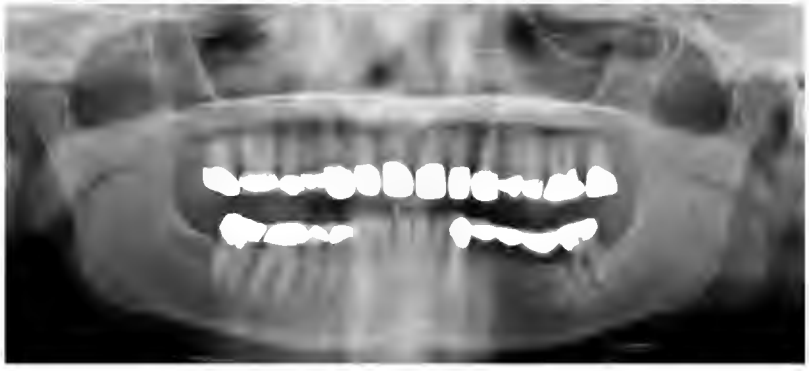


FIGURE 12-34. A panoramic radiograph with a five-unit fixed partial denture with three adjacent pontics. The cement seal on the molar separated, and the tooth decayed and has failed.



FIGURE 12-35. A panoramic radiograph of a six-unit fixed partial denture with three adjacent pontics. This is contraindicated because of biomechanical complications. The molar cement seal broke and the tooth has decayed and failed.

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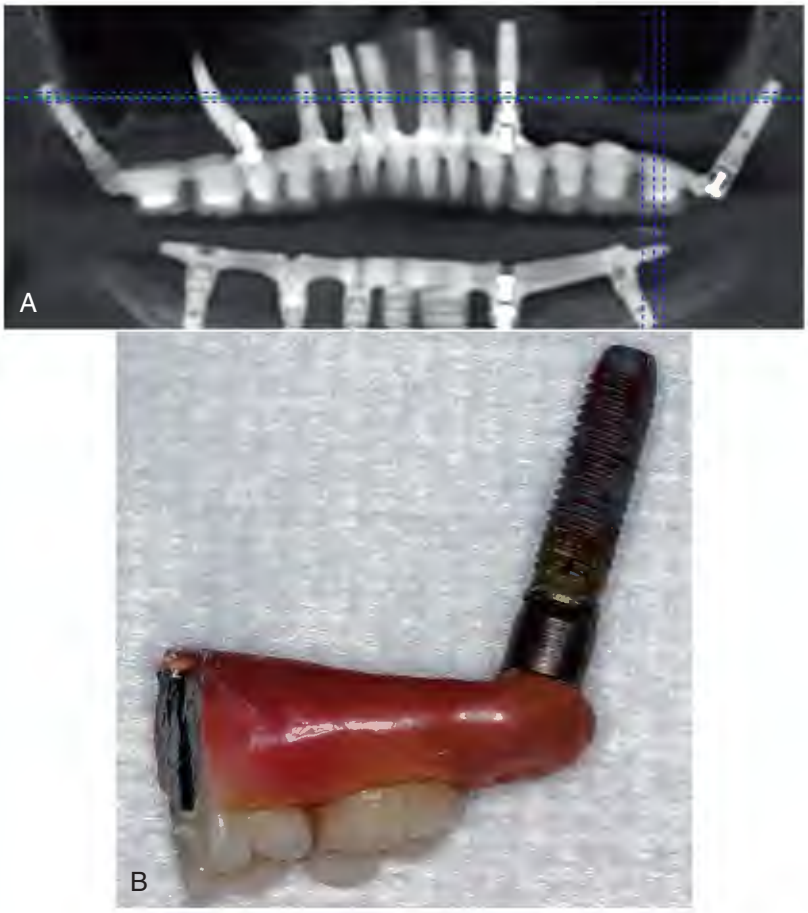


FIGURE 12-36. **A,** A panoramic radiograph with a maxillary and mandibular fixed prosthesis with three and four adjacent pontics. Bone loss is present on the most distal implants. **B,** The maxillary tuberosity implant was also mobile and failed.

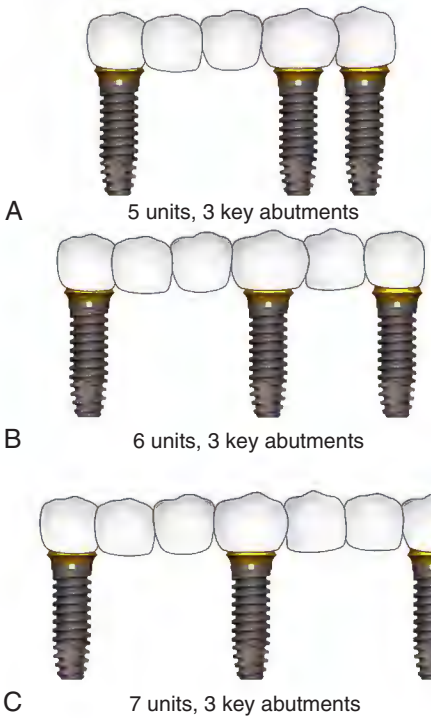


FIGURE 12-37. When five to seven adjacent teeth are missing, there are three key implant positions: the terminal abutments and another implant to limit the edentulous span to two teeth. Note additional implants are usually required, especially for six or seven missing teeth.



FIGURE 12-38. In a dental arch, the two most important biomechanical positions are represented by the canine and the first molars.

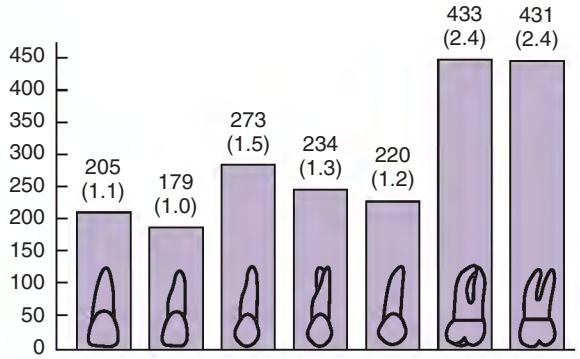


FIGURE 12-39. The canine has more root surface area than any anterior tooth and the first molar more area than any other posterior tooth.

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FIGURE 12-40. **A,** The lateral incisor is the weakest anterior tooth and the first premolar the weakest posterior tooth. They are poor abutments for a three-unit fixed partial denture option replacing a canine. **B,** A single tooth implant is the treatment of choice when a canine is missing.

BOX 12-4 Arch Position: Canine

- Most surface area of any anterior tooth
- Canine-guided excursion of the mandible reduces masticatory muscle contraction
- Canine and anterior teeth farthest from the temporal-mandibular joint (less force magnitude)
- Adjacent teeth are less ideal for additional force

than place a larger implant with a cantilever (see Figure 8-17). The implants should be at least 3 mm apart so the base of the interimplant papilla can support the soft tissue drape.

A traditional fixed prosthetic axiom on natural teeth indicates it is contraindicated to replace a canine and two or more adjacent teeth.[18,26,28] Therefore, if a patient desires a fixed prosthesis, implants are required whenever the following adjacent teeth are missing in either arch: (1) the first premolar, canine, and lateral incisor; (2) the second premolar, first premolar, and canine; and (3) the canine, lateral, and central incisors. Whenever these combinations of teeth are missing, implants are required to restore the patient because (1) the length of the span is three adjacent teeth, (2) the lateral direction of force during mandibular excursions increases the stress to the prosthesis, (3) the magnitude of the bite force is increased in the canine region compared with the anterior region, and (4) an implant in the canine region with implant-protected occlusion (mutually protected occlusion) distributes reduced lateral loads during mandibular excursions (Figure 12-41).

The canine is a particularly important position for the occlusal scheme of the patient.[32] Canine guidance or mutually protected occlusion is the primary occlusal format in most all fixed implant reconstructions or completely implant-supported removable restorations. The angled force of approximately 22 to 25 degrees in excursions should not be magnified on a canine pontic with an implant prosthesis supported by fewer implants.[38] Although the force reduction in excursions is not as great with an implant as with a natural canine tooth, there still is some force reduction as a consequence of the class III lever effect.[37,39] Therefore, whenever the canine and two or more adjacent teeth are missing, the canine is a critical site along with the terminal positions of the span (Figure 12-42).

When the three adjacent teeth are the first premolar, canine, and lateral incisors, the key implant positions are the first premolar, the canine, and the lateral incisor when the overall intratooth space is greater than 19 mm because three implants with no cantilever reduce any increased force factor risks. The minimum implant sizes are usually 3.5 mm for the premolar and canine and 3 mm for the lateral incisor.

When the first premolar, canine, and lateral incisor are missing and the intratooth span is less than 19 mm, only two implants are used to support the prosthesis. In this scenario, it is better to place terminal abutments and have a canine pontic, especially when the prosthesis is within the esthetic zone. The size of the implants is slightly increased to compensate for the angled forces during a lateral excursion. In addition, the amount of the incisal vertical overbite is reduced to decrease the leverage effect on the canine. The incisal guidance should be as shallow as possible to decrease the force during excursions. However, it must be steep enough to separate the posterior teeth in the mandibular excursions.

When there are multiple missing teeth on each side of the canine site, the canine edentulous site is a key pier abutment position'. The canine position is a key implant position to help disocclude the posterior teeth in mandibular excursions. As a result, when four or five adjacent teeth are missing, including a canine and at least one adjacent posterior premolar tooth, the key implant positions are the terminal abutments and the canine position. For example, when the first premolar, canine, lateral, and central incisor are missing, the key implant positions are the first premolar and central incisor (terminal abutments) and the canine (canine rule) (Figure 12-43).

When six or more adjacent teeth are missing, which include both canines, additional pier abutments (which limit the pontics' spans to no more than two teeth) are also indicated. For example, when the first premolar to first premolar are missing, five key implants are indicated, especially in the maxillary arch—the terminal abutments, the canines, and an additional implant in one of the central incisor positions (Figure 12-44). The same five key implant positions exist for the one-tooth span of second premolar to second premolar (Figure 12-45).

The canine position is also a key implant position in a full-arch prosthesis. In a three-dimensional finite element analysis, a comparison was made between full-arch fixed prostheses supported by four implants without a canine position and six implants including the canine position.[40] The six-implant model reduced its stresses between 7% to 29% when an implant was in the canine position dependant on the direction and position of applied load (Figure 12-46).

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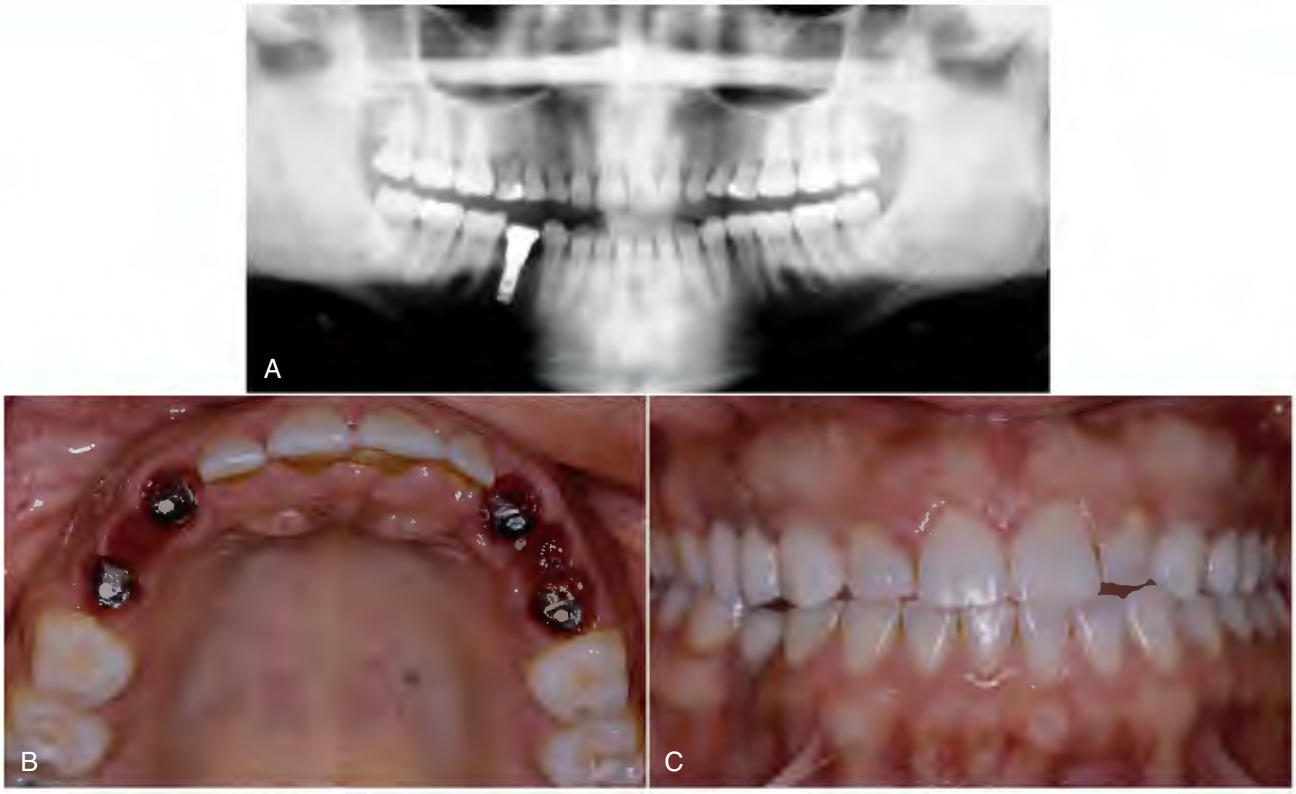


FIGURE 12-41. **A,** When the patient is missing a canine, a first premolar, and second premolar, it is contraindicated for a traditional tooth-supported fixed partial denture. This panoramic radiograph demonstrates the patient has these three permanent teeth missing on both sides of the arch. **B,** After the deciduous teeth were extracted, implants were inserted into the canine and second premolar position on each side. **C,** A bilateral three-unit fixed partial denture was cemented on the supporting implants.

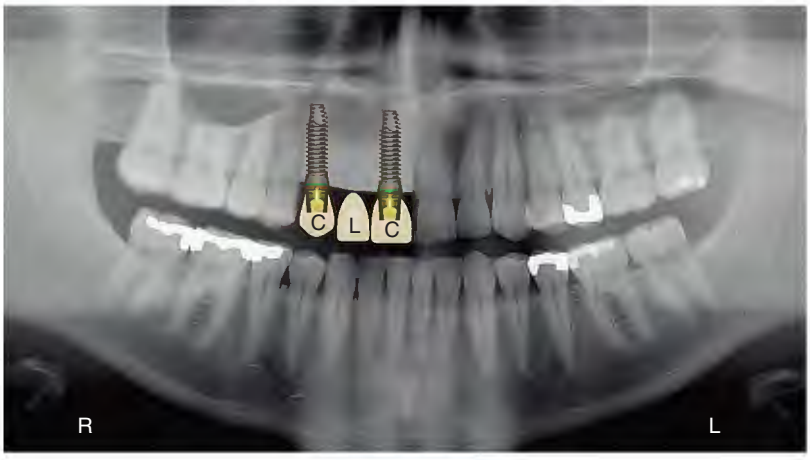


FIGURE 12-42. A panoramic radiograph of a patient missing a maxillary right canine, lateral incisor, and central incisor. The key implant positions are the canine and central incisor to support a three-unit fixed partial denture.

A Kennedy-Applegate class IV partial denture is often the least stable prosthesis of any arch condition. These patients have posterior teeth and are missing multiple anterior teeth, which crosses the midline. This type of partial denture acts as a lever, with the posterior teeth as fulcrums and the anterior removable prosthesis as a lever arm. When this prosthesis also replaces a canine, the restoration is even less stable. It rocks in all the mandibular excursions, especially during function (Figure 12-47). As a result, prosthetic guidelines indicate, whenever possible, a tissue bar or fixed prosthesis in the anterior region when restoring a class IV patient. When the restoration is also replacing missing posterior teeth (as the molars), the condition is even worse (because it rocks back and forth) and is often less stable than a denture.

The conditions for a class IV partial denture are made even worse when implants support the partial denture because the implants are more rigid. An implant overdenture is similar to a removable partial denture. When the anterior region (including canines) does not have implant support, the overdenture attachments loosen and routinely break (Figure 12-48). As a result, the restoring dentist attempts to make a rigid attachment system for the overdenture. However, when the prosthesis does not

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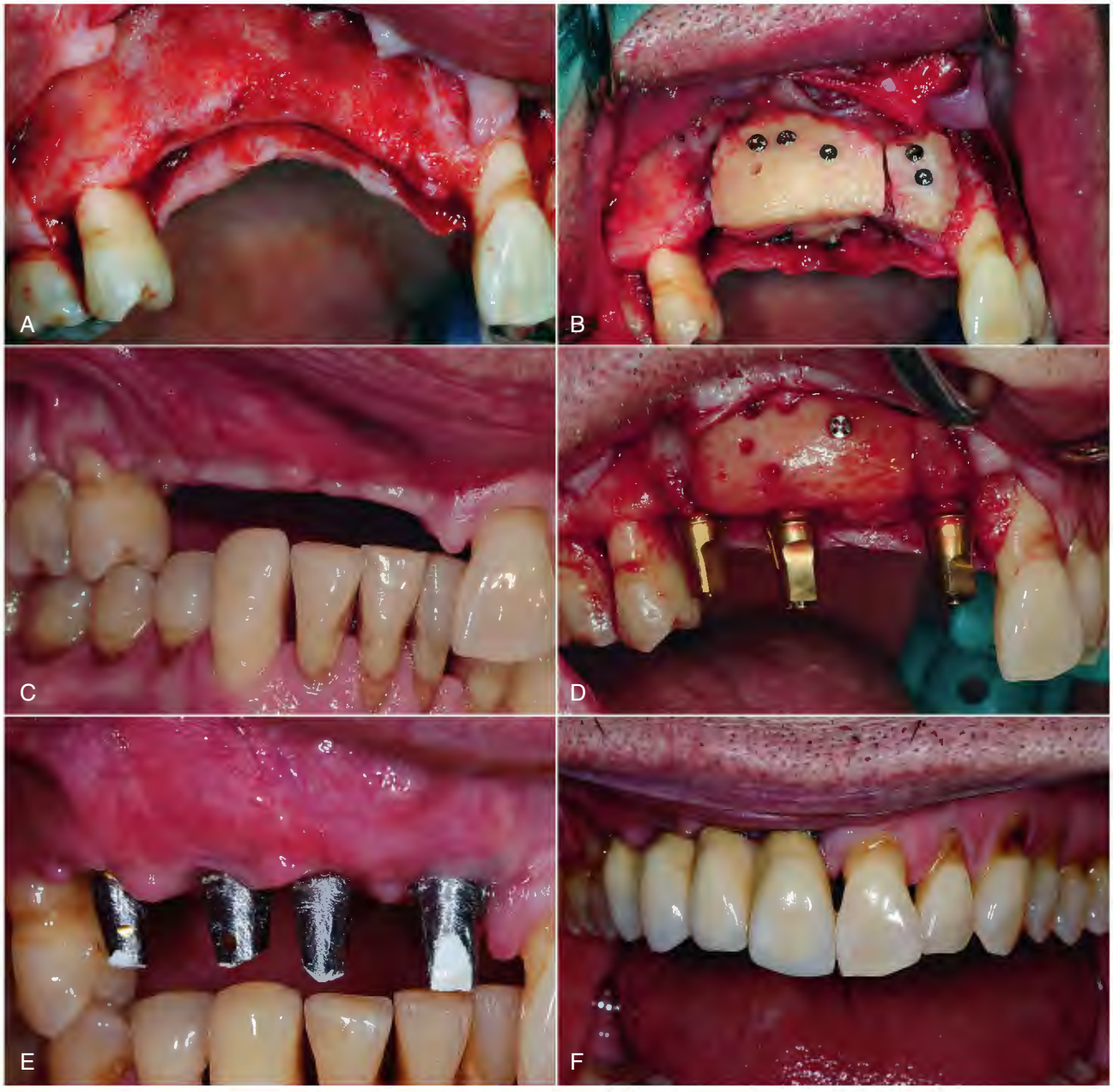


FIGURE 12-43. **A,** The patient is missing a maxillary central incisor, lateral incisor, canine, and first premolar. There is inadequate bone volume in the canine position. **B,** A block bone graft is positioned primary in the canine region. **C,** The block bone graft matures for 6 months. **D,** The key implant positions are the central incisor, canine, and first premolar. **E,** An additional implant was positioned in the lateral incisor region. (The patient is a man with deep vertical overbite.) **F,** A four-unit fixed partial denture was cemented in place.

move during function, it is a fixed prosthesis. It therefore needs as many implants and key positions as a nonremovable fixed restoration (Figure 12-49).

Because sinus bone grafting is very predictable, some treatment plan options for completely edentulous patients have used sinus grafts and molar implant placement for maxillary overdentures without implants in the anterior region. The consequence of this treatment when the canine positions are not used for support include overdenture complications, marginal bone loss around the implants, and implant failure (Figure 12-50). An implant in the canine position is a key position even for a maxillary overdenture.

First Molar Rule

The molars have the most root surface area of any natural tooth in the mouth and have two or three roots (see Figure 12-38). The biomechanical rationale for this condition is that the bite force doubles in the molar position compared with the premolar position in both the maxilla and mandible. In addition, the edentulous span of a missing first molar is usually 10 to 12 mm compared with a 7-mm span for a premolar. As a result, the first molar is also a key implant position.[15,33,34]

As previously presented, cantilevers should not be used in partially edentulous patients to replace a first molar, especially

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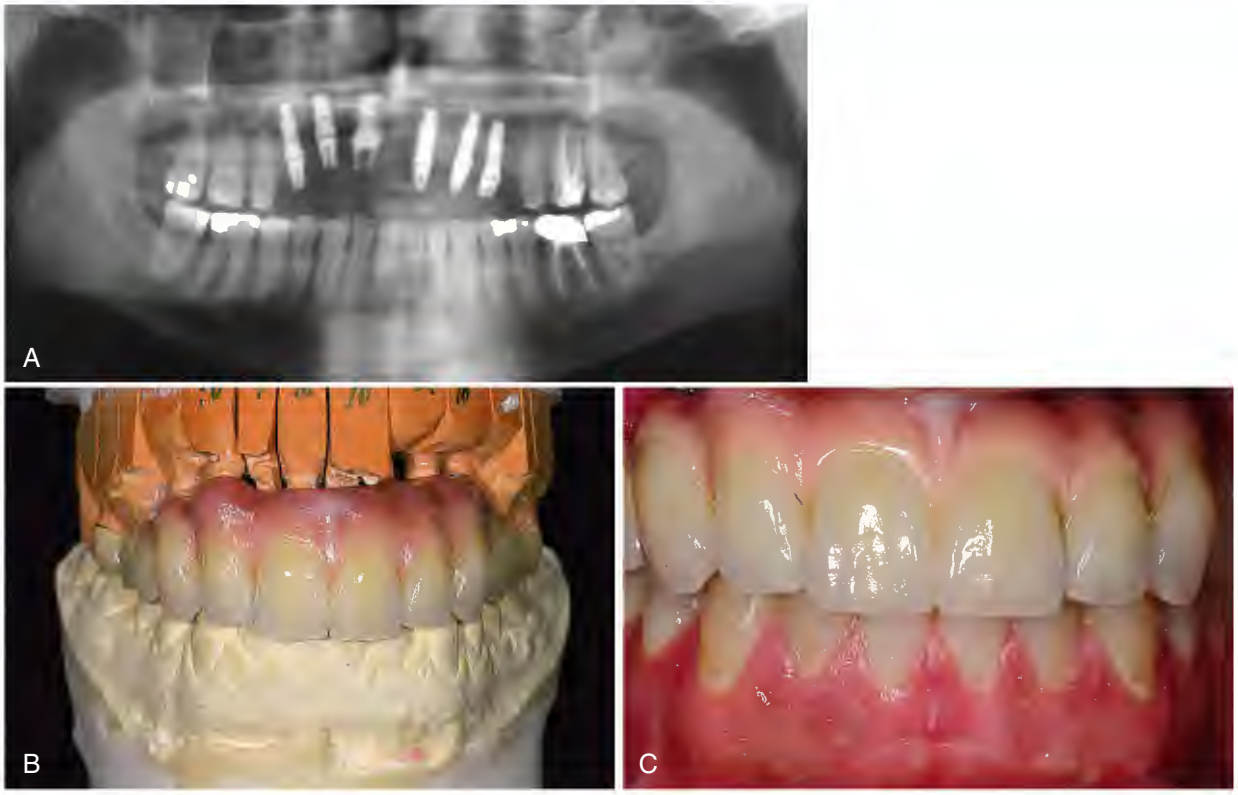


FIGURE 12-44. **A,** A panoramic radiograph of a patient missing eight anterior teeth—the premolar to first premolar. Six implants are inserted: the five key implants plus an additional one because of the large crown height space. **B,** A FP-3 fixed prosthesis was fabricated. **C,** The fixed eight-unit implant prosthesis in situ.



FIGURE 12-45. A panoramic radiograph of 10 anterior teeth missing. There are five key implants positions for this fixed prosthesis: the second premolars, the canines, and an anterior implant to limit the pontics to no more than two.

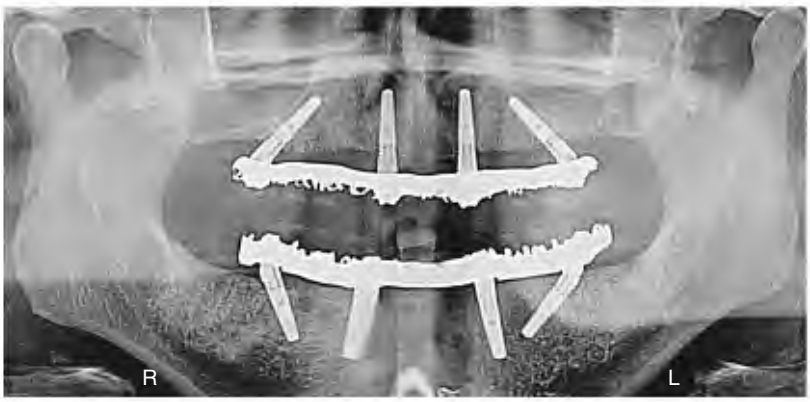


FIGURE 12-46. A panoramic radiograph of a fixed maxillary implant prosthesis with only four implants. There are four adjacent pontics, which include a canine. This is contraindicated for natural teeth (because of the length of the span and because of the missing canine). At least two additional implants are indicated (in the canine regions) to decrease the biomechanical stress to the prosthesis.

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FIGURE 12-47. A Kenney-Applegate class IV partial denture (missing teeth span which crosses the midline) is one of the most unstable prosthetic devices. It rocks on the posterior teeth, which act as fulcrums.



FIGURE 12-49. Maxillary overdentures that do not replace the canines are unstable during function. The restoring dentist fabricated two independent bars and rigid attachments (to reduce the anterior rocking). This patient constantly complained of attachment loosening and the need for replacement.

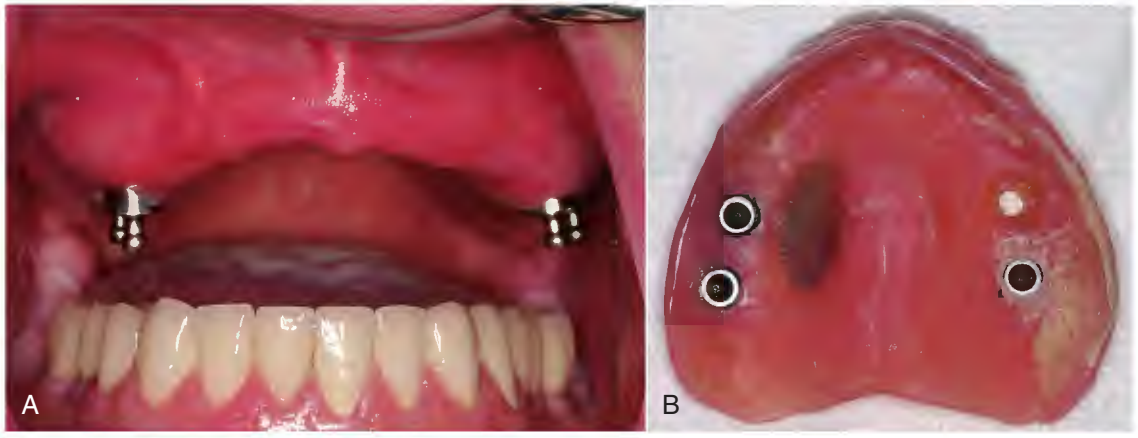


FIGURE 12-48. **A,** A maxillary overdenture with posterior implants; the patient is missing 10 anterior teeth. **B,** The overdenture rocks and is completely unstable. The attachments become loose and frequently fracture.

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when patient force factors are moderate to great (e.g., parafunction, opposing arch). The cantilever further increases the force of the molar region to the splinted abutments. As a result, uncemented restorations, bone loss, and failure are at greater risk (Figures 12-51 and 12-52).

When a first molar is missing, a 5- to 6-mm-diameter implant is indicated in the mid mesiodistal position of the edentulous site when the molar is less than 12 mm wide (Figure 12-53). When a first molar implant is indicated in the maxilla, a sinus bone graft is most always required. The maxillary sinus expands rapidly after tooth loss. Hence, more often than not, the sinus floor should be altered and grafted in conjunction with a first molar implant insertion (Figure 12-54).

When two adjacent teeth are missing, including a first molar, the key implant positions include the terminal abutments, including the distal molar position (see Figure 12-20). When three posterior teeth are missing and include a first molar, a first molar implant is included. For example, in a patient missing the second premolar, first molar, and second molar, three key implant positions are required to restore the full contour of the missing molars teeth: the second premolar and second molar terminal abutments and the first molar pier abutment (Figure 12-55). A similar scenario is present when all four posterior teeth are missing—first premolar, second premolar, first molar, and second molar. The key implant positions are the terminal abutments (first premolar and second molar) and the first molar (Figure 12-56). In the maxilla, a sinus graft is most always indicated to replace these four adjacent teeth (Figure 12-57). When one implant replaces a molar (with a span of 10–13 mm), the implant should be at least 5 mm in diameter. When a smaller-diameter implant is selected in a molar space of 14 mm or more, the molar may be considered the size of two premolars, and two smaller-diameter implants may be selected.[40,41]

It should be noted that when implants are inserted into existing bone volumes of the maxilla with a normal to large maxillary sinus, the third or fourth molar site (a tuberosity or pterygoid implant) and first (or second) premolar site are suggested in the literature, with pontics in the second premolar, first molar, and second molar site to avoid a sinus graft (Figure 12-58). This is not a biomechanically sound treatment option because of three adjacent pontics and no implant in the first molar position. One should wonder why so many dentists

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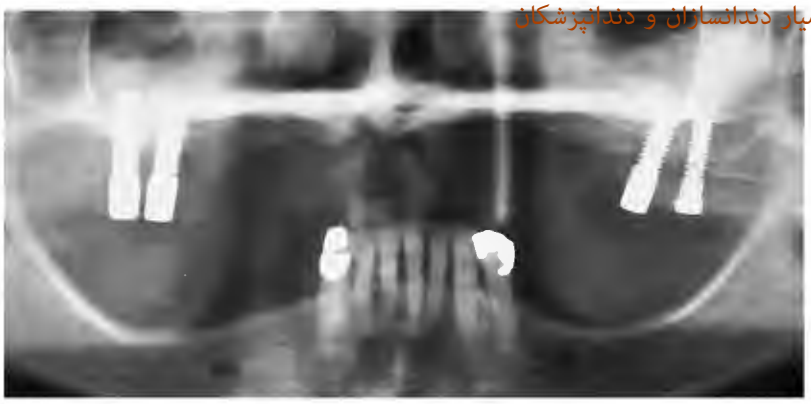


FIGURE 12-50. Bilateral sinus grafts permit posterior implants to be inserted to support a maxillary overdenture. This prosthesis was less stable during function than a maxillary denture.





FIGURE 12-51. **A,** A distal cantilever from two premolar implants was used to replace a first molar. **B,** The cement seal broke, and the distal implant lost bone.





FIGURE 12-52. **A,** A periapical radiograph demonstrating two premolar implants used to support a distal cantilevered fixed partial denture (FPD) replacing a molar. **B,** The FPD became uncemented from the first premolar implant, and as a result, the second premolar implant fractured.

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suggest third molar extractions, yet some implant dentists place third or fourth molar site implants. Why don't these dentists orthodontically move the third molar tooth to the fourth molar site and fabricate a three-unit FPD if they desire a fourth molar abutment?

Four to six implants in the anterior maxilla have been suggested in the complete edentulous maxilla, with posterior cantilevers (Figure 12-59). Full-arch restorations for the edentulous maxillary arch should also have a first molar implant. In general, density of bone in the maxilla is less than the mandible in both the anterior and posterior regions. The anterior maxillary implants receive an angled load (compared with the anterior mandible) in both centric and mandibular excursions. The anterior maxillary arch usually has shorter implants than the anterior mandible because the vertical height of bone is less compared with the anterior mandible. The shorter implants have less surface area and higher stresses, especially in soft bone. Maxillary fixed restorations most often oppose an implant prosthesis (usually fixed) or natural teeth. This increases the force to the maxillary prosthesis. Therefore, the biomechanical risks associated with full-arch maxillary prostheses with a molar cantilever are greater than for mandibular restorations. A literature review of full-arch prostheses reports a three times higher implant failure rate in full-arch maxillary implant fixed restorations compared with mandibular full-arch implant restorations.[4] Therefore, the treatment plan should be different for the two arches.



FIGURE 12-53. A 5- to 6-mm-diameter implant in the mid mesiodistal position is indicated to replace a first molar when it is less than 12 mm in width.

The key implant positions for an edentulous maxilla are the distal of the first molars bilaterally, the bilateral canines, and an implant in one of the central incisor positions between the canines. This permits the five sections of an arch to be splinted together and take advantage of the biomechanics of an arch (Figure 12-60).

Implant Number

In the past, the number of implants most often was determined in relation to the amount of available bone. This concept became popular in the mid 1980s when the Brånemark philosophy of osseointegrations was introduced for completely edentulous arches. In an edentulous arch, four to six anterior implants were used in available bone situations between the mental foramina in the mandible and anterior to the maxillary sinuses in the maxilla for a full-arch fixed prosthesis. The prosthesis cantilevered the molars from the anterior implant positions. Four implants were used in moderate to severe atrophic ridges for a fixed full-arch prosthesis.[2] This concept has been expanded to include zygomatic implants in the posterior regions, which engage the palate and the apical 4 mm of the zygomatic process (passing through the maxillary sinuses) (Figure 12-61). This treatment option does not consider the force magnifiers of CHS or the A-P distance (A-P spread) of the implants in relationship to the anterior cantilever replacing the anterior teeth. In addition, when four implants support a 12-unit fixed prosthesis, the position of the implants cannot follow the four key implant position rules and often have no implants in the canine positions and more than three pontics between the anterior implants or three pontics cantilevered from the most distal implants.

In full-arch prostheses, studies comparing six implants to four- and three-implant abutments show better distribution and reduced stress on the six-implant system components (crown, cement, abutment, abutment screw, marginal bone, implant–bone interface, and implant components)[42] (Figure 12-62). Silva et al.[40] evaluated with three-dimensional finite element analyses the difference in four versus six implants to support a full-arch cantilevered prosthesis.The cantilever length and crown height were similar in both models. The six-implant support model reduced the stress to the implant–bone regions between 7% to 29%, depending on the direction and position of the applied load.

On occasion, four implants in the mandible between the foramen may be used to support a full-arch implant-supported prosthesis—fixed or RP-4. The implants are typically positioned

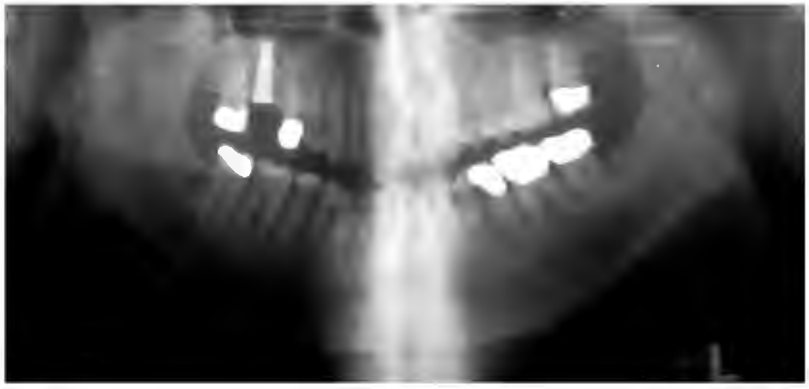


FIGURE 12-54. A sinus graft is most often required to place a first molar implant.

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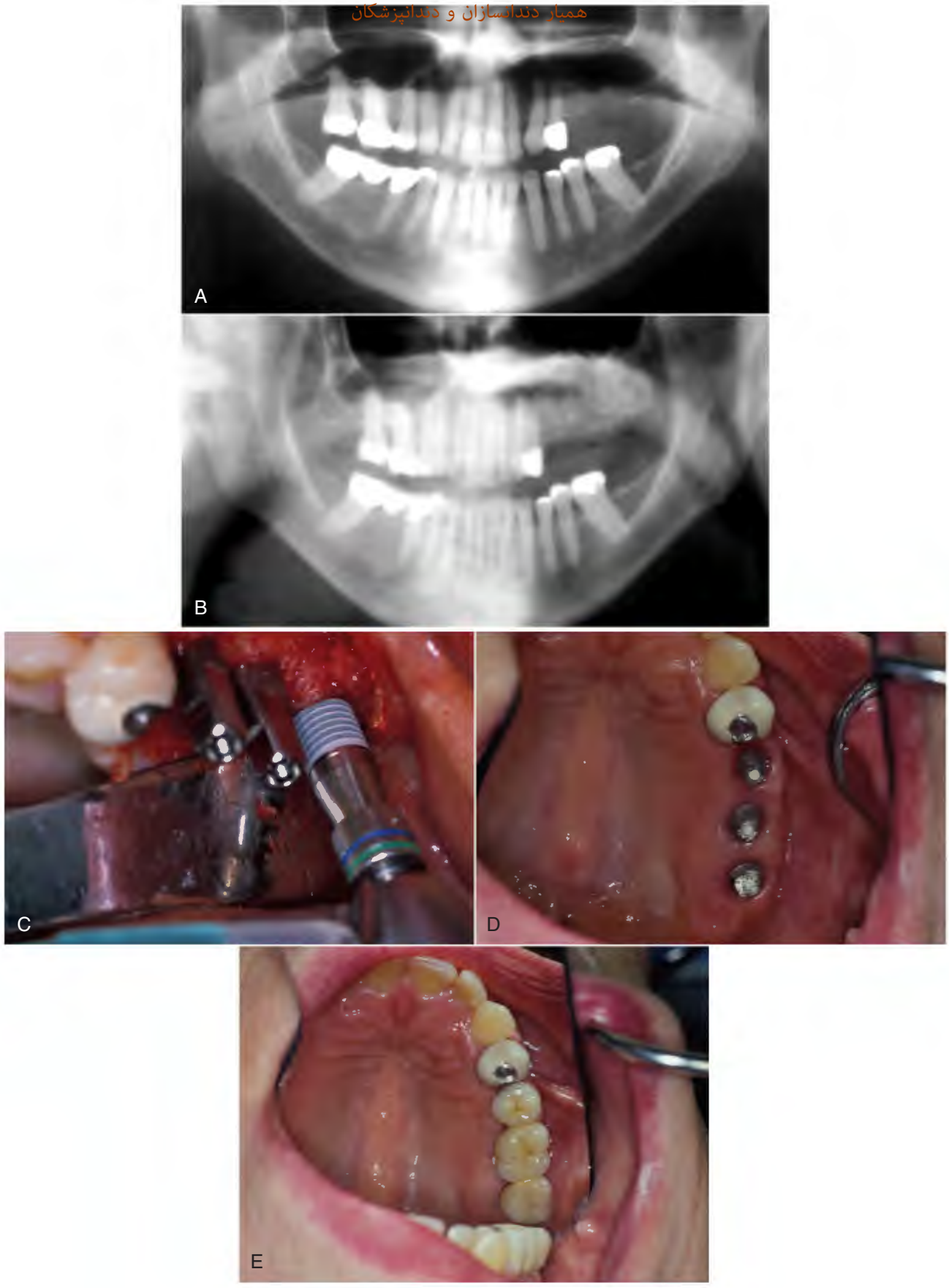


FIGURE 12-55. **A,** A panoramic radiograph of a patient missing the second premolar, first molar, and second molar. There is inadequate bone height because of the pneumatization of the maxillary sinus. **B,** A sinus graft restores the bone height to favorable limits. **C,** Three implants are inserted; the second premolar and the second terminal implants and a first molar implant. **D,** The three implants after integration. **E,** A three-unit fixed partial denture supported by three implants. Only the mesial half of the second molar is restored because there is no opposing mandibular second molar.

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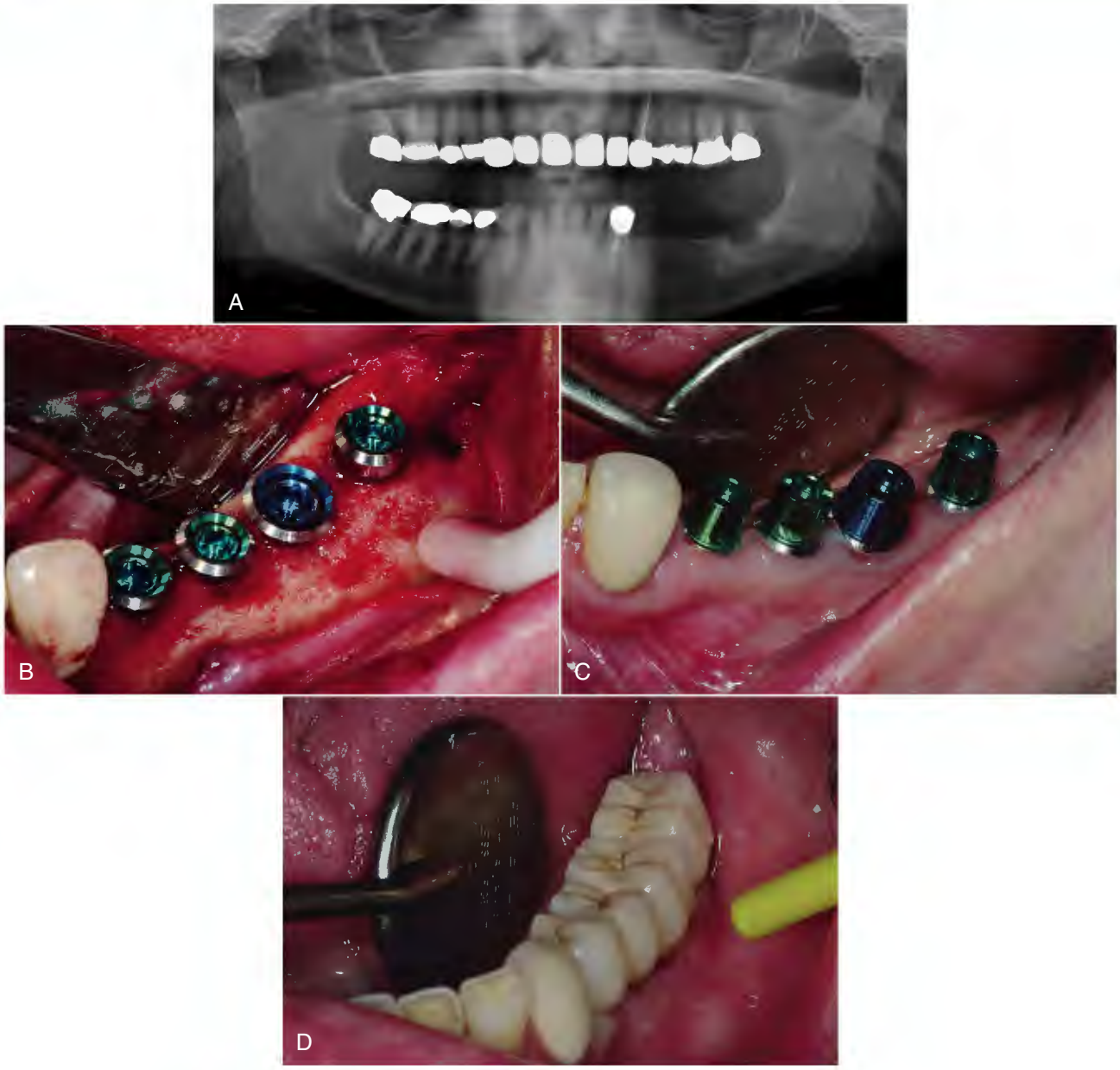


FIGURE 12-56. **A,** A panoramic radiograph of a patient missing mandibular first premolar to second molar. **B,** Four implants were used to restore the missing teeth. **C,** The key implant abutments are the first premolar and second molar (no cantilever) and the first molar. **D,** The four-unit fixed partial denture restores the missing teeth.

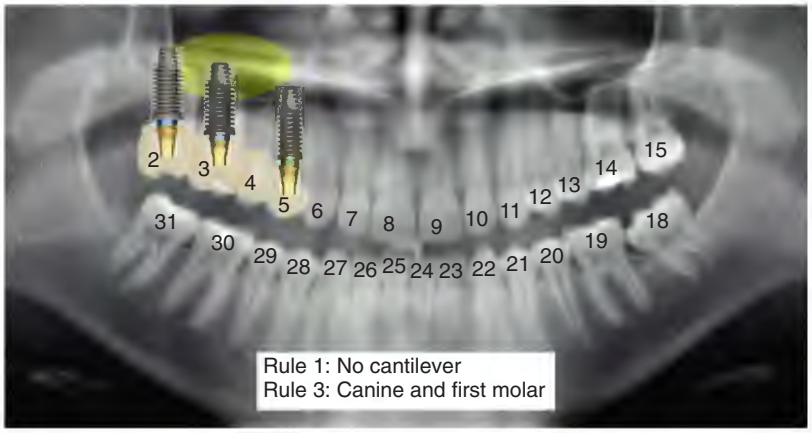


FIGURE 12-57. A panoramic radiograph replacing the first premolar to second molar. A sinus graft is most always required to place the molar implants.

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FIGURE 12-58. A tuberosity or pterygoid implant behind the maxillary sinus and an angled implant anterior to the sinus is suggested in the literature to support a fixed prosthesis without a sinus graft.

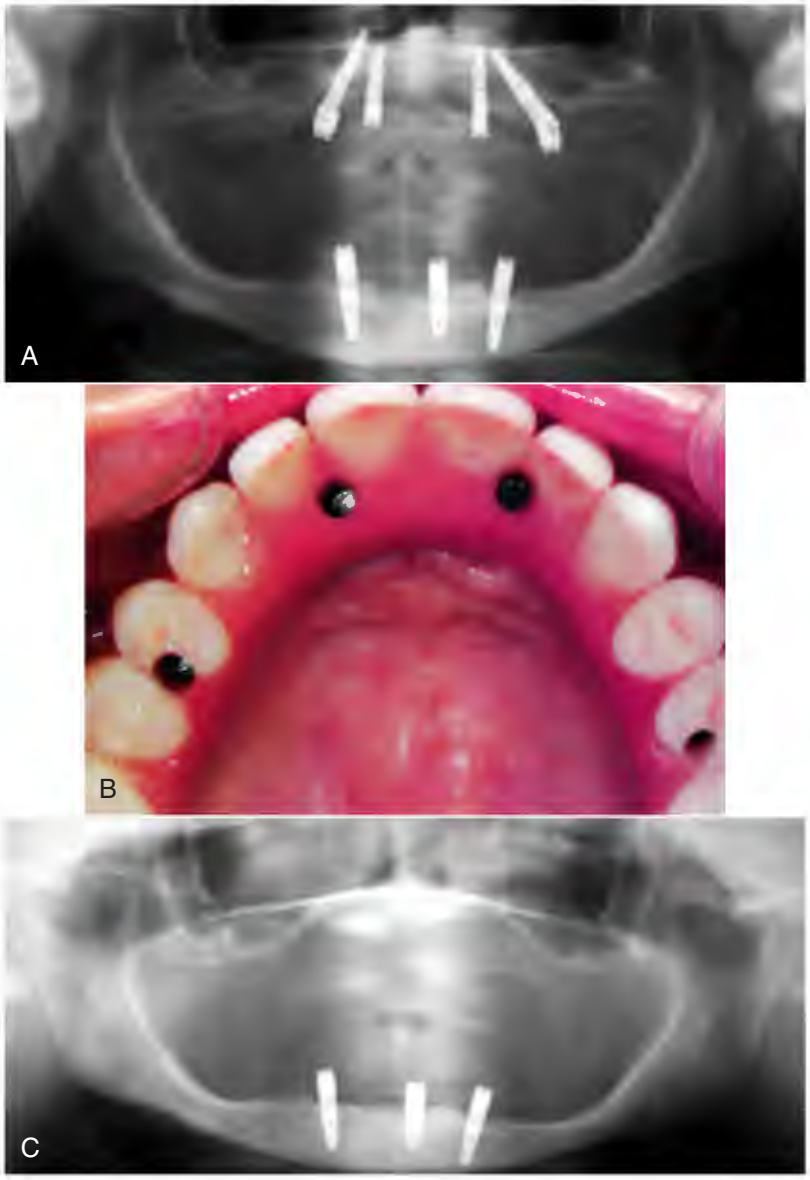


FIGURE 12-59. **A,** Four implants in an edentulous maxilla are suggested in the literature to support a fixed prosthesis. **B,** The fixed prosthesis supported by four anterior implants most often cantilevers the molars. In addition, there is also an offset cantilever to the facial in both the anterior and posterior regions. **C,** The failure rate of the maxillary implants usually causes additional bone loss. The maxilla may be unable to be restored without advanced bone grafts, more implants, and a new prosthesis.

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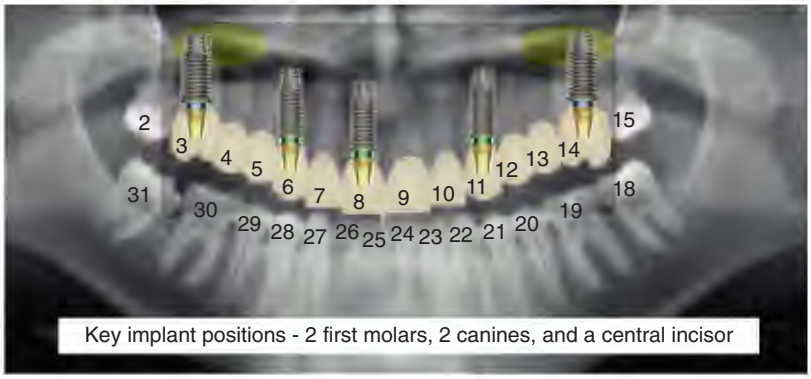


FIGURE 12-60. The key implant positions for an edentulous maxilla to support a fixed prosthesis (or RP-4 prosthesis) are the bilateral molars, the bilateral canines, and an implant in one of the central incisor positions.





FIGURE 12-61. **A,** A panoramic radiograph of four zygomatic implants supporting a fixed prosthesis in the maxilla. **B,** The full-arch maxillary prosthesis is cantilevered to the facial, and there are six adjacent pontics in the anterior region, including a canine position.

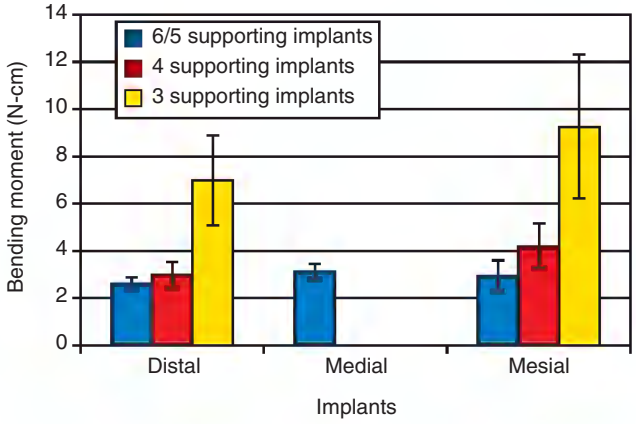


FIGURE 12-62. The more implants supporting a fixed prosthesis, the lower the bending movement and stress in the support system.[42]

in the first to second premolar positions and the canines. However, the other patient force factors should be low (e.g., no moderate to severe parafunction, crown height space less than 15 mm, older woman, and opposing a maxillary complete denture). In addition, the bone density should be favorable (D2). When all of these conditions are not present, consideration is given to the five key implant positions, and more implants are indicated when stress factors are moderate to severe.

When a full-arch fixed implant restoration is the treatment for a maxillary arch, the suggested number of implants by some authors is often the same as the mandible.[2] For example, "all on four" is a common treatment option presented to the profession in either arch along with similar fees for either arch to the patient[43] (Figure 12-63). Yet a literature review reveals the failure rate of the full-arch maxillary restoration is three times greater than the mandible.[4] The hardness of the bone is related to its

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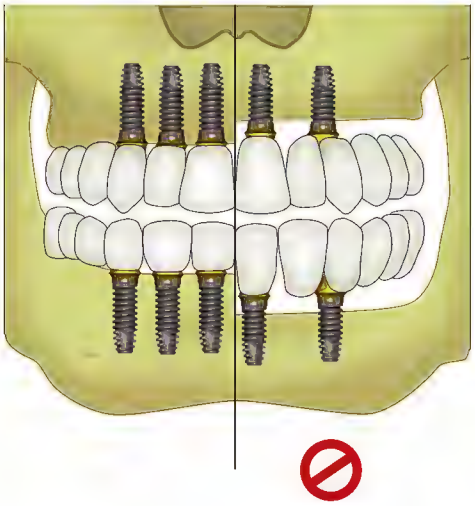


FIGURE 12-63. Full-arch implant fixed restoration by many authors uses the same number of implants in the maxilla and mandible. However, three times greater failure rates are observed in the maxillary arch.

TABLE 12-1
Implants versus Prosthesis Success: Four Implants per Prosthesis for 25 Patients (100 Implants for 25 Prostheses)

Implant Number Success Rate	Prosthesis Number	Prosthesis Success Rate
100%	25	100%
90%	15	60%
80%	5	20%
75%	0	0%

TABLE 12-2
Implants versus Prosthesis Success: Eight Implants per Prosthesis for 25 Patients (200 Implants for 25 Prostheses)

Implant Number Success Rate	Prosthesis Number	Success Rate
100%	25	100%
87.5%	25	100%
75%	25	100%

strength. The mandible more often has hard (strong) bone, and the maxilla more often has softer bone. In fact, the posterior maxillary bone may be five to 10 times weaker than the hard bone of the anterior mandible.[44] As a result, more implants should be used in the poorer-quality bone found in the maxilla. Increasing the implant number decreases the periimplant bone stress.[45]

The maxillary anterior arch receives a force at a 12- to 15-degree angle during occlusion and up to a 30-degree angle in excursions. A 15-degree angled force increases the force component on the implant by 25.9%, and a 30-degree force increases the force by 50%.[39] This is a biomechanical rationale for why maxillary anterior teeth are larger in size than the mandibular anterior teeth. Hence, the size or number of implants in the anterior maxilla should be greater than an anterior mandible.

The excursive forces in a maxillary restoration come from within the arch to push outside the arch. This force direction on the maxillary arch is more detrimental than in the mandible.[46] The mandible receives a force from outside of the arch toward the inside of the arch, which is the mechanism of force the Roman or gothic arch was designed to resist. As a result of these biomechanical issues, more implants should be used in maxillary compared with mandibular restorations. It is probably not a coincidence that there are more roots for the teeth in the maxillary arch compared with those in the mandibular arch.

The minimum number of implants used to support a restoration should include all of the key implant positions. Yet the number of implants in a treatment plan should rarely use a minimum number. There is no safety factor if an implant fails, the prosthesis becomes partially unretained, or the patient has a parafunctional episode. For example, if 25 patients receive four implants to support a fixed prosthesis, there would be 25 fixed prostheses and 100 implants in the report. This type of treatment planning may initially be less expensive for the patient, but an implant failure any time after implant surgery places the patient's restoration at considerable risk. If each patient lost one implant with this implant number per prosthesis, the overall implant success would be 75%, but there would only remain three implants in each patient. As a result, all 25 fixed prostheses would be at risk of overload failure. If 20% of the implants fail (with one failure per patient), only five of the 25 patients would have four implants to support the restoration (only 20% of the patients would be restored with a fixed prosthesis)[45] (Table 12-1).

If the 25 edentulous patients in this example have eight implants to support a full-arch, 12-unit fixed prosthesis, the risks of prosthesis failure is significantly reduced (Table 12-2). If each patient loses one implant, most likely all patients would still be able to function with their original prosthesis. Even if all 25 patients lost two implants, the 25 restorations may still function without risk (depending on the implant failure location). The additional implants also reduce the cantilever length and reduce the number of pontics in the prosthesis, providing more abutments for greater retention of the restoration, with reduced risk of screw loosening or uncemented prosthesis. As a general rule, it is better to err on the side of safety in numbers than on the side of too few implants. Therefore, when in doubt, add an additional implant to the treatment plan.

Previous studies have shown that three abutments for a five-tooth span distribute stress more favorably than two abutments for the same span.[47] The one additional implant may decrease the implant reaction force by two times and reduce metal flexure fivefold. In addition, in the three-abutment scenario, moment forces are reduced. Comparative evaluations of implant number and size have also been made for stress distribution for three-unit fixed prostheses.[48] Increasing the implant number decreased the force to the implant–bone stimulant, more than increasing the implant size.

The cost of the implant surgery and prosthesis should not be solely linked to the number of implants. When the risks are reduced, the treatment fee should be less than when the risks are greater. Therefore, the four-implant option for a full-arch prosthesis should often have a greater fee than the eight-implant option.

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Influence of Patient Force Factors

The additional number of implants, after the key implant sites are established, are related to the patient force factors and the bone density.[16,33,34,45] Five patient force factors determine the amount of stress transmitted to the prosthesis. They are:

1. Parafunction
   a. Bruxism (severe, moderate, mild, absent; this is the most important stress factor)
   b. Clenching (force magnitude may be as great as bruxism)
2. Masticatory muscle dynamics
   a. Sex (men have greater force)
   b. Age (younger patients have greater force and live longer)
   c. Size (larger patients have greater force)
3. Crown height space
   a. Double the crown height and double the force with any angled load or cantilever (mesial, distal, facial, or lingual)
4. Arch position
   a. Anterior regions: low forces
   b. Canine and premolar: medium forces
   c. Posterior regions: high forces
5. Opposing dentition
   a. Denture: lowest force
   b. Natural teeth: intermediate force
   c. Implant fixed prosthesis: higher forces

Not all patient force factors have the same risk. Each of these five patient force factors may have a scale of 1 to 10 (Box 12-5). When the values are added together for a particular patient, an additional implant is added to the key implant positions for every 10 units. For example, a severe bruxer (10 units) with severe masticatory dynamics (7 units) in a posterior mandible (5 units) and opposing natural teeth (2 units) should have two to three more implants than the basic key positions. Implant size may also be increased to decrease the risk factors. Hence, two implants of larger diameter or three regular-diameter implants would satisfy most situations.

When four or more adjacent teeth are missing, the key implant positions are often not enough support for the implant restoration unless all patient force factors are all low (e.g., parafunction, masticatory dynamics, CHS, opposing dentition and the missing teeth are only in the anterior and premolar regions of the jaw). Therefore, when multiple adjacent teeth are missing most often additional implants (besides the key implants) are added to the treatment plan, especially in the maxilla (Figure 12-64).

In conclusion, whenever the patient force factors are greater than usual, additional implants should be added to support the prosthesis. Of the patient force factors, severe bruxism is the most significant followed by clenching and CHS, region of the mouth, masticatory dynamics, and the opposing arch.

BOX 12-5 Force Factor Risks: 10-Point Scale

1. Parafunction	
A. Bruxism	
1. Severe	10
2. Moderate	7
3. Mild	4
B. Clenching	
1. Severe	9
2. Moderate	5
3. Mild	3
2. Crown height space	
A. Excessive	7
3. Masticatory dynamics	
A. Severe (male, large, young)	7
B. Mild	3
4. Arch position	
A. Maxilla	
1. Posterior	5
2. Anterior	3
B. Mandible	
1. Posterior	5
2. Anterior	0
5. Opposing arch	
A. Complete implants	4
B. Natural teeth	2

Influence of Bone Density

The additional number of implants after the key implant sites are established is also related to the density of bone.[49] The softest bone type (D4) has (1) the lowest strength and may be 10 times weaker than the most strong bone type on a scale of 1 to 10 for bone strength (D4 bone is a 1 or 2; (2) the greatest biomechanical mismatch with its modulus of elasticity compared with titanium; (3) the lowest bone–implant contact (~25%) and therefore higher stresses (Stress = Force/Area); and (4) strains in the bone are transmitted not only at the crest but also along the entire bone–implant surface.

The soft bone type (D3) has (1) a low bone strength, which is 50% weaker than hard bone (D2) (on a 10-point scale, its strength is a 3 to 4); (2) intermediate difference of modulus of elasticity compared with titanium; (3) low bone–implant contact (~50%); and (4) strain patterns at the crestal half of the implant.

The hard bone (D2) has (1) ideal strength (a 7 to 8 on a 10-point scale), (2) high bone–implant contact (~75%), (3) more stiff modulus of elasticity, and (4) strain patterns primarily at the crestal region of the implant. The hardest bone (D1) has the best biomechanical features of (1) strength (9 to 10 on a 10-point scale), (2) highest bone–implant contact (above 85%), (3) stiffest modulus of elasticity, and (4) strain values above the first thread.



FIGURE 12-64. In an edentulous maxilla, the most common additional implant site is in the second premolar region. Hence, seven implants (or more) are most often used to support a fixed (or RP-4) prosthesis.

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As the bone quality is reduced, the number of implants to support the prosthesis should increase. The risk factor scale for bone density is inversely related to the strength of the bone scale. Hence, D4 bone is a 10, D3 bone is an 8, D2 bone is a 4, and D1 bone is a 2. When the implants are inserted into D4 bone, a larger-diameter or another implant is suggested, depending on the number of teeth replaced. Hence, a full-arch fixed restoration in the mandible with D2 bone may often have five implants, but in D4 bone, nine implants may be appropriate. Therefore, the total number of implants is related to the key implant positions plus the influence of the patient force factors and the quality of bone.

One of the most efficient methods to increase surface area and decrease stress is to increase the implant number.[16] For example, when four adjacent teeth are missing from canine to first molar, the two implant key positions as terminal abutments for a four-unit implant prosthesis in the canine and first molar site represent inadequate implant support unless patient force factors are low, bone density is ideal, and implant size is not compromised. In most situations, three implants to replace four missing teeth is a more ideal implant number. When force factors are high and bone density is poor (i.e., posterior maxilla), four implants to replace four teeth is often appropriate.

In conclusion, the decision for the number of implants in the treatment plan begins with the implants in the ideal key positions. Additional numbers are most often required and are primarily related to the patient force factors or to bone density in the edentulous sites. For example, a young, large man who bruxes severely with greater than normal CHS in the posterior regions of the mouth opposing an implant restoration will require one implant for each missing root (two implants for each molar). Likewise, patients with moderate force factors and poor bone density (D4 bone) in the implant sites may also require this many implants.

Maximum Implant Number

In most situations, an implant should be positioned at least 1.5 mm from an adjacent natural tooth and 3 mm from an adjacent implant.[21,22] Using these guidelines, each 4-mm diameter implant requires 7 mm of mesiodistal space (see Figure 12-7). Therefore, the maximum number of implants between adjacent teeth can be calculated by taking the crest module of an implant (e.g., 4.0 mm) and adding these dimensions. For example, an edentulous span of 21 mm is required for three adjacent implants 4 mm in diameter and 28 mm for four adjacent implants between two teeth. A space of 21 to 27 mm would have three implants. Commonly, implant-supported crowns in the posterior regions of the mouth are the size of premolars. This concept often permits the placement of two implants to replace an intratooth molar when the span is at least 14 mm (for 4-mm-diameter implants). When the missing molar is the most distal in the arch, a 12.5-mm span is required for two 4-mm-diameter implants (3 mm between each implant and 1.5 mm from the anterior tooth) because the 1.5-mm distance from the last tooth is no longer required.

There are several advantages of a 7- to 8-mm-wide premolar compared with a molar-size crown of 10 to 12 mm: (1) more implants may be used to restore the missing teeth; (2) implants may range from 4 to 5 mm in diameter, which are the most common sizes, and often the available bone has adequate buccolingual bone dimension in this region; and (3) the emergence of the premolar size crown contours on implants of this dimension more easily permit sulcular probing and hygiene.[50]

Full-Arch Mandibular Fixed Prosthesis

As a general observation, the number of implants to replace all of the mandibular teeth ranges from five to nine, with at least four between the mental foraminae.[24,51] When the implants are limited to sites anterior to the mental foraminae to support a fixed prosthesis, a cantilever must be designed. Cantilevers in the mandible should ideally be projected in only one posterior quadrant to increase the A-P distance and reduce the force to the implants (Figure 12-65). Therefore, whenever possible, at least one implant should be positioned in a first molar site.[26] When implants are positioned in four of the five open pentagon positions in the mandible, a cantilever is at a reduced risk of overload because of favorable dynamics of an arch, increased A-P distance, and usually a more favorable bone density. When seven or more implants are used in the edentulous mandible with bilateral molar implants, two separate restorations may be fabricated with no posterior cantilever to permit mandibular flexure and torsion.[48] Usually, the second molar is not replaced in the edentulous mandible.

Full-Arch Maxillary Fixed Prostheses

The edentulous maxillary fixed prosthesis should usually not have a cantilever. The first seven ideal sites are often the bilateral first molars, bilateral second premolars, bilateral canines, and one implant between the canine positions[46] (see Figure 12-64). These positions satisfy the key implant positions and add an implant in the posterior region because the bone density is often poor. Additional implants in the bilateral second molar sites are a benefit to increase the A-P distance of the implants, which counters the anterior bite forces that may be increased from parafunction and so on (Figure 12-66). A greater number of implants are generally required in the maxilla to compensate for the less dense bone and more unfavorable biomechanics of the premaxilla and range from seven to 10 implants with at least three implants from canine to canine (Figure 12-67).

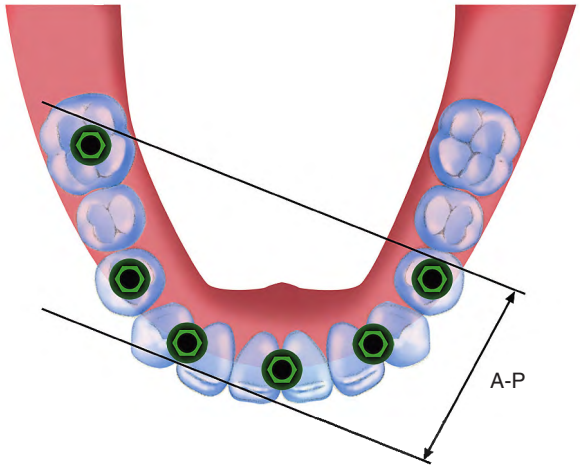


FIGURE 12-65. The anteroposterior (A-P) spread of implants is determined by drawing a line from the distal of the last implant on each side and a parallel line through the middle of the most anterior implant. When only one cantilever is used on the prosthesis, the A-P distance is large.

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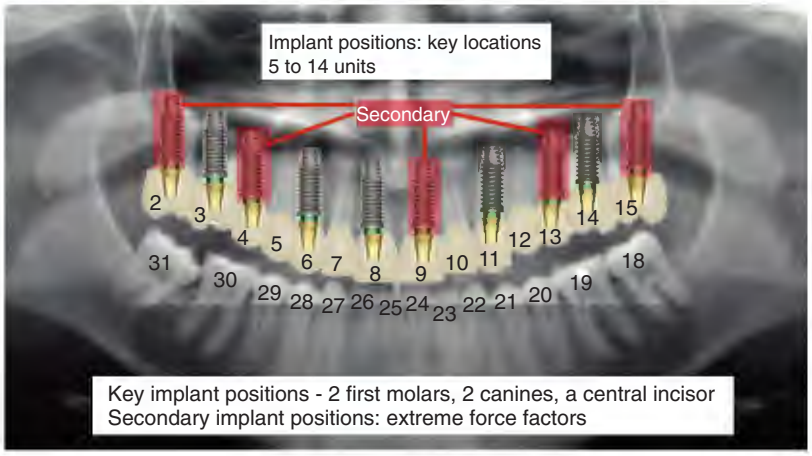


FIGURE 12-66. In the maxillary arch, secondary implants may be positioned to decrease the stress in soft bone or in patients with high force factors.

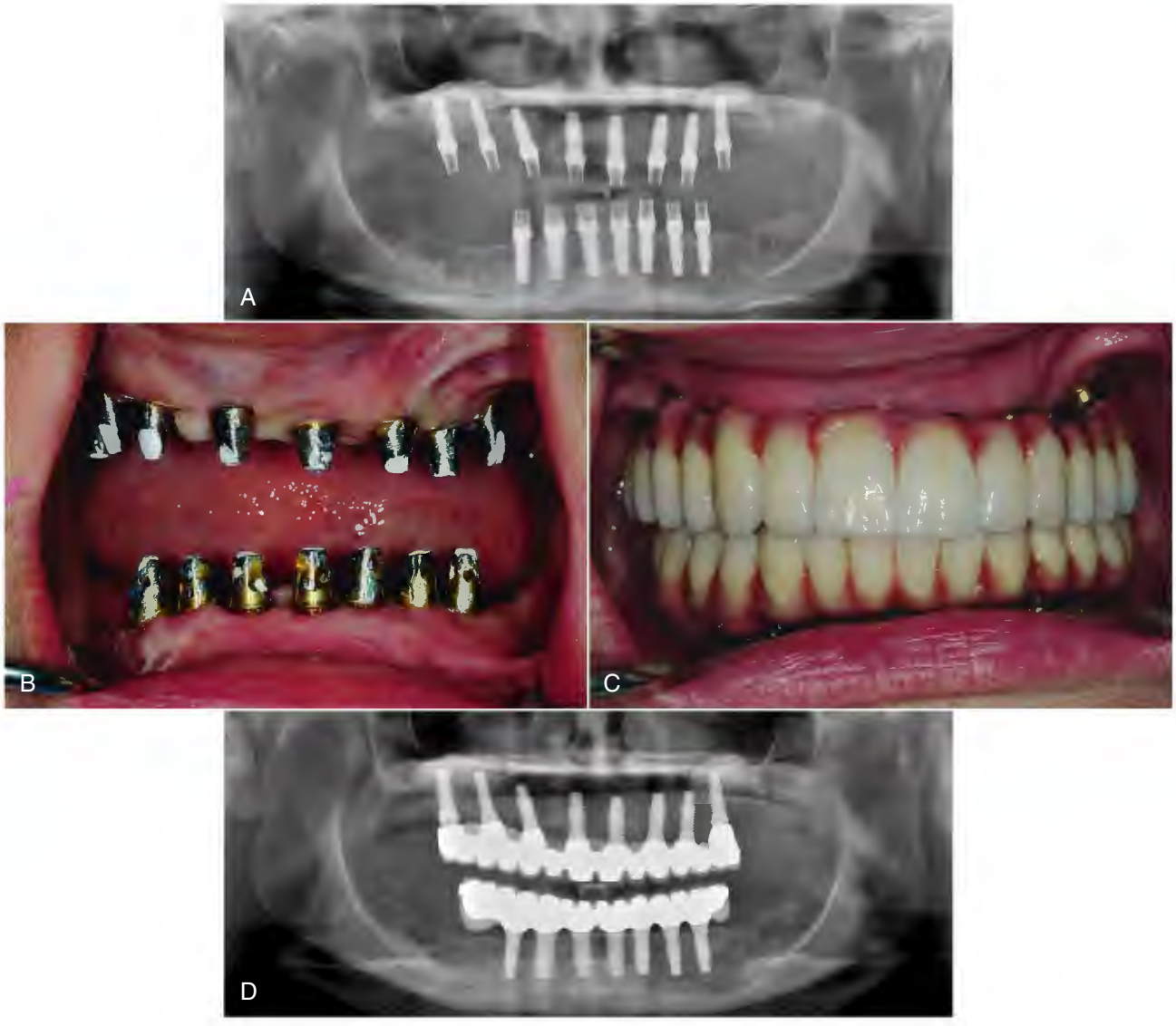


FIGURE 12-67. **A,** A panoramic radiograph of a maxillary bilateral sinus graft and maxillary and mandibular iliac crest bone grafts. Eight implants were used in the maxilla and seven implants in the mandible. **B,** An intraoral view of the maxillary and mandibular implants. **C,** FP-3 fixed restorations in situ. **D,** A panoramic radiograph of the implants and fixed restorations.

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Splinted versus Independent Implant Crowns

Independent Crowns

The primary advantages for independent crowns are related to biological complications on natural teeth. A single crown has a caries risk of less than 1% within 10 years. However, when natural teeth are splinted together, decay at the interproximal margin often occurs at a rate of more than 20%.[12,13] In addition, the endodontic risk is increased when crowns are splinted. Whereas a single crown has an endodontic risk of 3% to 5.6%, splinted teeth have an endodontic risk of 18%. Therefore, independent units reduce the incidence of complications and allow the practitioner to more readily treat these complications. However, implants do not decay or need endodontic therapy. As a result, independent units on implants would not be required to address these complications.

The primary perceived advantage of restoring implants as independent units is interproximal hygiene. When natural teeth crowns are splinted, interproximal aids are different to use. This is because the roots of the teeth are often less than 1½ mm apart. However, unlike natural teeth, which are often ½ to 1 mm apart at the cervical region, the adjacent implants are usually 3 mm or more apart. Most interproximal aids (e.g., floss threader, proxy brush) can easily reach and clean an intraimplant region (Figure 12-68). Unfortunately, fewer than 8% of our patients floss daily, and an even lower percent use any interproximal aid when their natural teeth are splinted together.[52] Because more than 90% of our patients do not floss and those that do can more easily use an interproximal device between implants, the perceived advantage of improved hygiene is not a relative concept for implant prostheses. In addition, implants do not decay and are less prone to bone loss from bacterial plaque than natural teeth.

A secondary advantage of separate dental units is the ability to replace a single unit to repair porcelain fracture. However, when dental implants are splinted together, the crown marginal ridges between the implants are supported by metal connectors; therefore, the porcelain is placed under compressive forces. As independent units, the margins of porcelain-to-metal crowns are most often placed over unsupported porcelain with shear loads, which increases the risk of porcelain fracture.



FIGURE 12-68. A perceived advantage of individual implant crowns is interproximal hygiene. However, because implant crowns are 3 mm or more apart, any hygiene aid has easy access.

Another perceived reason for independent implant crowns is the complication found when the laboratory work is made on analogs and the casting splints the implants. When the laboratory-fabricated or -prepared implant abutments are placed in the mouth and the splinted casting delivered, the prosthesis often does not fit.[53] As individual units, the interproximal contacts can be modified to seat the individual crowns. The cause of casting misfit is related to impression material shrinkage, stone expansion, and analog variance of the abutment or implant body. This complication is corrected when the abutments are inserted into the implant bodies before the final impression and never removed. Instead of working on analogs, the laboratory works on stone dies, similar to natural teeth. There is no analog variance with this technique, and the stone expansion and die spacer coated on the stone dies permit a casting to seat passively on the implant abutments.

Another perceived advantage of independent implant units is if one implant fails, the doctor only has to replace one implant and crown. However, the implant failure often causes bone loss, which then requires bone augmentation, implant reinsertion, and crown refabrication. These procedures are usually more difficult to perform around existing teeth and implants than the original implants. This is especially true when the soft tissue is affected by the failure and must be returned to a normal appearance (Box 12-6).

Splinted Crowns

There are many advantages to splinting implants together. To maximally benefit from an increased number of implants, the implants should be splinted together. Splinted implants (1) increase the functional surface area of support, (2) increase the A-P distance (A-P spread) to resist lateral loads, (3) increase cement retention of the prosthesis, (4) ease to remove the prosthesis for abutment screw loosening, (5) decrease the risk of marginal bone loss,[39] (6) decrease the risk of porcelain fracture, (7) decrease the risk of abutment screw loosening, (8) decrease the risk of implant component fracture, and (9) make the complications of implant failure easier to treat. In other words, the entire system benefits.[10]

1. Splinted implants increase the functional surface area to the support system. When implants are independent, they cannot share the occlusal load from one implant to another.[54] As a consequence, with splinted implant crowns, the risks associated with the biomechanical overload to the implant

BOX 12-6 Perceived Advantages of Individual Crowns

1. Reduce biological complications (natural teeth)
   a. Decay
   b. Endodontics
2. Interproximal hygiene
   a. Teeth ½ to 1 mm apart
   b. Implants 3 mm apart
3. Replace a single unit of prosthetic complications
   a. Porcelain fracture (more likely to fracture)
4. Analog variance of components with dental laboratory–assisted prosthetics
5. Replace single unit if implant failure
   a. Failure rate higher
   b. Often must bone graft before reimplantation

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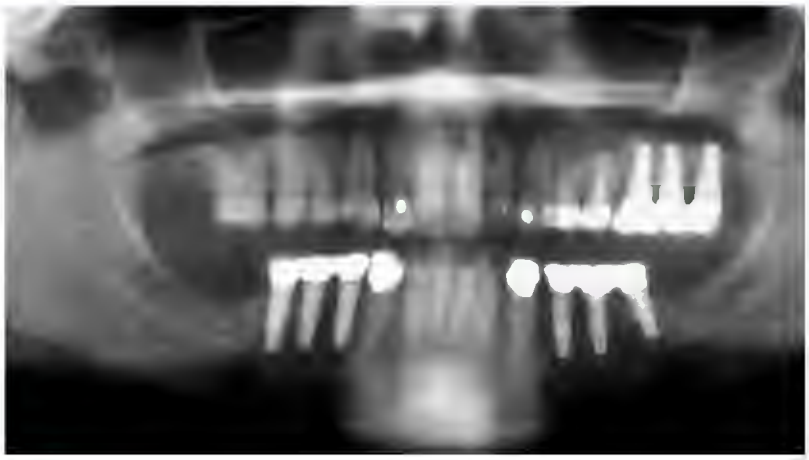


FIGURE 12-69. A maxillary fixed partial denture with three splinted implant crowns. The distal crown has no occlusal contact, but the occlusal load to the implant is distributed from the adjacent crowns.



FIGURE 12-70. When three or more implants are splinted together, an anteroposterior spread is obtained, which improves the resistance to lateral loads.

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system are reduced (occlusal porcelain, cement, or screw, which retains the prostheses, marginal bone, implant–bone interface, and implant components). If a maxillary second molar implant is connected to a maxillary first molar implant, it can share an occlusal load to the first molar even when the second molar has no direct occlusal load (Figure 12-69). As a consequence of splinting, implant survival may be greater. For example, Quiryman et al.[55] reported success rates of 90% for single implants, 97% for two splinted implants, and 98% for three splinted implants.

2. An A-P distance between two or more implants is a benefit for any angled load or cantilever, especially when three or more implants are not in a straight line[56] (Figure 12-70). The biomechanics of an arch is of most benefit because there are five different planes connected together (bilateral molar, bilateral premolar, bilateral canines, and an anterior implant).[57] Rotational forces, angled forces, and cantilevers to the facial or lingual (offset loads) are all reduced when splinted implants are not in the same plane and receive a load compared with individual units.
3. Splinted dental units provide greater abutment surface area and resistance form, so the prosthesis has more retention. In addition, there is less force transferred to the cement interface. As a result, the restoration is less likely to become uncemented (Figure 12-71). This is especially significant when the abutments are short or lateral forces are present. Both cement retention and resistance are increased with splinted crowns. The prosthesis is less likely to become uncemented, so less hard cements may be used. This allows the restoration to be more easily removed when necessary.
4. If a prosthesis does become partially retained or an abutment screw becomes loose, a splinted restoration is much easier to remove than individual units. The impact force to an individual crown that is mobile as a result of a loose abutment screw decreases the force to the cement seal, and it is difficult to remove the crown. In addition, attempting to engage a single crown margin is often difficult for the crown remover, especially when a subgingival margin is present. As a consequence, the crown may need to be cut off and destroyed to gain access to a loose abutment screw (Figure 12-72). Rather than attempting to engage a single crown margin, the crown remover needs to only engage the interproximal space of the prosthesis when crowns are splinted together (Figure 12-73).
5. Splinted implants have less stress transmitted to the crestal marginal bone. Stress may be related to marginal bone loss around an implant. As a consequence, there is less risk of marginal bone loss (Figure 12-74).
6. Splinted crowns have less risk of porcelain fracture. The marginal ridges (and often buccal mandibular cusps) of implant crowns are usually unsupported by the metal work. As a consequence, the load on a marginal ridge is a shear load, with porcelain weakest to shear loads. In a report by Kinsel and Lin,[6] porcelain fractures occurred in 35% of patients with implant crowns, especially when bruxing patients were restored in group functions (Figure 12-75). Splinted implant crowns have the metal connectors of the casting below the marginal ridges. Hence, the interproximal porcelain has a compressive force on the porcelain, and porcelain is strongest to compressive loads (Figure 12-76).
7. Splinted implants reduce the risk of screw loosening. One of the highest prosthetic complications with single tooth or independent implant crowns is abutment screw loosening. In a review of the literature by Goodacre et al.,[4] independent crowns had a screw loosening rate of 8%, with a range as high as 22%. In a report by Balshi and Wolfinger,[41] single-tooth implants replacing a molar had 48% screw loosening over a 3-year period. When two implants were splinted

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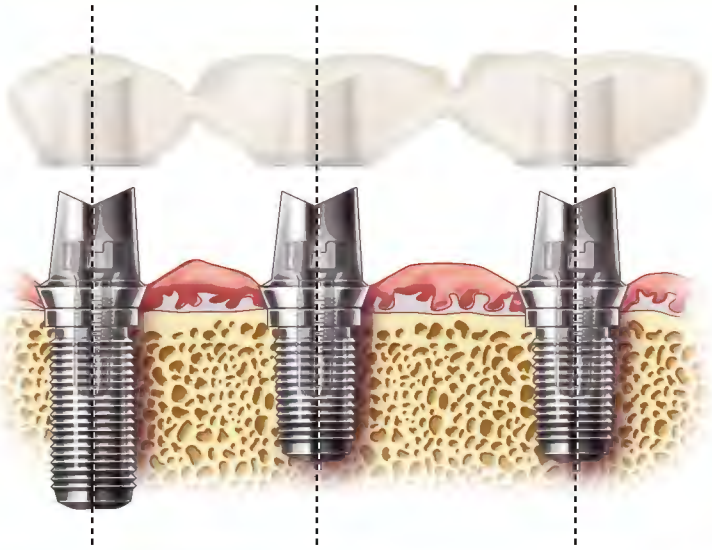


FIGURE 12-71. Splinted implant crowns have more abutment surface area, and improved retention and resistance form.



FIGURE 12-72. A loose abutment screw in an individual implant crown may need to be destroyed to gain access to the abutment screw.



FIGURE 12-73. Splinted crowns may be removed with a crown remover more easily because it needs only to engage the interproximal regions, not the subgingival crown margin.



FIGURE 12-74. Individual implant crowns have more stress than splinted crowns, so crestal bone loss from occlusal overload is a greater risk.



FIGURE 12-75. Individual implant crowns most often have unsupported porcelain on the marginal ridges and are more prone to fracture.

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FIGURE 12-76. Splinted implant crowns have metal connectors under the marginal ridges between implants. Therefore, the marginal ridges of porcelain are supported.

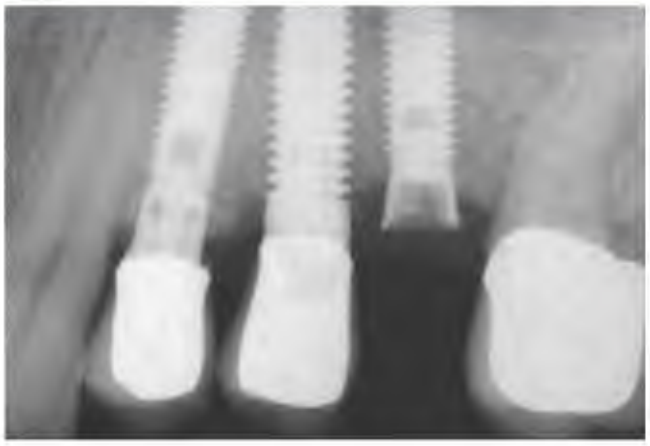


FIGURE 12-77. Individual implant crowns have greater strains during loading than splinted crowns and are more at risk of fracture.

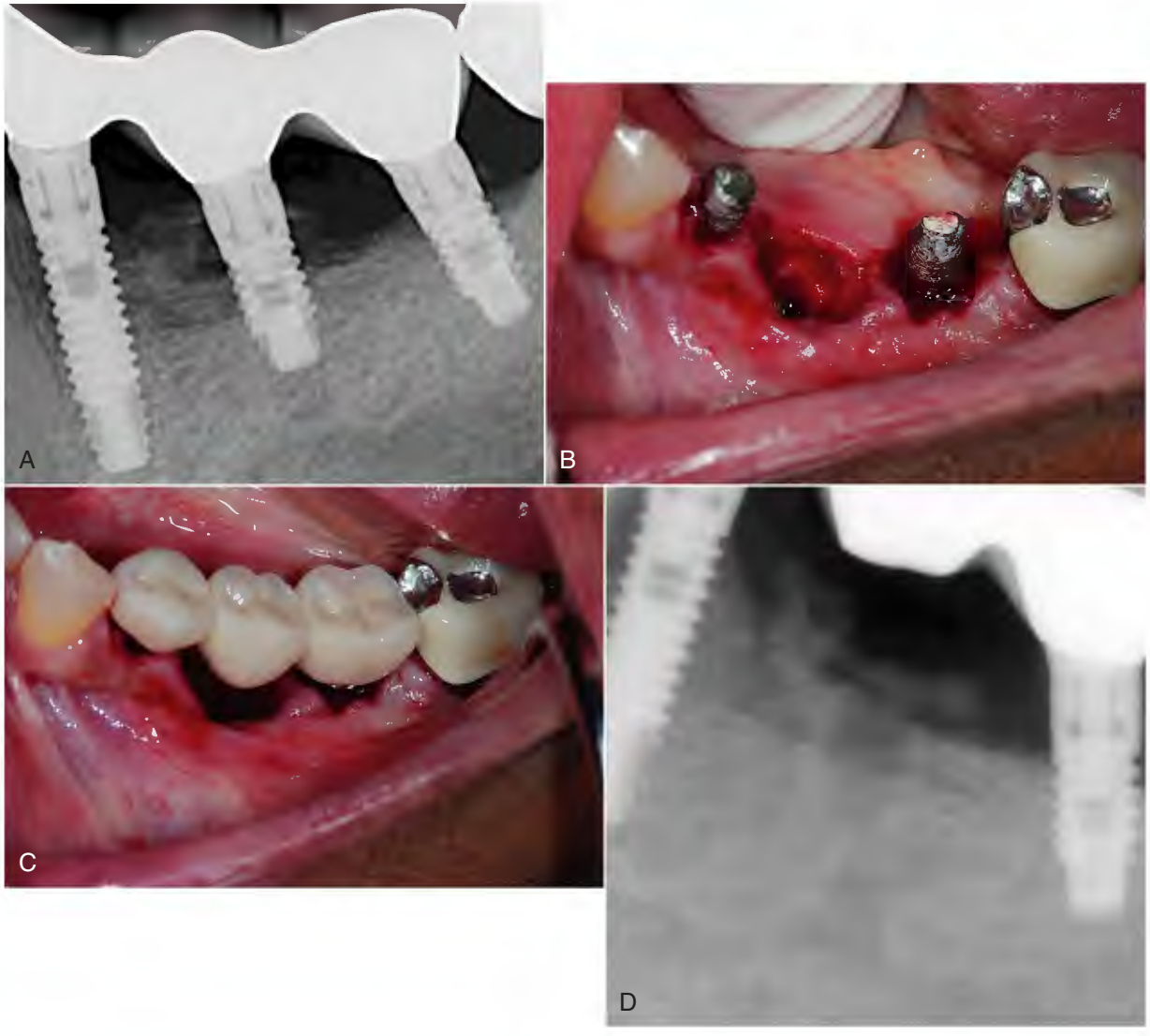


FIGURE 12-78. **A,** A periapical radiograph of a three-unit splinted crown had an implant with bone loss and exudate. **B,** The prosthesis was removed, and the center implant was extracted. **C,** The prosthesis was modified by filling the abutment and making it a pontic. **D,** A postoperative periapical radiograph of the three-unit fixed partial denture with improved periimplant health.

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together to replace a molar, the incidence of screw loosening was reduced to 8% over the same time period.

8. Splinted implants distribute less force to the implant bodies, which decreases the risk of implant body fracture. In a report by Sullivan and Siddiqui,[58] a 4-mm single implant replacing a molar had implant body fracture in 14% of the cases. In comparison, multiple implants splinted together report a 1% implant body fracture[4] (Figure 12-77).
9. If an independent implant fails over time, the implant may be removed, the site of bone grafted and the site reimplanted. This may require multiple surgeries over a 1-year period of time. In addition, a new crown must be fabricated. When multiple splinted implants have an implant that fails, the affected implant may often be removed and the implant crown converted to a pontic using the same prosthesis (Figure 12-78). As a result, rather than several surgical and prosthetic procedures over an extended period when independent units are restored, the problem may be solved in one relatively short appointment. As a consequence, of all the advantages of splinted implant crowns over individual units, the rule is to, whenever possible, keep natural teeth as independent units and, whenever possible, splint implant crowns together.

The exception to the splinted implant rule is a full-arch mandibular implant prosthesis. The body of the mandible flexes distal to the foramen upon opening and has torsion during heavy biting with potential clinical significance for full-arch implant prostheses.[24,48] As a result, a full-arch mandibular implant prosthesis should not be splinted from molar to molar on the opposite sides. Therefore, full-arch mandibular restorations should have a cantilever or be made in two or three sections to accommodate the mandibular dynamics during function. The concept of flexure and torsion does not affect the maxilla, where all implants often are splinted together, regardless of their positions in the arch.

Summary

A biomechanical-based treatment plan reduces complications after implant loading with the prosthesis. To reduce stress conditions, there are key implant positions for a prosthesis replacing missing teeth in partially edentulous patients and full-arch maxillary prostheses: (1) no cantilevers should be ideally designed on the restoration, (2) three adjacent pontics should be eliminated, and (3) the canine and (4) first molar sites are important positions in an arch.

Increasing the number of implants is the most efficient method to increase surface area and reduce overall stress. Therefore, after the key implant positions are selected, additional implants are indicated to reduce the risks of overload from patient force factors or implant sites with reduced bone density. When in doubt of the number of implants required, an additional implant should be added. These implants, whenever possible, should be splinted together to further reduce the biomechanical complications.

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CHAPTER 13

Implant Body Size: A Biomechanical and Esthetic Rationale

Carl E. Misch

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The initial treatment plan for implant dentistry should include the ideal implant size based primarily on biomechanic and esthetic considerations. In traditional prosthetics, when a tooth is replaced, the abutment teeth are already provided by nature with wide posterior abutments for posterior teeth. When teeth are replaced with dental implants, the implant team should preselect the ideal implant size based on the ideal esthetic restoration within biomechanical guidelines.

Historically, the size of an implant was determined primarily by the existing bone volume in height, width, and length. The surgeon would select longer implants in the anterior regions of the mouth and shorter ones in the posterior areas (or use cantilevered prostheses) because of the limits of the mandibular canal and maxillary sinus. The width of the implant, also determined during surgery, would relate to the existing width of available bone, and one diameter implant (4 mm) would be used in most all situations[1] (Figure 13-1).

Over the years, dental implant treatment plans incorporating biomechanics have been advocated by the author to decrease the most common complications—those related to biomechanical stress.[2] (Figure 13-2) The prosthesis first is planned, including whether the restoration is fixed or removable, how many teeth are replaced, and the esthetic demands. The patient force factors are then considered to evaluate the magnitude and type of force applied to the restoration. The bone density is evaluated in the regions of the potential implant placement. The key implant positions are determined followed by the additional implant number based on the patient force factors and the bone density in the implant sites. The key implant positions are important regardless of the patient force factors and bone density. The total implant number, on the other hand, is directly related to these force factors and bone density. For example, more implants should be used when the patient has parafunction or the bone is less dense because the greater force exerted on the implant abutments will transmit greater stresses to the implant–bone interface. In fact, implant number may also be a factor when the ideal size of the implant is inadequate for the biomechanical load. The next consideration in this ideal treatment plan sequence is the implant size[2] (Box 13-1).



FIGURE 13-1. Historically, one size implant in width (4.1 crest module) was used for all clinical situations.

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BOX 13-1 Treatment Plan Sequence

1. Prosthesis
2. Key implant positions
3. Patient force factors
4. Bone density
5. Implant number
6. Implant SIZE

BOX 13-2 Complications of Stress to the Implant System

Complete implant failure
Porcelain fracture
Uncemented restorations
Abutment screw loosening
Implant and component fracture
Crestal bone loss



FIGURE 13-2. Abutment screw fracture is more common in situations of increased stress (e.g., parafunction, implant diameter).



FIGURE 13-3. Implant body fracture is related to the amount of force and the diameter of the implants.

A comprehensive approach to the overall dental implant size begins with the identification of clinical problems to be addressed. Dental implants function to transfer loads to surrounding biological tissues.[3,4] Biomechanical load management is dependent on two factors: the character of the applied force and the functional surface area over which the load is dissipated.[5] The implant size directly affects the functional surface area that distributes a load transferred through the prosthesis. Fundamental scientific principles related to force and surface area are then combined with engineering principles to pursue the desired clinical goals. When relevant, esthetic considerations in regard to implant size are part of the evaluation. This chapter builds on and applies basic biomechanics and demonstrates how these principles also relate to the ideal dental implant size to support a prosthetic load. The esthetic guidelines related to implant size are also addressed.

Character of Forces Applied to Dental Implants

Stress and Strain

The presence of fibrous tissue has long been known to decrease the long-term survival of a root form implant.[1] Excessive loads on an osseointegrated implant may result in mobility of the supporting device even after a favorable bone–implant interface has been obtained.[6] Excessive loads on the bone result in increased strain conditions in the bone.[7] These microstrains in the bone may affect the bone remodeling rate and cause pathologic overload, which results in the loss of bone. The amount of bone strain is directly related to the amount of stress applied to the implant–bone interface. The stress may cause complete implant failure, porcelain fracture, uncemented restorations, abutment screw loosening, implant and component fracture, and crestal bone loss (Box 13-2). Although several conditions may cause crestal bone loss, one of these may be prosthetic overload.[8] The greater the stresses throughout the implant–bone interface, the greater the risk factor for any biomechanical complication, including crestal bone loss and implant failure.[9] Therefore, the stress and strain relationship has been shown to be an important parameter to decrease any biomechanical complication.

Screw loosening is a complication that is especially noted in single-tooth replacement or individual crowns restored with multiple adjacent implants. Prosthetic screw loosening is affected by implant diameter.[10] The larger the diameter of an implant, the less the force applied to the abutment screw and the less screw loosening. Hence, when lateral forces or cantilevers are present, especially when crown height or parafunction is greater than usual, the diameter of the implant body or the implant number (splinted together) should be increased to limit this complication.

The increase in stress to an implant body also increases the risk of implant abutment screw or body fracture (Figure 13-3). The strength of an implant abutment screw or body is related to the radius times the power of 4. Hence, an implant or abutment screw twice the size is 16 times more resistant to failure. Hence, implant body size has several related biomechanical factors, including abutment screw loosening, crestal bone maintenance, implant survival, and implant component or body fracture. In addition, the emergence profile of the crown is related to the implant diameter (Figure 13-4). A deficient emergence profile from a narrow implant may affect esthetics, food entrapment, sulcular hygiene considerations, and probing assessment to evaluate long-term health.

Forces applied to dental implants may be characterized in terms of five distinct (although related) factors: magnitude, duration, type, direction, and magnification.[5] Each factor should

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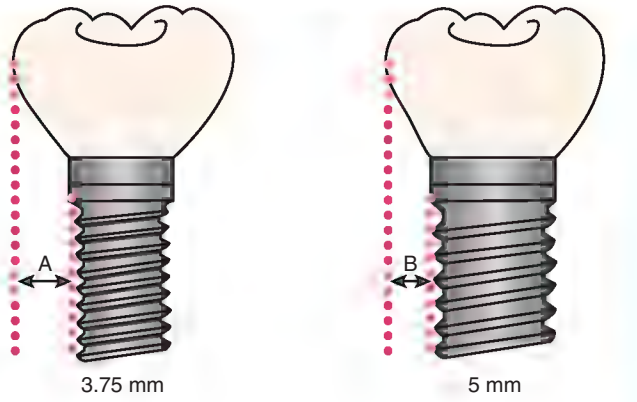


FIGURE 13-4. The emergence profile of a crown is related to the diameter of the implant. The implant on the left *(A)* has more narrow emergence than the implant on the right *(B)*.

be considered within the physiologic constraints on implant size. As a result, a relative risk factor for different implant sizes may be established.

Force Magnitude

The physiology of the stomatognathic system imposes a range on the magnitude of forces that may be applied to an implant in the oral environment. The magnitude of bite force varies as a function of anatomical region and state of the dentition.[11] Average bite forces can range from 10 to 350 lb. The magnitude of force is greater in the molar region (200 lb), less in the canine area (100 lb), and least in the anterior incisor region (25–35 lb).[12] These average maximum bite forces increase with parafunction to magnitudes that may approach 1000 lb in the posterior regions.[13]

After sustained periods of edentulism, the bone foundation often becomes less dense. Studies on dentate and edentulous jaws illustrate greater trabecular bone density in the anterior regions compared with the molar regions.[14] The bone's ultimate strength is highly dependent on its density.[15] As such, less dense bone may no longer be able to support normal physiologic bite forces on a dental implant. Careful treatment planning, including appropriate implant size selection, is imperative to lower the magnitude of loads imposed on the vulnerable implant–bone interface under these less ideal conditions. Thus, the posterior regions with higher bite forces and lower bone densities should use a different parameter for implant size compared with the anterior regions. As a consequence, the implant size in the molar region should be larger in diameter than the anterior and premolar region. When implant size is not greater than the anterior regions, implant number or design considerations (or both) should compensate for the greater force factors or deficient bone density.

Force Duration

The duration of bite forces on the dentition has a wide range. Under ideal conditions, the teeth come together during swallowing and eating for only brief contacts. The total time of these brief episodes is less than 30 minutes per day.[13] Patients who exhibit bruxism, clenching, or other parafunctional habits, however, may have their teeth in contact for several hours each day. Fatigue fractures increase in direct relationship to the amount of the force and the number of cycles of load.[5] Therefore, an increase in force duration directly increases the risk of

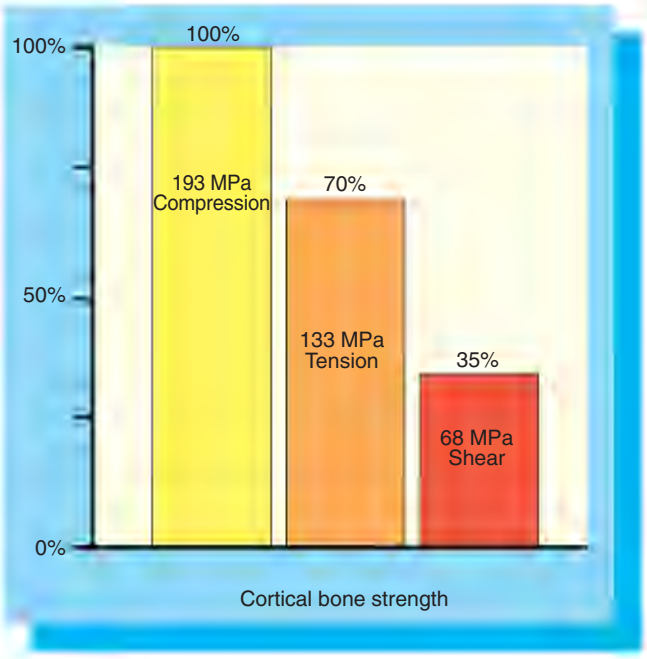


FIGURE 13-5. Bone is strongest to compressive loads, 30% weaker to tensile loads, and 65% weaker to shear loads.

fatigue load to the implant body when the force is higher than the endurance limit of these entities.[16] The implant body width is directly related to the strength of an implant, and wider-diameter implants reduce the risk of fatigue fracture. Hence, the bending fracture resistance should be altered in patients with greater bite forces (e.g., parafunctional patients) by increasing implant diameter.

The duration of a force may also alter the implant–bone interface. Fatigue damage to cortical bone has been reported under relatively high-frequency loading rates (e.g., shin splints in runners).[17] Although fatigue damage to alveolar bone has not yet been reported in the literature, it is unlikely the alveolar bone reacts differently to parafunctional loads. Roberts et al. report the bone around an implant may be remodeled at a rate of 500% each year after loading compared with normal trabecular physiologic remodeling around a tooth of 40% per year.[18] The dramatic increase in remodeling rates may eventually lead to fatigue damage and resultant bone loss.[19] This bone loss may be primarily at the crestal marginal regions or extend throughout the interface and cause implant failure.

Force Type

Three types of forces may be imposed on dental implants within the oral environment: compression, tension, and shear. Bone is strongest when loaded in compression, 30% weaker when subjected to tensile forces, and 65% weaker when loaded in shear[20] (Figure 13-5). Therefore, an attempt should be made to limit shear forces on bone because it is least resistant to fracture under these loading conditions. This is most important in regions of decreased bone density because the strength of bone is also directly related to its density.[15] An increased width of an implant may decrease offset loads and increase the amount of the implant–bone interface placed under compressive loads. Hence, when forces are more tensile or shear in nature (as with cantilevers or angled loads), the implant diameter or implant number should be increased to compensate for the weakened bone state (Figure 13-6).

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FIGURE 13-6. **A,** A cantilever on the prosthesis increases the stress to the implant system. **B,** The diameter of the implant is related to its strength. A larger-diameter implant reduces the risk of implant body fracture.

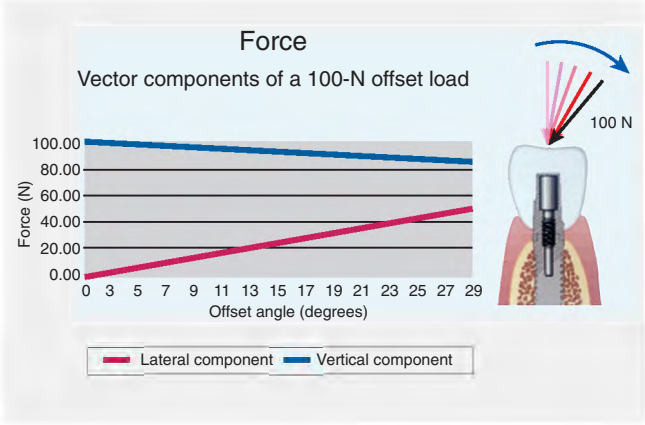


FIGURE 13-7. The greater the angle of load to the prosthesis, the greater the lateral component of force. The lateral component of force is primarily shear and tensile loads.

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Force Direction

The direction of the load has a significant effect on the magnitude of compressive and lateral load components (tension and shear forces). Angled loads increase the amount of shear loads transmitted from the implant body to the bone, and the bone is weakest to shear-type loads.[21] By increasing the angle of the load by only 15 degrees, the lateral component of that load (shear and tensile forces) is increased by 25.9%. Every degree of angled load increases the shear load component to the implants, which is the most damaging component of the load because the bone is weakest to shear. The forces to an implant body are typically greatest at the crestal bone interface.[22] Angled loads to the implant prosthesis produce angled loads to the crest module of the implant and hence the marginal bone; therefore, the implant angulation is important to consider (Figure 13-7).

Under ideal conditions, the implant body should be oriented to provide long-axis compressive loads to the implant and to decrease shear loads to the crestal bone region. The occlusal forces are usually the greatest in centric occlusion. As such, the implant should be inserted perpendicular to the curve of Wilson and curve of Spee. Additionally, axial alignment places less stress on the overall implant system (i.e., abutment and abutment screw components) and decreases the risk of screw loosening and fatigue fractures of the implant or its components.

The anatomy of the mandible and maxilla often places significant constraints on the ability to surgically place root form implants for loading along their long axes. For example, resorptive patterns after prolonged edentulism exacerbates the normally occurring angulation challenges of the maxilla and mandible.[23] In addition, bone undercuts constrain implant placement in either arch and thus affect load direction imposed on the implant. Almost all undercuts occur on the facial aspects of the bone, with the exception of the submandibular fossa in the posterior mandible.[24] Implant bodies are often angled to avoid perforation of the bony undercut during insertion. These angulations increase biomechanical complications and may be reduced by increasing the diameter of the implant (or increasing the implant number).

The maxillary anterior region does not permit an ideal implant position even under ideal conditions. The natural maxillary anterior teeth are 12 to 15 degrees off the long axis of load, and the bone of the premaxilla is in a similar relationship after tooth loss. Therefore, implants in this region are often positioned with a greater relative angle to occlusal loads than any other region.[21] To decrease the effect of an angled load on the implant, the implant body may be increased in diameter. It is interesting to note that the maxillary anterior teeth have greater diameter than the mandibular corresponding teeth. Whereas the lower anterior teeth are loaded in their long axis, the maxillary teeth are not. Hence, the diameter of the anterior natural teeth follows this biomechanical rationale.

Force Magnification

Force magnification further increases the stress beyond the usual conditions of load (e.g., a cantilevered prosthesis with a crown height greater than normal, an angled load, or parafunction).[5] Multiple force magnifiers, such as a patient with parafunctional habits and an excessive crown height, may exceed the capability of any dental implant to withstand occlusal loads. Careful treatment planning with special attention to the implant position, implant number, occlusal loading, and an increase in implant size to increase functional surface area is indicated when a clinical case presents the challenge of force magnifiers.

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A magnifier of force around an individual implant is also affected by the density of bone. Four distinct bone density categories within the maxilla and mandible exhibit a broad range of biomechanical strengths (i.e., ability to withstand physiologic loads).[14] Significantly increased clinical failure rates in poor-quality, fine trabecular bone compared with denser bone have been documented worldwide by multiple independent clinical investigators for more than a decade, with failure rates as high as 35% with implants in D4 (type IV) bone.[25–28] Bone density is directly related to bone strength, and D4 bone may be more than 10 times weaker than D1 bone and 70% weaker than D2 bone.[15] Most implant failures in soft bone are from occlusal overload from a decrease in bone strength, a decreased bone–implant contact percentage, and the type of load transfer to the implant–bone interface on functional loading.[29] Therefore, the effect of a resultant force is magnified as to its clinical result when placed in softer bone types.

Considerable effort should be made in the treatment plan to decrease the negative effects of compromised bone density, including implant number and size. The most important factor to decrease stress to the implant–bone interface is usually an increase in implant number, which dramatically increases the effective surface area over which the occlusal loads are dissipated and in turn decreases stress. Implant number also relates to implant position, which can effectively reduce cantilever lengths and subsequent harmful bending loads and shear stresses. After the implant number has been increased in the treatment plan, the next beneficial step to decrease the risk of overload is to increase the implant size, primarily in diameter.

Surface Area

The surface area over which the occlusal forces are applied to the implant system is very relevant and is inversely proportional to the stress observed within the implant system (Stress = Force/Surface area). It can be clearly seen from this basic engineering equation, to reduce stress, the force must decrease or the surface area must increase. Therefore, an increase in implant size is beneficial to decrease the stress applied to the system. The size of an implant may be modified in either length or diameter.

Implant Length

Longer Implant Lengths

Most all dental implant manufacturers provide implants of various lengths. The most common sizes range between 7 and 16 mm (Figure 13-8). The length of the implant is directly related to the overall implant surface area when all other variables are constant. A 10-mm-long cylinder implant increases surface area by approximately 30% over a 7-mm-long implant and has about 20% less surface area than 13-mm-long implants[30,31] (Figure 13-9). As a result, a common axiom has been to place an implant as long as possible. However, the length of the implant used for prosthetic support most often corresponds to the height of available bone in the edentulous site. Hence, shorter implants are often used in the posterior regions and longer implants in the anterior sections of the jaw (Figure 13-10).

Conventional thinking suggests that very long implants provide maximum functional surface area in a healed implant interface. However, when the length axiom is reevaluated,



FIGURE 13-8. Almost all manufacturers provide implants with different lengths, usually ranging from 7 to 16 mm.

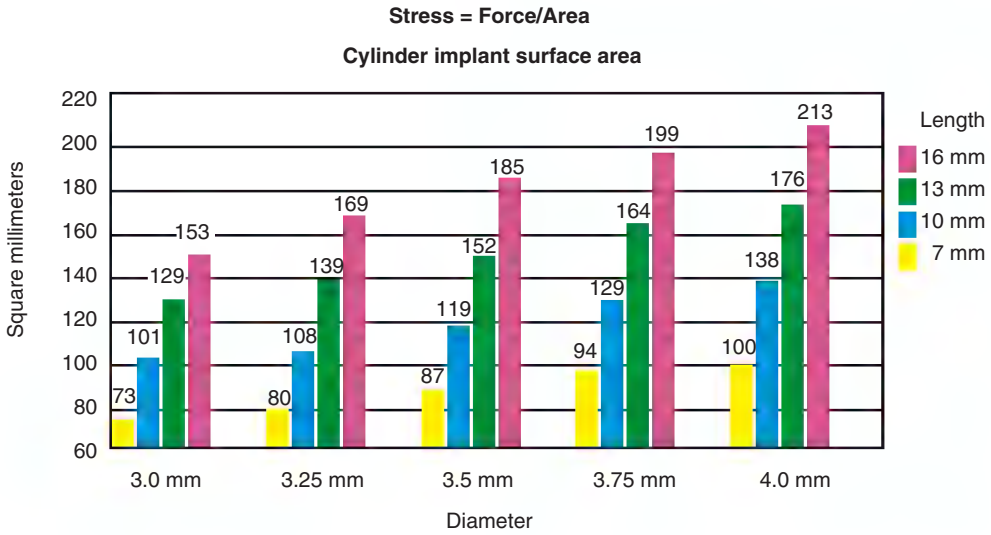


FIGURE 13-9. A longer implant has more surface area. The biggest increase in surface area percent is usually from the 7- to 10-mm implant.

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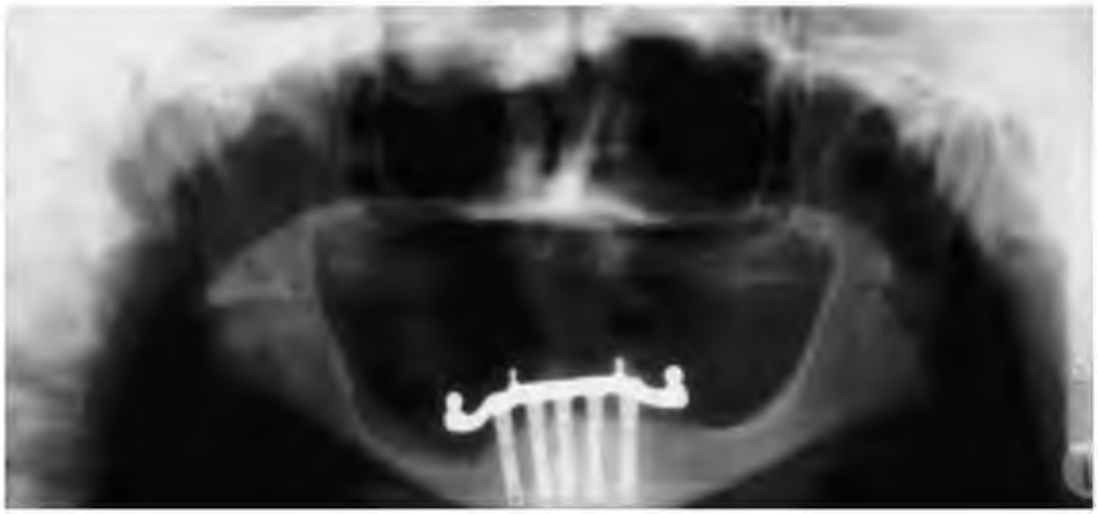


FIGURE 13-10. The greatest vertical height of bone is most often the anterior mandible. Hence, when bone height determines implant length, the longest implants are inserted into this region.

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several challenges ensue. The available bone height is greater in the anterior regions of the mouth, especially the anterior mandible. Yet the bite forces are lower and the bone density is greater in these regions, especially in the mandible. The posterior regions have less bone height, and the implant cannot engage the dense opposing cortical plate because it is either nonexistent (maxilla) or beyond anatomical limits (neurovascular canal in the mandible). The posterior maxilla often has less height than the mandible, and the bone is less dense. As a result, the anatomic limitations result in shorter implants in the posterior region. On the other hand, many reports indicate similar survival rates in anterior and posterior regions when implants are greater than 10 mm in length.[32]

Implants longer than 15 mm have been suggested to provide greater stability under lateral loading conditions. However, reports suggest that increasing the length beyond a certain dimension may not reduce force transfer proportionately.[22,33] Finite element analysis provides an analytical means to investigate the influence of implant length relative to functional surface area under such extreme loading conditions. Misch and Bidez placed cylindrical implants of different lengths in a computer bone model with ideal bone density and volume. The embedded implant body lengths were 5, 10, 15, 20, and 30 mm. A 10-mm crown height was designed above the level of bone, and a lateral force of 50 N was applied to the top of the 10-mm crown. For these loading conditions, the percentage of maximum stress was plotted against the percentage of embedded length (Figure 13-11). Peak stresses were not completely dissipated in the 5-mm-long implant model, with approximately 35% of the maximum stress still present at the apex of the implant. The 5-mm implant model, therefore, did not provide sufficient length for lateral force dissipation despite good bone density and volume and ideal crown height.

In the 10-mm implant model, 80% of maximum stress was dissipated in approximately 95% of the embedded length. For the 15- and 20-mm lengths, 80% of the maximum stress was dissipated in approximately 90% of the embedded length. For the 30-mm length, 80% of the maximum stress was dissipated in approximately 70% of the embedded length. In other words, the 15- to 30-mm implants did not reduce the stress in the crestal bone region and was able to constrain the stress within

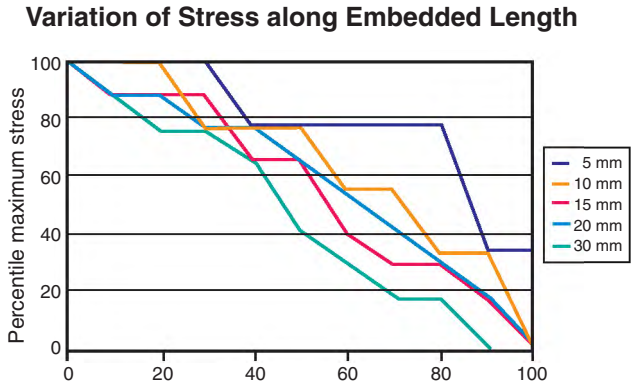


FIGURE 13-11. Implants of 5, 10, 15, 20, and 30 mm were evaluated with finite element analyses that had a 10-mm-high crown and a lateral force in a good bone simulant. The 5-mm-long implant still had 35% of stress in the system at the apex of the implant. Implants in the 15- to 20-mm range were very similar, both at the crestal 20% and the apical 40%.

the length of the implant. Therefore, the length of the implant in favorable bone quality (e.g., D1 or D2 bone) and crown height may range from 10 to 15 mm with similar strain conditions. All implant lengths exhibited 80% to 100% of the stress in the crestal 40% of the implant length in this ideal bone simulant.

The results of this analysis point to the fact that the majority of the maximum stress generated by a lateral load can be dissipated as well by implants in the range of 10 to 15 mm in length, compared with implants in the range of 20 to 30 mm in length. In addition, the highest stresses were observed in the crestal bone regions, regardless of the implant length. This biomechanical analysis supports the opinion that longer implants are not necessarily better in good bone volume and density, such as that found in the anterior regions of the mandible. An implant length of 12 mm is usually sufficient under most patient force and bone density conditions. However, poorer bone densities provide a different strain condition.[29]

The ideal length of an implant may be affected by the bone density. The occlusal loads are primarily concentrated at the

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crest of the ridge in good-quality bone (i.e., D1, D2). In softer bone types (D3, D4), the stress contours around the implant body extend more apically. As a result, longer implants are a benefit in softer bone types. For example, in a three-dimensional finite element analysis study by Tada et al., the strain around an implant in D1 bone is similar for all implant length from 9.2 to 14 mm.[34] In type 2 bone, the implant length also did not influence the amount of strain at the implant–bone interface. However, the strain around an implant body in D3 bone had two to three times more strain than the harder bone types, and the 9.2-mm length had almost 30% more strain than the 14-mm-long implant. In type 4 bone, the amount of strain around a 9.2-mm implant was four times more than the D1 and D2 bone simulant model, and the 14-mm-long implant was three times more (Figure 13-12). In addition, longer implants become more fixated in soft bone during surgical placement and may resist more movement during initial healing. This aspect decreases the failure rate during healing time for implants in soft bone. Hence, implants up to 15 mm long are suggested in the softest bone types, especially when cantilevers or lateral loads exist on the prosthesis.

Bicortical stabilization in the anterior mandible, a rationale often cited for longer implants, is not needed in D1 bone, which is primarily homogeneous cortical bone.[14] Bone overheating is a primary cause of surgical failure in dense bone, and attempting to engage the opposing cortical plate in D2 bone and preparing a longer osteotomy may result in overheating the cortical bone.[35] In D3 bone, a threaded implant may not readily engage the denser bone of the apical cortical plate, and the implant threads may strip along the rest of the osteotomy because it is in a fine trabecular bone type. In addition, after the implant–bone interface is formed, excessively long implants do not transfer stress to the apical region because most of the stresses are transmitted within the crestal 7 to 9 mm of bone (except in the softer bone types), and therefore longer than 12-mm implants are often not needed in the anterior mandible.[22]

The anterior mandible is also the region that has less bite force and the implants are more long axis loaded. It should be noted that the incisal edge of an anterior mandibular tooth is often more facial than the inferior cortical plate (Figure 13-13). As a result, a longer implant in the anterior mandible with abundant bone often engages the lingual cortical plate, not the inferior border. Because this landmark is more superior, the surgeon may inadvertently perforate the lingual plate and increase the risk of bleeding, swelling of the floor of the mouth, and postoperative complications.

D3 and D4 bone are primarily present in the posterior regions of the jaw, where less available bone height is observed compared with the anterior regions. Mandibular inferior alveolar nerve repositioning has been cited as an acceptable clinical treatment to facilitate placement of longer implants in the posterior mandible (Figure 13-14). However, this advanced surgical procedure represents an increased risk for paresthesia and is often not indicated, especially when other treatment options are available.[36]

To place the longest implants in the maxillary posterior regions, a sinus graft is often required. Sinus grafts have been shown to grow bone into the graft from the surrounding walls of bone, and bone does not form under the sinus mucosa for several years. Therefore, the apical end of longer implants will not benefit from the sinus bone graft procedure for some time, and the crest of the bone below the graft will remain at greater risk. However, it should be noted that implants in D4 poor-density bone (as often found in the posterior maxilla) benefit when they are at least 12 mm in length. Implants up to 15 mm may be advantageous in conditions of higher force factors; therefore, a sinus graft is often required in this region.

Increasing surface area primarily by length in the posterior regions of the jaws often requires advanced grafting or surgical techniques in either the maxilla or mandible. When incisal guidance eliminates all lateral forces and no cantilevers are present on the prostheses, the implant length requirement may be reduced, especially in good-quality bone. Implant lengths greater than 12 mm offer few benefits under these conditions and often increase the surgical risks of the procedure.

Shorter Implant Lengths

Different risk factors for implant longevity have emerged over the years. A review of the literature related to implant failure

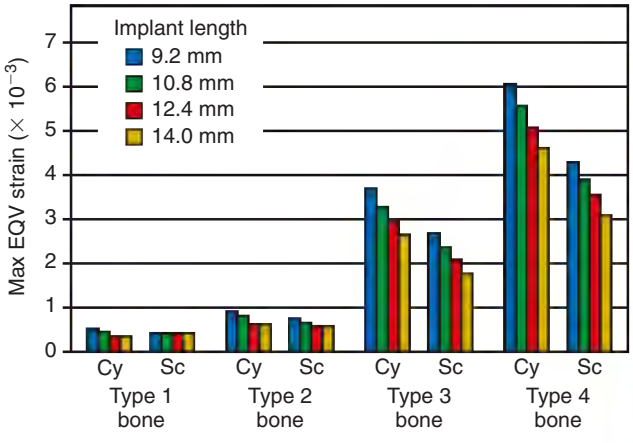


FIGURE 13-12. Tada et al. evaluated implant length related to bone quality and maximum strains. The softest bone types affected the strain conditions more than implant length.[34] *Cy*, Cylinder implant; *Sc*, screw-type implant.

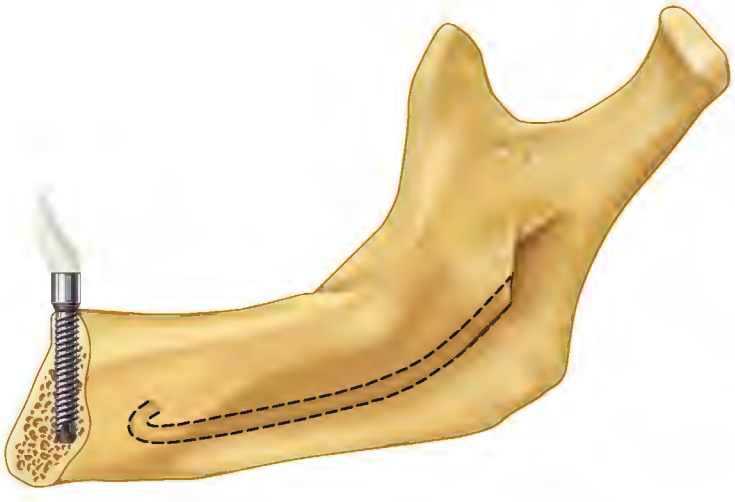


FIGURE 13-13. Implants in a division A (abundant bone) often engage the lingual cortical plate, not the inferior border of the anterior mandible.

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FIGURE 13-14. Mandibular nerve repositioning has been suggested to increase implant length in the posterior mandible.

TABLE 13-1
Short Implants (Literature Review Below 90%)

Author (Year)	No. of Implants	Success Rate (%)	Implant System
Jemt and Lekholm[40] (1995)	298	76	Brånemark
Minsk et al.[28] (1996)	50	84	Brånemark (six systems)
Saadoun and Le Gall[41] (1996)	15	79	Steri-Oss
De Bruyn et al.[47] (1999)	9	87	Screw-Vent
Winkler et al.[38] (2000)	152	81	Screw-Vent (six designs)
Naert et al.[6] (2002)	1168	67	Brånemark
Weng et al.[39] (2003)	97	79	3i
Total implants: 1889			
Average success rate: 80.3%			

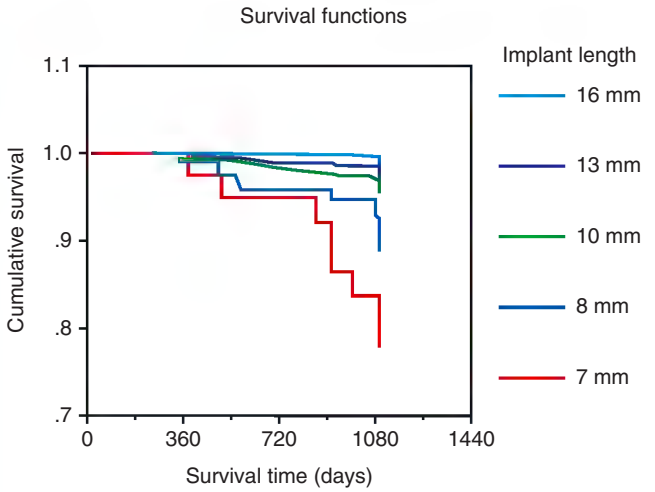


FIGURE 13-15. A multicenter study found that whereas the 7-mm implant failed 26.4% of the time, the 16-mm failed 0.8% of the time. Note that the implants did not fail the first year. Rather, they failed after loading.[38]

and implant length was published by Goodacre et al. in 2003.[32] Many implant manufacturers provide implants in 7-, 8.5-, and 10-mm lengths. In the majority of articles addressing implant length, implants smaller than 10 mm have increased failure rates. In the reports summarized, the failure rates of these shorter implants were 15% compared with a 3% failure rate of longer implants. The failure is even more apparent when the literature reviews implants smaller than 10 mm in the posterior regions of partially edentulous patients. Fewer than half of the clinical reports had survival rates higher than 90%, and more than half of the reports had implant failure higher than 19.7%[6,28,37–46] (Table 13-1).

A review of several of the multicenter reports of short implants is noteworthy. Minsk et al. reported the results of a training center in 1996, with 80 different operators using six different systems over a 6-year period.[28] Implants 7 to 9 mm in length were reported to have a 16% failure rate. The overall survival rate of all longer lengths was 95%. Winkler et al. published a multicenter report over a 3-year period in 2000.[38] The implant survival was directly related to the length of the implant. Whereas the 7-mm-long implants had a 26.4% failure rate, 16-mm implants demonstrated only a 2.8% rate of failure. Whereas implants of 8 mm had a 13% failure rate, 10-mm implants in the report failed at a rate of 10.9%, and the 13-mm implants failed 5.7% of the time (Figure 13-15). A multicenter report by Weng et al. in 2003 found that 60% of all failed implants were 10 mm or less in length.[39] The overall failure rate of all implants in the study was 9%, yet the 7-mm implant failed 26% of the time, and the 8.5-mm implant had a 19% failure rate (Figure 13-16). Naert et al. reported in the literature on clinical outcomes of short dental implants.[6] Whereas implants shorter than 10 mm had a survival rate average of 81.5%, longer implants had a survival rate higher than 95%.

It should be noted the failure rates in most of these reports are not surgical failures or failures to osseointegrate. The failures associated with short implants most often occurred after prosthetic loading. In other words, the surgical success was not affected by implant length. However, after the prostheses were in function, an increase in early loading failure was observed, especially within the first 6 to 18 months.[39]

Four reasons linked to biomechanics may explain why the short implant may have a higher failure rate after loading compared with longer implants[48]:

1. Less surface area to dissipate occlusal loads
2. Higher bite forces in posterior regions
3. Poorer bone density in posterior regions
4. Increased crown height (crestal bone resorption decreases implant length and increases crown height space)

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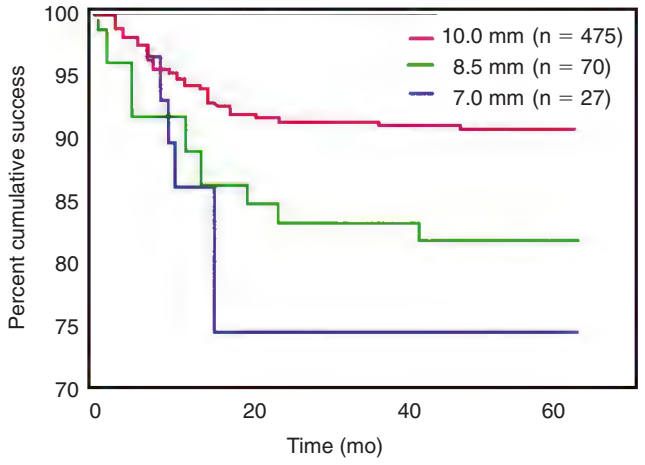


FIGURE 13-16. A multicenter study observed a 7-mm implant failed 26% of the time, and the 8.5-mm implant failed at a 19% rate. A total of 60% of all failures were shorter than 10 mm in length.[39]

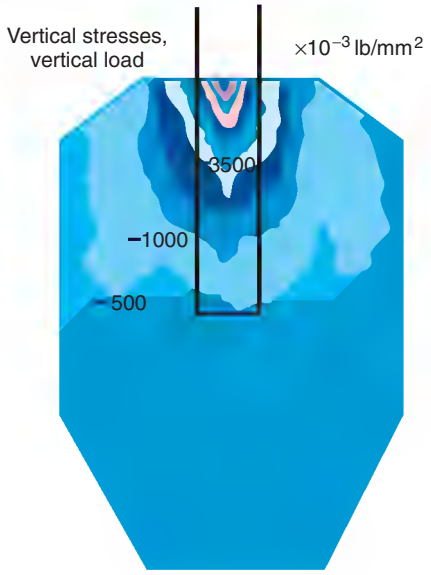


FIGURE 13-17. A three-dimensional study observed most of the strains in the bone simulant were in the crestal 5 mm of bone. Note this is in a dense bone simulant.

Rationale of Short Implants

The height of existing available bone is often used by the implant dentist to determine the implant length after adequate width and mesiodistal space are confirmed. The height of available bone is measured from the crest of the edentulous ridge to the opposing landmark. The posterior regions of the jaws usually have the least height of existing bone because the maxillary sinus expands after tooth loss and the mandibular canal is 10 mm or more higher than the inferior border of the mandibular body.[24] A radiographic study of 431 partially edentulous patients revealed that the posterior existing available bone height was 6 mm or greater in only 38% of maxillae and 50% of the mandibles.[36] The author observed that the posterior regions of either jaw in the completely edentulous patient has more than 6 mm of bone less than 20% of the time. As a result, in the posterior regions of the mouth with the highest bite forces, without advanced surgical procedures (i.e., sinus grafts, onlay grafts, nerve repositioning), the implants are often shorter when compared with the anterior edentulous sites.

Advantages of Short Implants

Implant length does affect the overall functional surface area of the implant body and is therefore theoretically desirable. However, unlike what occurs for a natural tooth and its periodontal membrane, stresses around implants during function and parafunction are typically concentrated on the marginal bone at the crest of the ridge in good-quality bone.[22] Three-dimensional analysis demonstrate that for an implant with a direct bone contact, the greatest magnitude of stress is concentrated in the crestal 5 mm of the bone–implant interface[33] (Figure 13-17). Stresses distributed to the apical third of an implant are of much less magnitude than those in the crestal third. As a result, under some clinical conditions, stress transfer patterns to the bone may be similar between a short and a longer implant.[49]

Shorter implants may offer several advantages compared with longer implants.[50] Bone grafting before and in conjunction with implant placement is not as frequent when short implants are used. Bone grafting is often less predictable than the initial healing of placing implants into existing bone volumes. The treatment time is often increased as a result of the bone graft before implant insertion. The discomfort of the patient is often greater for the bone graft than the implant insertion surgery. The cost of the procedure is increased when bone grafts are required. There is also less surgical risk of mandibular canal violation and paresthesia in the lower posterior jaw compared with nerve repositioning or placing implants lateral to the canal.

When an adjacent tooth root presents angulations of more than 15 degrees or has apical dilacerations of the root, the shorter implant may be inserted above the apex of the tooth without compromising the implant position. In ridges with undercuts or fossae or when basal bone and the original alveolar ridge are not in the long axis of the missing teeth, a shorter implant may be inserted at a better angulation for occlusal load (Figure 13-18).

From a surgeon's standpoint, the implant surgery is simplified. Drilling to the first line on the drill is easier to visualize during surgery. Because osteotomy drills may be shorter, the interarch space in order to position the drills is less, so the patient may more easily open his or her mouth so the implants can be placed in the posterior regions. This is especially advantageous in a patient with a small skull size. The surgical procedure is reduced in complexity with decreased risk of overheating the bone and subsequent ease of site preparation and implant insertion. From an office overhead perspective, less inventory and overhead in the office are additional benefits (Box 13-3).

In 2006, Misch et al. reported on a retrospective multicenter 6-year case series study,[51] during which 273 consecutive patients received 745 implants, either 7 or 9 mm long. These implants supported 338 restorations, all in the posterior regions of the mouth. There were 102 single-tooth implants and 236 fixed restorations supported by multiple implants. From stage I to stage II healing, there were six failures (99.2% success rate). During the fabrication of the restorations (early loading period), there were two implant failures (99.7% success rate). The 737 successful implants and 338 restorations were followed from 1 to 6 years after prosthesis delivery. A total of 140 implants were evaluated for at least 5 years and 263 implants for more than 4 years. No implants were lost after prosthesis delivery. Therefore, the overall success rate was 99% for up to 5 years (see Table 13-2).

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FIGURE 13-18. When a tooth is angled or has an apical dilaceration, a short implant may be placed adjacent to the tooth with less risk of injuring the adjacent tooth root.

BOX 13-3 Advantages of Short Implants

1. Crestal stress patterns similar to longer implants in most bone qualities
2. Less bone grafting in height required
   a. Less time for treatment
   b. Less discomfort
   c. Less cost of treatment
3. Less surgical risk of:
   a. Sinus perforation
   b. Paresthesia
4. Less damage to adjacent tooth root if angled or dilaceration
5. More correct implant loading and esthetic position with fossa or undercut
6. Surgical ease
   a. Decreased interarch space required for implant placement
   b. Osteotomy trauma from heat reduced
7. Less inventory and cost

In this multicenter report, a short implant dimension protocol was used to reduce biomechanical stress factors (Figure 13-19). For example, incisal guidance eliminated lateral posterior forces in excursions, multiple implants without cantilevers were always splinted together, and additional implants or wider implants were used when possible (Figure 13-20). Other recent reports in the literature also support the use of short implants, provided proper force orientation and load distribution are favorable[44-46,50,52] (Table 13-2). Therefore, when a biomechanical approach to decrease stress or increase area is followed, an implant survival similar to other reports may be obtained (Box 13-4).

It is interesting to note that most reports of short implant success (survival) are in the posterior regions of the partially



FIGURE 13-19. Implants smaller than 10 mm long should use a biomechanical approach to decrease stress. Increasing implant number, splinting implants, no cantilever, and no lateral loads are indicated.



FIGURE 13-20. When short implants are used, they should be splinted to longer implants when possible. In addition, the width of the implant may be increased.

TABLE 13-2
Short Implants (Literature Review Above 90%)

Author (Year)	No. of Implants	Success Rate (%)	Implant System
Higuchi et al.[42] (1995)	109	94	Brånemark
Lekholm et al.[43] (1999)	101	94	Brånemark
van Steenberghe et al.[44] (2000)	16	100	Astra
Testori et al.[45] (2001)	31	97	3i
Tawil et al.[46] (2006)	116	93	Brånemark
Misch et al.[51] (2006)	437	99	BioHorizons
Total implants: 810			
Average success rate: 96.8%			

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BOX 13-4 Short Implant Protocol

1. Increase diameter
2. Splint together
3. Minimize lateral force
4. Decrease cantilever length
5. Increase surface area design
6. Overdenture versus fixed partial denture in patients with nocturnal parafunction
7. Improve bone density (progressive loading)

edentulous mouth or completely edentulous mandibles opposing a conventional denture. A partially edentulous patient has incisal guidance and no lateral forces in the posterior regions. A completely edentulous atrophic mandible opposing a denture has a dramatic decrease in functional force, has the biomechanical advantage of an arch in the anterior mandible, and usually has a good bone quality.

Ideal Implant Length

To obtain predictable success in situations with most patient force factors or bone densities, there is an ideal implant length, depending on the implant body width and the implant design.[48] When available bone height is not a factor, the implant should be between 12 and 15 mm in height. When a reduced height of the implant is used, more attention to biomechanical conditions that reduce stress is required. The softer the bone, the greater the implant body length and diameter suggested.

The literature observes a wide range of implant studies reporting higher implant survival rates when the implant is at least 12 mm in length. For example, Ivanoff et al. reported a 30% failure with short implants compared with 5% with longer implants.[53] Winkler et al. found the difference in survival to be 25% compared with 3%,[38] Weng et al. found it to be 26% versus 9%,[39] and Naert et al. found it to be 19% compared with 8% for short implants.[6] Goodacre reviewed 13 articles and found a combined difference of 15% failure compared with 3% with longer implants.[32]

Shorter implants usually increase the risk of failure and therefore are not initially treatment planned as a first option. Rather than establish an ideal treatment plan that may be deficient in implant loading surface area, the minimum length of an implant for an unloaded healing protocol is usually 12 mm or more for most implant designs. Therefore, after the ideal treatment plan determines the key implant positions and implant number, the implant length selected for most treatment plan options is at least 12 mm long. Implants from 12 to 15 mm in length are usually considered sufficient for most clinical situations. When the ideal implant length is not possible (or practical), a shorter implant with more implant numbers, increased width, and no cantilever and no lateral forces on the prosthesis is an alternative.

It is interesting to note the posterior teeth are not a different length than the anterior teeth. Although they differ in width and root design, the length of the tooth root is similar. A typical tooth length is greater than 12 mm long. Hence, under ideal conditions of a cortical lining and periodontal complex, the root length is a more consistent variable than many other factors. It is logical to treatment plan an ideal implant length for an ideal treatment outcome.

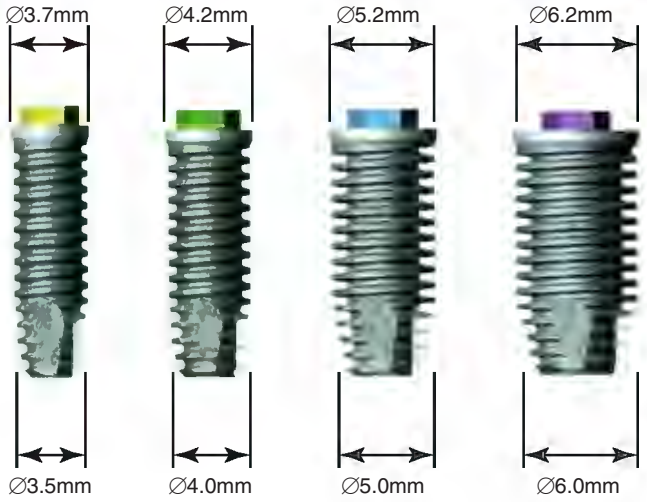


FIGURE 13-21. Several manufacturers offer implants with several different diameters. (BioHorizons Dental Implants, Birmingham, AL.)

Implant Diameter

Wide-Diameter Implants

Over several decades, implants have gradually increased in width. The pin implants of Scialom in the 1960s and 1970s were less than 2 mm wide.[54] Brånemark et al. introduced a constant implant body diameter of 3.75 mm.[1] An implant body of 4 mm in diameter was also available and was primarily used as a rescue or "backup" implant when the initial implant inserted lacked stability during surgical placement. Any implant body greater than 4 mm may be considered a "wide-diameter implant."

In the 1990s, several implant manufacturers provided implants with diameters greater than 4 mm and a few as large as 8 to 10 mm (Figure 13-21). These larger-diameter implants were primarily used to simulate the diameter of the tooth being replaced and improve the emergence profile of the implant crown. It was rationalized that if the implant was similar in diameter to the replacement tooth size, the crown would be more esthetic. The wide-diameter implant may present surgical, loading, and prosthetic advantages. In addition, because the cost of the implant is not related to diameter, the placement of one wide implant has less cost than two smaller-diameter implants.

Surgical Advantages

The surgical advantages relate to the use of a wide implant as a rescue implant when the regular body size does not adequately fixate to the surrounding bone. The regular implant may be removed and replaced with the wide-body implant. When an implant fails, because of lack of osseointegration or fracture, the implant may be removed, and the wide-body implant is immediately inserted.[55] This eliminates the need for bone grafting, the time for bone augmentation healing, and the additional surgery to replace the implant. The same concept may be used for the immediate placement of an implant after the extraction of a tooth.[56] Because the diameters of most teeth are larger than 4 mm, a wider-diameter implant has less space between the walls of the extraction site and the wide implant body. It also has more fixation to the apical walls of the socket (Box 13-5).

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BOX 13-5 Wide-Diameter Implants: Surgical Advantages

Surgical Rescue Implant
1. Implant not fixated when inserted
2. Failed implant: immediate placement
3. Tooth extraction: immediate placement

BOX 13-6 Wide-Diameter Implants: Loading Advantages

1. Increase surface area
   a. Compensate for unfavorable patient force factors
   b. Decrease effect of cantilevers
   c. Decrease effect from angled implant
   d. Compensate for poor bone density
   e. Enhance surface area for short implants

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Loading Advantages

A logical method to increase functional surface area of an implant body in higher stress conditions (i.e., in the posterior regions) is to increase the implant diameter, especially when the opposing landmarks limit the implant length. Wider root form designs exhibit a greater area of bone contact than narrow implants of similar design, partly from an increase in circumferential bone contact. For each millimeter implant diameter increase, the functional surface area is increased by 30% to 200%, depending on the implant design (i.e., cylinder versus some thread designs)[57] (see Figure 13-9) An implant shorter than 12 mm is more often used in the posterior regions of the mouth. Under such conditions, the wide-diameter implant may compensate for the less than ideal implant length. Because occlusal stresses to the implant interface are concentrated at the crest of the ridge in good-quality bone, width appears more important than height after a minimum height has been obtained for initial fixation and resistance to torque and bending loads. It is interesting to note that this trend is also noted in natural teeth to compensate for increased force in the posterior regions; molar teeth are wider in diameter than incisors but not necessarily longer.

The loading advantages of a wider implant relate to a greater surface area, especially in the crestal region of the implant. The greater surface area is a benefit when the patient force factors are greater (e.g., parafunction, increased crown height, increased masticatory dynamics, and the molar regions in the posterior regions of the mouth). The greater surface area is an advantage when a cantilever (either in a mesiodistal or facial-lingual direction) is necessary to restore the dentition. The most distal implant with a posterior cantilever acts as a fulcrum and receives the greatest force. The wider diameter reduces the risk of overload. An angled load to the implant body increases the magnitude of the force at the crestal marginal bone and to the abutment screw of the implant. A larger diameter implant reduces the magnitude of forces to the entire implant system. In situations of poor bone density, there may be overload even with normal occlusal forces. Wider diameter implants distributing forces over a greater surface area may decrease this risk (Box 13-6).

A comparative evaluation on strains in the alveolar crest of implants with different diameters was performed by Petrie and Williams.[58] In this three-dimensional finite element analysis, there was as much as 3.5-fold reduction in stress when wider-diameter implants (up to 6 mm) were compared with narrow diameters (3.5 mm). It should be noted that the implant length reduced stress by 1.6-fold and a tapered implant body increased stress by a similar 1.6-fold amount. In 2004, Himmlova et al. confirmed the findings on a three-dimensional computer model (using good-bone quality) evaluating implant lengths and diameters from 2.9 to 6.5 mm.[59] The stresses were primarily at the marginal bone levels at the crest of the implant. The greatest decrease in stress was found between 3.6- and 4.2-mm implants (31.5%); the 5-mm implant compared with the 4.2-mm diameter reduced the stress by less (16.4%). The length of the implant also reduced the amount of stress but was not as pronounced as the diameter. A study by Aparicio and Orozco in 1998 used Periotest values to clinically confirm less stress transferred to the implant–bone complex.[60] The observed Periotest values from 5-mm-wide implants in the maxilla and mandible were 1.1 and 0.6 units lower than for 3.75-mm-diameter implants in the same patients. Hence, in this report, softer bone (i.e., maxilla) demonstrated more of a benefit for a larger diameter implant than more ideal bone densities.

Several clinical studies in the literature report a similar or improved implant survival rates with larger-diameter implants compared with the regular diameters. Graves et al., in 1994, reported a 96% survival rate over a 2-year period with 268 wide implants in 196 patients.[61] All failures occurred before stage II surgery from nonintegration of the implant. In 2000, Winkler et al. reported on the influence of implant diameter and length related to implant survival.[38] Whereas the survival of implants 3.0 to 3.9 mm in diameter was 90.7%, the survival rate of implants from 4.0 to 4.9 mm was 94.6% over a 3-year period. The 5.5-mm-wide implant was evaluated by Krennmair and Waldenberger in 2004 with 121 implants in 114 patients.[62] The study yielded a 98.3% overall survival rate, with 100% in the mandible and 97.3% in the maxilla. Griffin and Cheung reported on short, wide implants in posterior areas with reduced bone height for 168 hydroxyapatite (HA)-coated implants 6 mm in diameter and 8 mm long in 167 patients.[50] The overall cumulative survival rate for up to 68 months (mean, 34.9 months) after loading was 100%.

In 2005, Anner et al. found a 100% survival rate in 45 implants with a mean loading period of 2 years with a 6-mm-wide, tapered, HA-coated implant.[63] Misch et al. compared 4- and 5-mm implants that were 7 and 9 mm long, respectively, in the posterior maxilla and mandible.[48] The 5-year retrospective study yielded 100% implant success for the 5-mm implant and a 98% survival rate for the 4-mm implant. In 2007, Albrektsson et al. reported on data from 18 different centers.[64] The 3.5-mm implant failed 11.8%, and the 4.3-mm-diameter implant failed 2.8% of the time. Therefore, many clinical reports seem to indicate that larger-diameter implants can achieve similar (or greater) implant survival compared with the standard 3.75-mm-diameter implant body.

Prosthetic Advantages

The prosthetic advantages of the wide-diameter implant include an improved emergence profile for the crown replacing a larger diameter tooth. The larger the implant diameter, the more closely the emergence profile resembles the natural tooth, especially in the posterior region of the jaws. Most natural roots are

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greater than 4 mm in cross-section. The closer the implant diameter to the root diameter, 2 mm below the cementoenamel junction (CEJ), where the ideal crestal bone level resides, the more similar the crown emergence profile to a natural tooth. This is especially noted in the maxillary first molar region because the root diameter approaches 8 mm, or twice the size of a 4-mm implant (Figure 13-22). The wider crown contour also decreases the interproximal space of the crown and decreases the incidence of food impaction during function (Figure 13-23, *A*). The wide-diameter implant may also improve sulcular daily oral hygiene by improving the crown emergence and avoid the need for a prosthetic ridge lap of the crown. The improved contour also allows access to the sulcus for periodontal probing depths.

In 1997, Jarvis emphasized the biomechanical advantage of wide-diameter implants, particularly in reducing the magnitude of stress delivered to the various parts of the implant.[65] The diameter of the implant is related to the bending fracture resistance or moment of inertia, and the increase in diameter decreases the risk of fracture to the power of 4, provided all other geometric features remain the same. Therefore, to decrease the risk of implant body fracture, an implant placed in a young, bruxing man should be larger in diameter than an implant for an older, nonparafunctional woman (Figure 13-23, *B*).

The force on an abutment screw is reduced with a large-diameter implant.[10] Boggan et al. modeled the implant assembly as an engineering assembly and found the following formula:

$$Fs = \frac{\{P(H) - R2(h)\}^2}{D}$$

Where:
Fs = load on abutment screw
P = lateral load on the abutment
H = abutment height
R2 = reaction force on external (or internal) hex
h = external (or internal) hex height (or depth) of the implant
D = platform diameter of the implant
Point A = point of abutment rotation (see Figure 13-23)

By increasing *D* (platform diameter), the force on the screw is decreased. Hence, larger-diameter implants have less force on the abutment screw. A decrease in force to the abutment screw results in less screw loosening and less risk of abutment screw fracture (Figure 13-24). Hence, not only is the risk of facture reduced because of the diameter, but the force on this abutment screw is also reduced to decrease screw-loosening complications (Box 13-7). When a smaller abutment diameter is placed on an

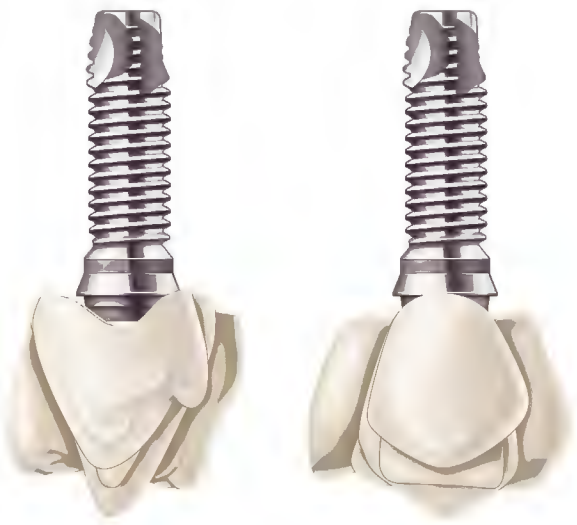


FIGURE 13-22. The diameter of a tooth is often larger than an implant to replace it. As such, the larger the implant, the more the emergence profile at the cervical region resembles a tooth.

BOX 13-7 Wide-Diameter Implants: Prosthetic Advantages

1. Improve emergence profile of wider teeth
2. Facilitate oral hygiene and periodontal probing
3. Minimize implant body fracture
4. Decrease abutment screw loosening

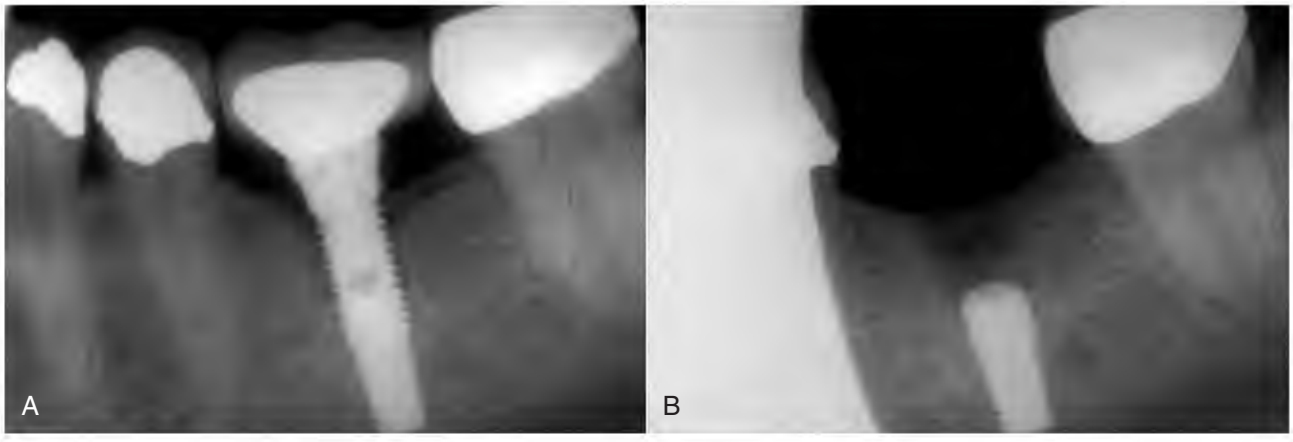


FIGURE 13-23. **A,** A regular-diameter implant in the molar region has more interproximal spaces and results more often in food entrapment between the teeth. Note the marginal bone loss to the seventh thread. **B,** The implant in **A** fractured as a consequence of too much biomechanical stress. The fracture occurred after the crestal bone loss.

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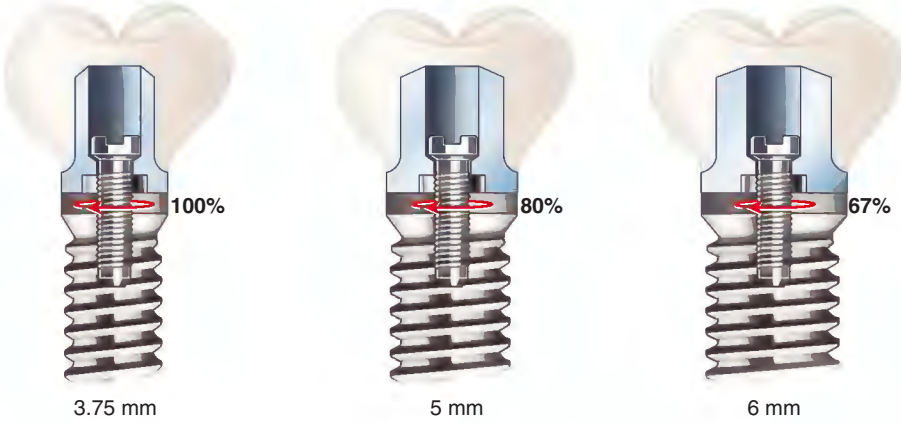


FIGURE 13-24. The wider-diameter implant transmits less force to the abutment screw. Hence, screw loosening is less often observed.

implant (platform switching), the force on the screw will increase along with the risk of screw loosening.

In a clinical article by Cho et al., wide-diameter implants had 5.8% screw loosening compared with 14.5% for standard-diameter implants.[66] When a greater force is applied to the system, two regular-diameter implants rather than one wide-diameter implant is advantageous to decrease screw loosening. For example, Balshi et al. reported a 40% abutment screw loosening during a 3-year period when replacing a molar with one implant.[67] This complication was reduced to 8% when two implants replaced a single molar.

Disadvantages of Wide-Bodied Implants

The disadvantages of a wide-bodied implant are primarily related to the surgical aspects and early healing period. Some reports indicate a higher failure rate of wide-diameter implants. Eckert et al. found 19% implant loss in the mandible and 29% in the maxilla with 85 wide-platform implants in 63 patients.[68] Attard and Zarb compared the success rate of the standard-diameter 3.75-mm-implant at 15 years and the 5-year survival rate of the wide-platform, 5-mm-diameter implant replacing posterior teeth.[69] Whereas the standard-diameter implant had a 91.6% implant survival, the 5-mm implant had a 76.3% rate. Shin et al. found an 80.9% survival rate of 5-mm-diameter wide-bodied implants compared with 96.8% for the regular-diameter implants over a 5-year period.[70]

Ivanoff et al. stated that the higher failure rate of wide diameter implants may be caused by an early learning curve, implants used in poor bone quality, and the use of the wide-diameter implant as a rescue implant when the standard diameter did not reach stability or failed.[53] In addition, for most implant systems, the wider implant does not use as many sequential drills to increase the implant osteotomy diameter compared with the regular-diameter implant. As such, the final drill cuts more bone and increases the amount of heat generated during the process. Hence, the bone trauma may be increased.

The higher bite forces and lower bone density of the posterior regions may not always be able to be addressed adequately by primarily implant width. Ivanoff et al. found 6-mm-long implants with a 5-mm diameter had a failure rate of 33% in the mandible and 10% in the maxilla.[53] The 8-mm-long, 5-mm-diameter implant failed 25% of the time in the maxilla and had a 33% failure rate in the mandible. In this study, the longer 10- and 12-mm implants that were 5 mm in diameter reported 0% mandibular failure and a 10% failure in the maxilla. Therefore, the increase in implant diameter alone was not enough to compensate for the shorter implants in this report.



FIGURE 13-25. A wide-diameter implant replacing an anterior tooth may result with the implant closer than 1.5 mm from the adjacent tooth or the facial plate of bone.

A wide-bodied implant may be closer than 1.5 mm to the adjacent tooth or result with less than 1.5 mm of facial or palatal bone (Figure 13-25). As a result, the bone loss around the platform from an "implant biologic width," microgap position, smooth metal below the bone, or loading bone loss may also cause bone loss on the adjacent tooth or facial bone loss and gingival recession.[71–73] Therefore, abundant bone volume is necessary for wide-diameter implants to prevent these occurrences.

Stress shielding occurs when insufficient stress is transferred to the implant–bone interface, which results in disuse atrophy of the bone, similar to a condition when no strain is transferred to bone after tooth loss. Because the implant is made of a material 10 times more rigid than cortical bone and the implant modulus (stress–strain curve) is related to implant diameter, the larger-diameter implants must receive more stress to stimulate the bone. Implants 6 mm or wider in the anterior regions of the mouth were initially inserted because a central incisor root is approximately 6 mm at the CEJ. However, these implants

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often exhibited crestal bone loss from inadequate stress conditions and were also too close to the adjacent lateral incisors. As a result, bone loss and gingival recession were common (Figure 13-26). In the posterior regions, 8-mm-diameter implants were used in the molar sites. Again, the implant is so wide that the bone was often not strained enough to maintain a load-bearing lamellar pattern. Instead, the lack of strain resulted in disuse atrophy and bone loss. (Titanium has almost 20 times the modulus of elasticity of fine trabecular bone.) In other words, the bending fracture resistance of an 8-mm-diameter implant is 16 times more than a 4-mm-diameter implant, and as a result, the stimulation of the interface may be too low to maintain bone. Therefore, an implant should not be wider than 5 mm in the anterior region when adequate mesiodistal space is present, and the implant should not be greater than 6 mm in the posterior region unless adequate forces exist to stimulate the bone (Box 13-8).

Narrow-Diameter (Mini) Implants

In the 1970s, narrow-diameter implants smaller than 2 mm diameter were very popular in Europe and South America. These "pin" implants were often used in two or three sets for each tooth (Figure 13-27). They did not maintain crestal bone, often would fail or fracture, and became unpopular after the 3.75-mm-diameter root form implants were developed. More recently, these implants have reemerged in the marketplace.



FIGURE 13-26. Six-mm-diameter implants were often suggested to replace maxillary central incisors. However, they were often too close to the lateral incisor and often would lose crestal bone.

BOX 13-8 Wide-Diameter Implants: Disadvantages

1. Increased failure rate
2. Bone trauma—drill sequence
3. Too close to adjacent tooth; poor interproximal esthetics
4. Decreased facial bone thickness may lead to bone loss and increased pocket depths or recession
5. Stress shielding

The initial reentry of the mini-implant was for a transitional prosthesis; the diameter of these implants ranged from 1.8 to 2.4 mm. After the final implant positions and numbers were inserted in a two-stage healing process, additional mini-implants were used to immediately restore and support a transitional prosthesis. This approach still has validity when patients do not want to wear a removable restoration during the initial healing process or to protect a bone graft site during augmentation. Although the transitional mini-implants may fail in some clinical situations, the regular-size implants are not affected, and the final restoration is not at risk.

After a few years, the "mini" implants were suggested for implant overdenture support. The concept (as presented) places multiple "mini" implants with O-ring or other overdenture attachment systems and immediately is used to retain and support the prosthesis (Figure 13-28). It is also presented as a "simple solution for denture comfort because of flapless implant



FIGURE 13-27. In the 1970s, narrow-diameter implants were often splinted together for implant support. They did not maintain crestal bone and would often fail or fracture.



FIGURE 13-28. The small-diameter (mini) implants have recently been reintroduced into the marketplace to be immediately used to retain an overdenture.

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installation."[74] This concept also encourages a reduced fee to have greater patient acceptance.

Disadvantages of "Mini" Implants

Compared with implants 3.75 mm or larger, with thousands of clinical reports, the small-diameter implant has almost no long-term studies. Even studies longer than 3 years are limited in numbers. Because implants smaller than 3 mm in diameter are usually too narrow for a two- or three-piece implant body abutment design, a one-piece implant is most often designed (Figure 13-29). This requires the implant abutment portion to extend into the mouth upon insertion. Hence, the implant most often is immediately placed into more function compared with the one- or two-stage approach. This increases the risk of failure during the healing period of bone because the surgical healing and the early loading period occur at the same time.

An implant has an increased risk of healing and early loading failure of 5% to 30% when used for an immediate restoration, in part related to a number of factors, including the implant diameter and design. In a report by Albrektsson et al. from 18 different clinical centers, immediate- or early-loaded implants had a failure rate of 11.8% compared with a 1.7% failure rate for delayed loading.[64] In this report, the 3-mm-diameter implant failed 20% of the time, the 3.5-mm-diameter implant 11.8% of the time, and the 4.3-mm-diameter implant 2.8% of the time. The mini-implant is usually less than 2 mm in width. In a study by Misch, the small-diameter implant (2.2–2.4 mm) had a 75.7% survival rate after 6 weeks when used immediately for retention of a mandibular denture using four to five implants per patient.[74]

To decrease the risk of healing and early loading failure, a wider-diameter implant with an implant body with more surface area is of benefit. Because the mini implants are too narrow to increase the depths of each thread, they act more as a nail than a screw. Hence, the surface area for initial fixation, early loading, and mature loading is reduced.



FIGURE 13-29. Most "mini" implants are too narrow for a separate abutment-to-implant connection. As a result, they are one piece implants with the abutment connected to the implant body and often placed in function after insertion.

The mini implant designs are usually deficient in seven ways: (1) decreased diameter and less surface area for loading, (2) a decreased thread depth, (3) less initial fixation, (4) greater risk of fracture, (5) narrow range of prosthetic abutment options, (6) difficult to splint implants together, and (7) immediate restoration often required (Box 13-9).

The "flapless" surgical approach is often suggested with the mini implant and has a perceived benefit of surgical ease and less patient discomfort. However, there is an increased risk of bone perforations in the areas of concavities or minimal thickness regions of the crestal bone. If a computed tomography (CT) scan is not performed before surgery, it is almost impossible to evaluate most edentulous maxillae and many edentulous mandibles without reflecting the tissue. In a study by Misch there was no difference in the postoperative pain medication requirements of patients with a "flapless" surgery compared with the regular reflection surgical technique.[74] Therefore, it is suggested to directly observe the bone region before and during implant insertion unless abundant bone and CT scans are available.

Less risk of early implant failure is present when the implants can be splinted together. The "mini" implant is most often used as an independent unit because angled abutments are not available (because the implant–abutment is all one piece). Therefore, the stresses are generally greater and the failure rate risk is greater because the implants are independent units.

In addition to a higher risk of failure, the bending fracture resistance and fatigue fracture of the mini implant is 16 times less than a regular 4-mm-diameter implant (Figure 13-30). Cycles to fracture may be as few as 11,000 to 20,000 cycles at 200 N (1350 lb). The teeth often have 440 cycles/day of function and parafunction with 314 cycles/day of ¾ maximum bite force.[75] Hence, the mini implant may be at risk of fracture even within the first year of loading.

A mini implant is often promoted as a less expensive option for the patient. The product cost to the doctor of a "mini" implant is approximately half a regular-size implant. It is safer to reduce the fee in half and then add the extra cost of a regular implant than to reduce the fee; use a mini implant; and have a greater risk of early failure, greater risk of fracture, greater risk with independent units, and limited prosthetic options. A two-stage implant system may have confirmation of successful integration healing without a prosthetic load (Figure 13-31). A range of abutments permits individual loading or splinting the implants together after integration is confirmed. However, the mini implants do have a benefit for transitional prostheses and transitional solutions to protect a bone graft, especially when the patient does not accept a transitional removable restoration.

BOX 13-9 Narrow "Mini" Diameter Implants: Disadvantages

1. Few studies more than 2 years
2. Immediate restoration often required
3. Less surface area for loading
4. Less initial fixation
5. Higher failure rates
6. Limited prosthetic options
7. Greater risk of fracture
8. Higher risk procedure

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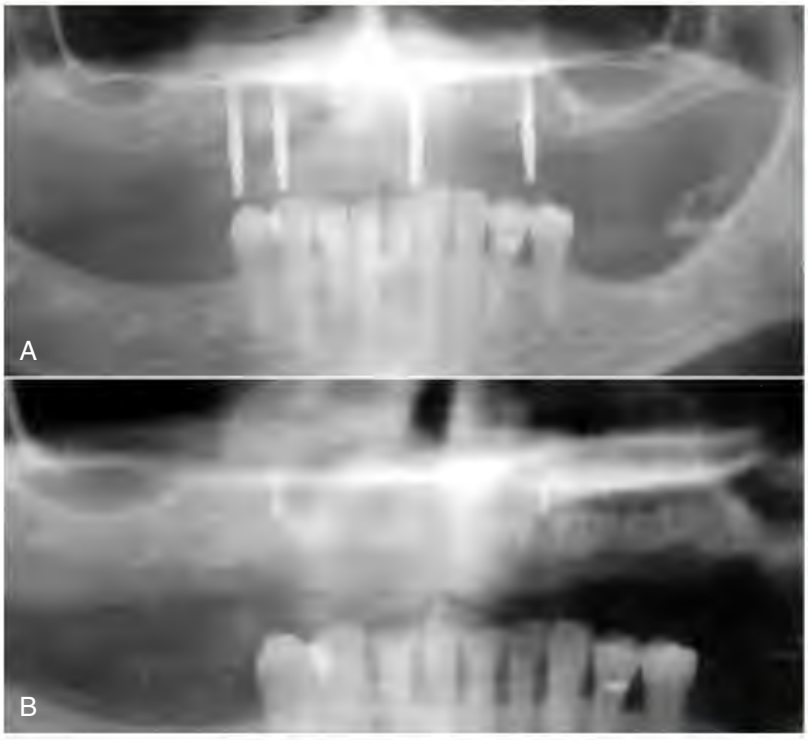


FIGURE 13-30. **A,** Five "mini" implants were inserted into the anterior maxilla to support a denture. The left canine implant has fractured. **B,** After a brief time, the other four implants also fractured.



FIGURE 13-31. A two-stage regular-diameter implant may integrate before loading and have a wide range of abutments to help retain the prosthesis.

Ideal Implant Width

Biomechanics

The natural teeth may be used as a guideline to determine the ideal implant width for function loads. The roots of the natural dentition optimize the amount and direction of forces found with the mouth. The smallest-diameter roots are in the mandibular anterior region, where the forces are less and the direction of force is along the long axis of the root. The maxillary anterior teeth have larger roots and a different cross-section shape to compensate for the off-axis loading that increases lateral forces on the structure. The canines have a greater root surface area in response to the higher bite forces (90 lb/in^2 compared with 35 lb/in^2) and the direction of force during mandibular excursions.

BOX 13-10 Ideal Implant Diameters: Function

Mandibular incisors and maxillary lateral incisors: 3–3.5 mm diameter
Maxillary centrals, maxillary and mandibular canines and premolars: 4 mm diameter
Molars: 5–6 mm diameter

The premolars have less surface area than the canines because they do not receive a lateral load in excursions. The molars have multiple roots splinted together in one crown. The maxillary posterior region has the least bone density; the mandibular counterpart has coarser trabecular bone. The maxillary molars have more roots than the mandibular components and therefore have more surface area to dissipate loads in the fine trabecular bone located in this region of the mouth. The molar crowns are almost twice as large in diameter, and the root surfaces are twice those of the premolars. This compensates for the amount of load increase by two to three times and decreases the risk of damaging stresses (Figure 13-32).

In this light, the mandibular incisors region and the maxillary lateral incisor may be replaced with 3- to 3.5-mm-diameter implants; the maxillary centrals, canines, and premolars in both arches may use 4-mm-diameter implants. The molars may be restored with 5- or 6-mm-diameter implants in both arches. When larger-diameter implants cannot be used in the molar region, two 4-mm-diameter implants for each molar should be considered, especially in the maxilla (Box 13-10).

Esthetics

Maxillary Anterior Single-Tooth Replacement

When a FP-1 crown is the treatment of choice, the available bone, soft tissue drape, implant position, and implant size should be ideal. Of these parameters, the implant size is one of

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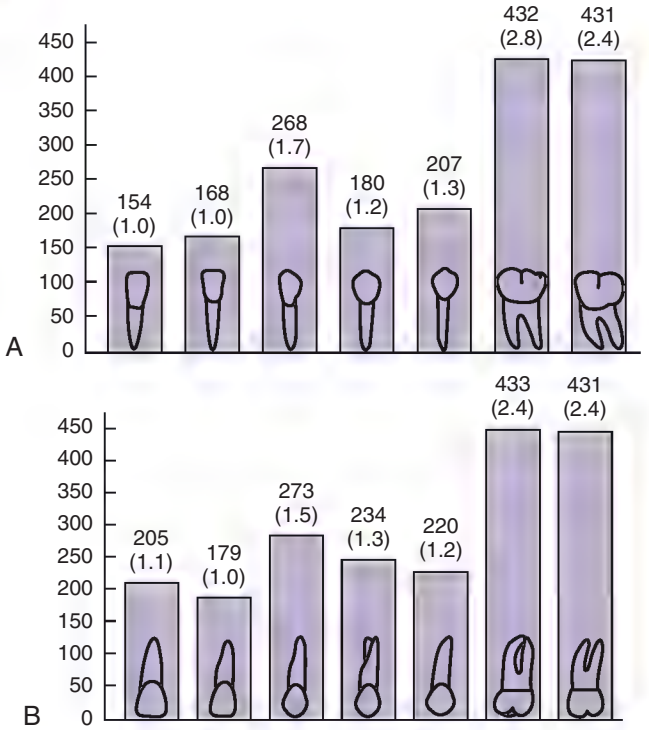


FIGURE 13-32. **A,** The root surface area of the mandibular teeth is greater in the posterior regions, where the bite forces are greater. **B,** The root surface area of the maxillary teeth is greater than that of the mandibular teeth because the surrounding bone is less dense.

the variables most in control of the dentist, which may affect the clinical outcome. It is usually better to err to the smaller diameter than place an implant too large in diameter.

There are several criteria to select an implant diameter based on esthetics. The first guideline is the size of the natural tooth that is replaced. The average mesiodistal dimension for a central incisor is 8.6 mm for a man and 8.1 mm for a woman, a lateral incisor is 6.6 mm for a man and 6.1 mm for a woman, and a canine is 7.6 mm for a man and 7.2 mm for a woman. However, the implant body should not be as wide as the natural tooth or clinical crown it replaces. Otherwise, the emergence contour and interdental papillae region cannot be established properly. The teeth become narrower as they proceed apically. The mesiodistal dimension of the maxillary central incisor at the cervix of the CEJ averages 6.4 mm, the lateral incisor dimension is 4.7 mm, and canine natural teeth at the cervix are 5.6 mm.[75,76] This dimension is also too wide for an implant to restore the soft tissue and emergence profile of a crown associated with the implant.

The bone level on natural teeth is 2 mm below the CEJ. The natural tooth (root) dimensions at this bone level are reduced to 5.5 mm for central incisors, 4.3 mm for lateral incisors, and 4.6 mm for canines. Therefore, the latter dimensions most closely approximate the widest implant diameter to mimic the emergence profile of a natural tooth as it emerges from the bone crest through the soft tissue drape.

The second factor that determines the mesiodistal ideal implant diameter to replace a tooth for esthetics is the necessary distance from an adjacent tooth root or implant. The horizontal dimension of a wedge-shaped bone defect around an implant at the crest of the ridge from the "implant biological width" or implant design, or occlusal overload is about 1.4 mm wide.[77]

BOX 13-11 Ideal Implant Diameter: Esthetic Considerations

- Size of natural tooth
- Mesiodistal diameter of implant versus tooth (3 mm or more difference)
- Faciolingual dimension of bone

When the implant is closer than 1.5 mm to an adjacent root of a tooth, the wedge-shaped vertical defect may become a horizontal defect, creating bone loss on the adjacent tooth root. Initial vertical bone loss around an implant during the first year of loading varies and ranges from 0.5 mm to more than 3 mm. This effect is important to consider because the interseptal bone height in part determines the incidence of presence or absence of the interdental papillae between the teeth or implants.[78] As a result, an implant should be at least 1.5 mm from the adjacent teeth whenever possible.

It should be noted that natural tooth roots are often closer than 1.5 mm to each other. As a consequence of the 1.5 mm or more guideline, the ideal mesiodistal implant size is usually less than the natural root dimension. Most often, the ideal implant diameters used to replace the average-size anterior tooth correspond to a 4-mm implant for a central incisor, a 3- to 3.5-mm implant for a lateral incisor, and a 4-mm implant for an average canine (Figure 13-33).

A third criterion for the ideal diameter of an implant is the faciolingual dimension of bone. In the esthetic zone, 1.5 mm or more of bone on the facial of the implant body is a benefit in case crestal bone loss occurs. Otherwise, gingival recession is more likely to occur if bone loss is present. In addition, the incidence of crestal bone loss is reduced when the width of the ridge is 2 mm or more wider than the implant crest module (with 1.5 mm on the facial aspect).

In summary, three conditions determine the ideal anterior tooth implant diameter. The ideal diameter most often corresponds to the width of the missing natural tooth, 2 mm below the CEJ. In addition, the implant diameter plus 1.5 mm on each side should be equal to or less than the mesiodistal dimension between the two natural roots at the level of the crest of the residual ridge. Third, the faciolingual dimension of the bone should be 2 mm or greater than the implant diameter, with 1.5 mm or more on the facial aspect of the crest module (Box 13-11). Hence, the functional and esthetic determinants of an ideal implant width are similar.

The implant dimension in question is the size of the crest module, not the implant body dimension. For example, a 4.1-mm crest module (on a 3.75-mm implant body) needs 7.1 mm of mesiodistal crestal bone, a 3.5-mm crest module (on a 3.25-mm implant body) is indicated for 6.5 mm of bone, and a 5.2-mm crest module requires 8.2 mm of bone.

The difference in the emergence profile between a 4-mm-diameter implant and a 5-mm-diameter implant is often not clinically relevant and provides a zone of safety related to the available bone around the implant.

Multiple Anterior Implants

Multiple adjacent implants should be splinted together, which permit a smaller diameter to fulfill biomechanical guidelines. Therefore, when in doubt, a smaller size diameter implant should be selected. As such, a 4-mm-diameter implant often is

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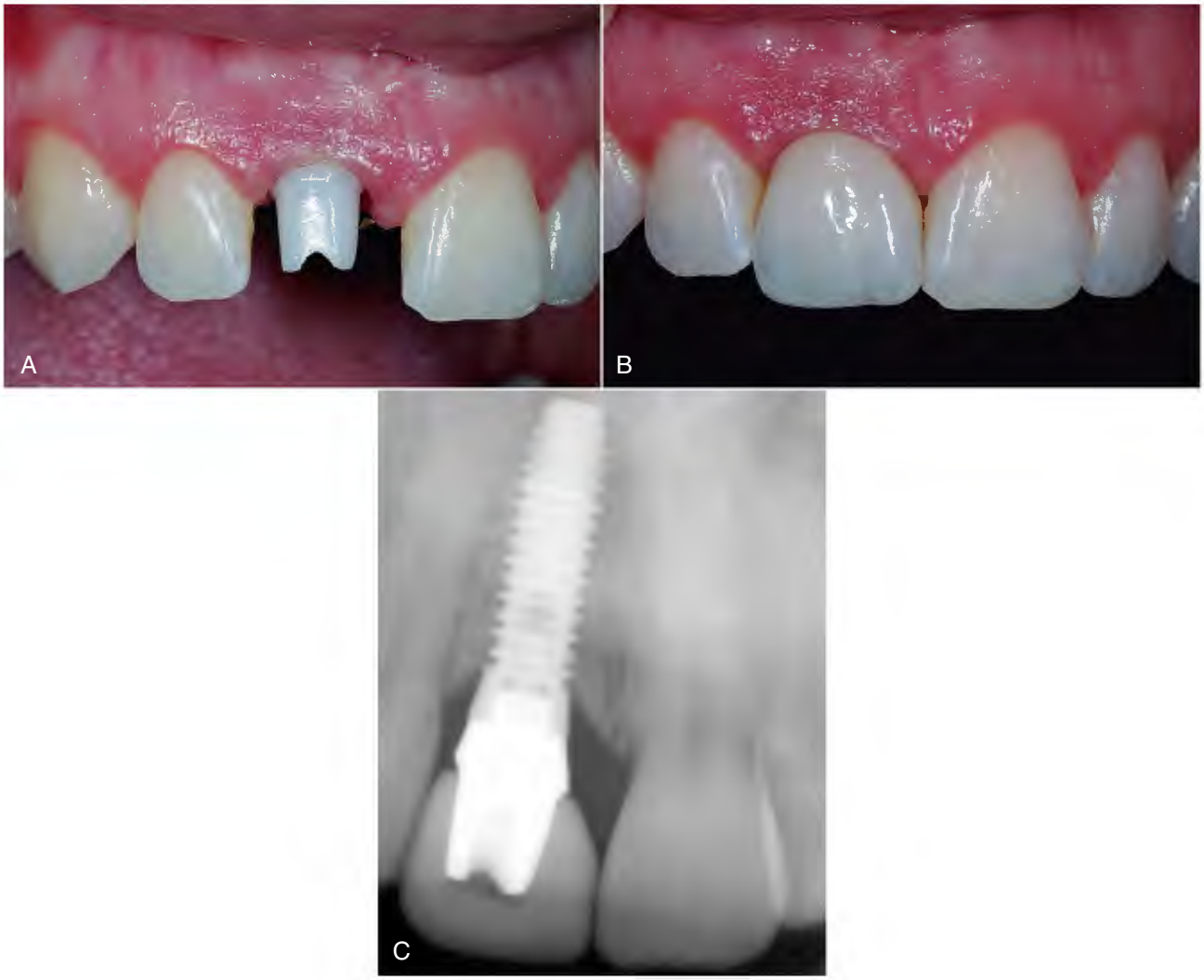


FIGURE 13-33. **A,** A 4-mm implant to replace a maxillary central incisor is most often the diameter of choice. **B,** The emergence of the implant crown gives the perception of a natural tooth. **C,** A 1 year post-operative radiograph of the 4-mm diameter implant.

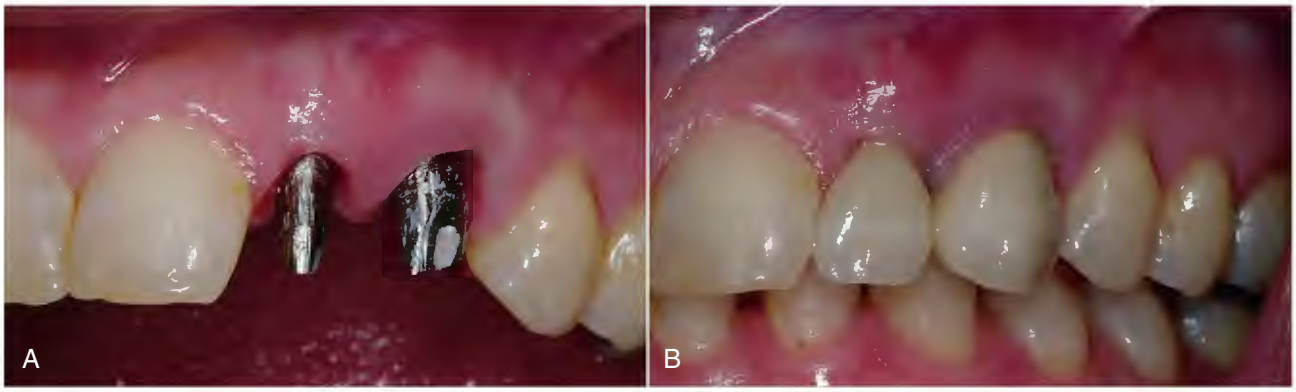


FIGURE 13-34. **A,** When two or more adjacent teeth are replaced with implants, the implant diameter is often reduced. The lateral implant is 3 mm in diameter, and the canine implant is 4 mm. **B,** The implant crowns are splinted together. The reduced implant width allows more interimplant tissue, and the interproximal papilla may be restored.

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used in the central implant position. Likewise, a 3-mm-diameter implant often is used for a lateral incisor restoration when the mesiodistal tooth dimension is less than 6.5 mm (Figure 13-34). The exceptions to this rule may be in a bruxing patient. A wide-diameter implant will decrease the risk of abutment screw loosening, crestal bone loss, and long-term implant body failure in situations of greater occlusal load.

When implants are placed adjacent to each other, a minimum distance of 3 mm is suggested between the implants, especially when crestal bone loss is expected around the implants, to accommodate for the risk of crestal bone loss and maintain interseptal bone levels.[77] This distance permits a 1.5-mm defect to form on adjacent implants without the vertical wedgelike defect becoming a horizontal defect and increasing the occurrence of tissue shrinkage between the implants.

To accommodate 3 mm of space between adjacent implants, the size dimension of two adjacent anterior implants should most often be reduced compared with the ideal dimensions of a single-tooth implant. The smaller implant diameters increase the amount of bone on the facial, increase the amount of soft tissue interdentally, and decrease the risk of esthetic complications. As usual, the adjacent implants should be splinted together to permit smaller implant diameters to be used without biomechanical complications.

Posterior Tooth Replacement

The natural maxillary first and second premolar teeth have an average mesiodistal size of 7.1 and 6.6 mm, respectively. The dimensions of these teeth at the CEJ are 4.8 and 4.7 mm.[75,76] At a distance of 2 mm below the CEJ, the teeth are also similar in size and average 4.2 and 4.1 mm. Therefore, although the first premolar is often slightly larger than the second premolar at the occlusal surface, both teeth are similar at the level of the bone. A 4-mm implant is often used to replace one premolar and two 3.5- to 4.0-mm implants are used to replace adjacent premolars.

The ideal implant size for the posterior molars depends on four criteria:

1. The implant dimension should correspond to the natural tooth (2 mm below the CEJ).
2. The implant should be at least 1.5 mm from the adjacent teeth.
3. The implant should be at least 3 mm from an adjacent implant.
4. The implant should be at least 4 mm in diameter, and the 5.0- to 6.0-mm diameter is often more appropriate.

In this way, bone loss on one implant will not affect the adjacent tooth or implant, and the implant is strong enough to resist fatigue fracture and screw loosening under higher bite forces in the posterior region of the mouth.

The natural maxillary molars have the greatest diameter and largest surface area of any teeth. The maxillary molars have a 200% increase in surface area compared with the premolar teeth because they increase diameter and the number of roots. The first molar is 10.4 mm in mesiodistal dimension, and the second molar is 9.8 mm.[75,76] The CEJ dimensions of these teeth are 7.9 and 7.6 mm, respectively, and 2 mm below the CEJ these teeth are both 7 mm. However, the ideal implant diameter is usually 5 to 6 mm for the maxillary molars. Titanium is approximately 10 times more rigid than natural teeth, and the modulus of elasticity for an implant of sizes greater than 6 mm may be too great and cause stress shielding in the bone–implant interface. As a result, bone loss around the implant may occur from inadequate stimulation of the bone. Keep in mind that the 6-mm diameter should not be used in the anterior regions because the magnitude of the occlusal force is not large enough to strain the bone within the ideal physiologic zones next to such a wide-diameter implant.

When the bone density is D2 bone, the increase in diameter of a molar is less necessary than when bone density is D3 or D4, and 4-mm-diameter implants have been used with a wide range of success.[79] When the bone density is D3 or D4, implant diameter (or number) is more important to decrease the biomechanical overload to the bone. As a general rule, 5-mm-diameter implants are sufficient in most posterior molar regions.

When the diameters of molar implants do not provide sufficient surface area, the number of implants should be increased. Rather than two implants replacing the first and second molars, three implants may be considered. Treatment plans for implant number to compensate for implant size may be used for very soft bone types or unfavorable force factors (i.e., parafunction). When multiple adjacent posterior teeth are missing, increasing the number of implants affects the overall surface area greater than the implant size.

Summary

The ideal size of the implant body should be incorporated into a treatment plan rather than the surgeon determining this dimension at the time of surgery. The initial size of an implant is determined in both length and diameter. In a two-stage healing protocol, the ideal implant length should be at least 12 to 15 mm. The softer the bone, the longer the implant requirements. The greater the bite force, the longer the implant dimension. Therefore, the shortest implant length may be treatment planned in the anterior mandible, the anterior maxilla may have a slightly longer implant, the posterior mandible may have a longer implant, and the longest implant requirement for an ideal treatment plan is usually found in the posterior maxilla.

The diameter of the implant is also an important part of an ideal treatment plan. The diameter of an implant has surgical, loading, and prosthetic considerations. In the initial treatment plan, the loading and prosthetic components are most important. The width of the implant is directly related to the overall functional surface area. Therefore, where the forces are greater or the bone is less dense, the implant is wider, ranging from 3 to 6 mm. As a general rule, the narrowest implant is found in the anterior mandible followed by the anterior maxilla and the posterior mandible; the widest-diameter requirements are found in the molar region of the posterior maxilla.

The prosthetic aspects of the implant width are primarily related to the esthetics of the emergence profile, the force on an abutment screw, and the strength of the implant components. As a result, wider-diameter implants are selected in the molar regions; standard diameters in the canines, premolars, and maxillary central incisors; and the smallest-size implants in the maxillary lateral and mandibular incisors.

The natural dentition follows the guidelines established in the implant-size treatment plan considerations. The correlation is most likely found because of the biomechanical relationship of the amount and type of the forces in the location of the jaws and the type of the bone in the region. Therefore, in the maxilla, fine trabecular bone is used to dissipate forces, and the amount of force is the greatest in the molar region. The angle of the force to the premaxilla is 12 to 15 degrees. The mandible is a force-absorbing unit and has coarse trabeculae and dense cortical

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bone. The tooth size difference is reflected in the diameter of the tooth, not in the overall length dimension. These guidelines are consistent for both teeth and implants when engineering principles determine tooth and implant size.

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CHAPTER 14

Available Bone and Dental Implant Treatment Plans

Carl E. Misch

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Long-term success in implant dentistry requires the evaluation of more than 50 dental criteria, many of which are unique to this discipline.[1] However, the doctor's training and experience and the amount and density of available bone in the edentulous site of the patient are arguably primary determining factors in predicting individual patient success. In the past, the available bone was not modified and was the primary intraoral factor influencing the treatment plan. Today the prosthodontic needs and desires of the patient should be first determined, relative to the number and position of missing teeth. After the intended prosthesis and key implant positions are designed, the patient force factors and bone density are then evaluated to determine the additional implant number and size. After these factors are considered, the most important element in the implant region to fulfill the ideal treatment plan is the available bone. Greenfield already appreciated its importance in implant dentistry in 1913.[2] This chapter describes the three-dimensional concept of available bone and the implant treatment options for each type of bone anatomy.

Literature Review

The process of bone volume atrophy after tooth loss and its effect on dentures was reported as early as 1922 by J. Misch[3] (Figure 14-1). Since that time, many researchers and clinicians have studied its process and effect on dentistry.[4–17] Characteristic bone volume changes after tooth loss were evaluated in the edentulous anterior mandible by Atwood in 1963[4–6] (Figure 14-2). The five residual ridge stages are beneficial to appreciate the shapes and range of bone loss. Tallgren reported the amount of bone loss occurring the first year after tooth loss is almost 10 times greater than the following years.[7] Other more recent studies in complete denture wearers have confirmed the higher rate of resorption in the first year of edentulousness.[10,11] Karkazis et al. found, in the mandibular symphysis, that women present higher total reduction and more rapid bone loss during the first 2 years.[9] The posterior edentulous mandible resorbs at a rate approximately four times faster than the anterior edentulous mandible.[8]

The edentulous anterior maxilla appears to resorb in height slower than the anterior mandible. However, the original height of available bone in the anterior mandible is twice as much as the anterior maxilla. Therefore, the resultant maxillary atrophy in height, although slower, affects the potential available bone for an implant patient with equal frequency. The changes in the edentulous anterior maxillary ridge dimension can be dramatic in height and width (up to 70%), especially when multiple extractions are performed.[12] In addition, many patients lose additional bone by simultaneous alveolectomy procedures after tooth extraction before the delivery of a maxillary denture.[13] Although slight differences exist between different alveolectomy techniques, all are detrimental to the ridge volume.[14]

The residual ridge resorbs in a palatal direction in the maxilla and lingually in the mandible as related to tooth position at the



FIGURE 14-1. Maxillary and mandibular atrophy after tooth loss was documented by J. Misch in 1922.[3]

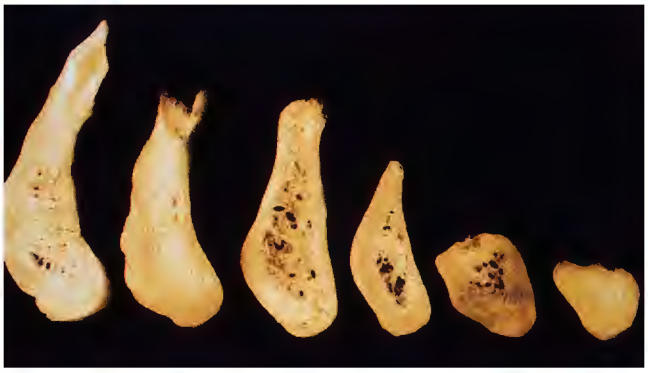


FIGURE 14-2. Atwood presented a classification of bone loss after tooth loss in the anterior mandible in 1963.[4]

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expense of the buccal cortical plate in all areas of the jaws regardless of the number of teeth missing.[15–19] However, after the initial bone loss, the maxilla continues to resorb toward the midline, but the mandibular basal bone is wider than the original alveolar bone position and results in the late mandible resorption progressing more facially (Figure 14-3). This, in addition to a marked change in mandibular position, leads to the classical appearance of the denture wearer with a protruding chin and mandibular lip (e.g., especially when restored at a closed vertical dimension).[20]

The posterior maxilla loses bone volume faster than any other region. Not only does periodontal disease cause initial bone loss before the loss of teeth, but the crestal bone loss is also substantial after tooth extraction. In addition, the maxillary sinus after tooth loss expands toward the crest of the edentulous ridge (Figure 14-4). As a result, the posterior maxilla is more often indicated for bone augmentation compared with any other intraoral location.

Weiss and Judy developed a classification of mandibular atrophy and its influence on subperiosteal implant therapy in 1974.[21] Kent presented a classification of alveolar ridge deficiency designed for alloplastic bone augmentation in 1982.[22] Another bone volume classification for the anterior regions of the jaws was proposed by Lekholm and Zarb in 1985 for residual jaw morphology related to the insertion of Brånemark fixtures.[23] They described five stages of anterior jaw resorption, ranging from minimal to extreme (Figure 14-5). The mandibular resorption was only described in loss of height. All the five stages of resorption in either arch used the same implant modality, surgical approach, and type of final prosthesis. In addition, as the bone volume decreased, the implants became shorter and the number of implants reduced to support a cantilevered fixed prosthesis. The classifications of Atwood and Zarb and Lekholm do not describe the actual resorption process of the bone in chronological order and are more descriptive of the residual ridge by clinical appearance.

A maxillary alveolar process of resorption after tooth loss following Atwood's description for the anterior mandible was presented by Fallschüssel in 1986.[24] The six resorption categories of this arch ranged from fully preserved to moderately wide and high, narrow and high, sharp and high, wide and reduced in height, and severely atrophic. The Fallschüssel classification is more anatomically correct.[25] Another bone resorption classification, which included the expansion of the maxillary

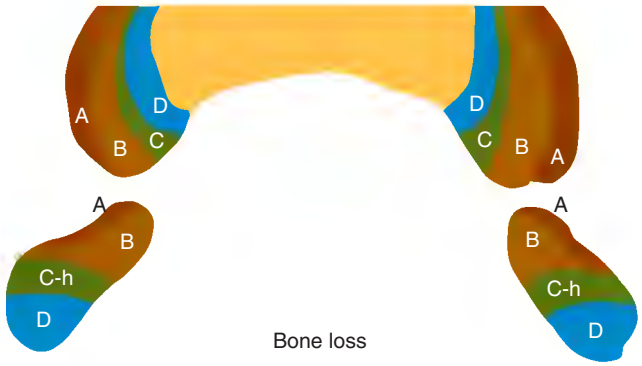


FIGURE 14-3. The resorption of bone in the maxilla results with the ridge becoming more narrow because it resorbs toward the midline. The initial mandibular bone loss also resorbs toward the midline. However, moderate to severe bone loss conditions result with the mandible wider than the original mandibular crest.



FIGURE 14-4. The posterior maxilla loses bone height more rapidly than any other region because the maxillary sinus expands after tooth loss. Hence, the bone height is lost from both the crestal and apical regions.

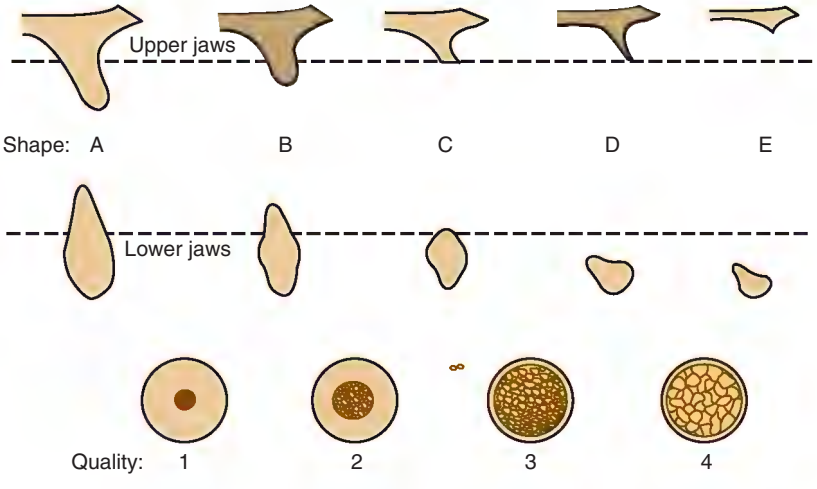


FIGURE 14-5. Lekholm and Zarb presented a classification of anterior bone loss in the edentulous jaws in 1985.[23]

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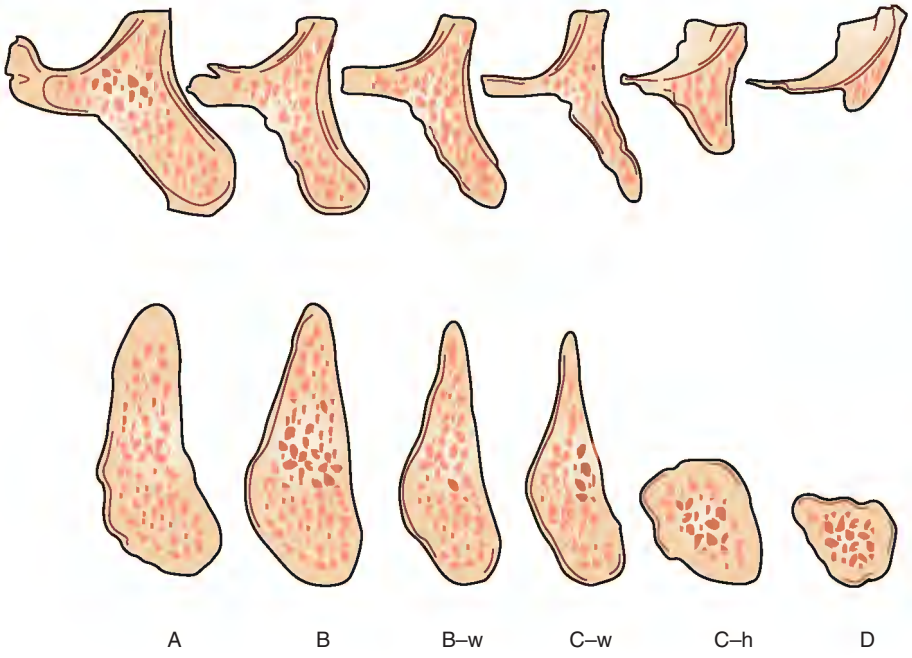


FIGURE 14-6. In 1985, Misch and Judy presented a classification of available bone (divisions A, B, C, D), which is similar in both arches. Implant, bone grafting methods, and prosthodontic-related treatment was suggested for each category of bone. *A,* Abundant; *B,* barely sufficient; *C,* Compromised; D, deficient; *h,* inadequate height; *w,* inadequate width.

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sinuses, was proposed by Cawood and Howell in 1988.[26] As a consequence, it is more descriptive of the posterior maxilla and is similar to the other classifications relative to the bone volume changes.

In 1985, Misch and Judy established four basic divisions of available bone for implant dentistry in the edentulous maxilla and mandible, which follow the natural bone resorption phenomena of each region, and determined a different implant approach to each category.[27–33] The angulation of bone and crown height were also included for each bone volume because they affect the prosthetic treatment. These original four divisions of bone were further expanded with two subcategories to provide an organized approach to implant treatment options for surgery, bone grafting, and prosthodontics[34] (Figure 14-6).

The ability to organize the available bone of the potential implant site into specific related categories of common treatment options and conditions is of benefit to both beginning and experienced clinicians. Improved communication among health professionals and the collection of relevant specific data for each category are also beneficial. The Misch–Judy bone classification has facilitated these processes during the past 2.5 decades within the profession, universities, implant programs, and international implant societies.

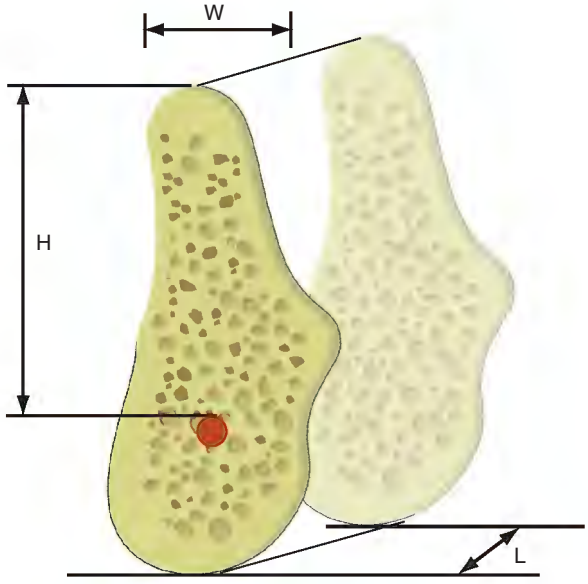


FIGURE 14-7. Available bone is measured in height (H), width (W), and length (L). Also considered are crown height space and angulation of bone (which is related to the direction of force to the implant body).

Available Bone

To develop an ideal implant treatment plan, the category and design of the final prosthesis and key implant positions are first determined after a patient interview and evaluation of existing medical and dental conditions. The patient force factors and bone density are of particular note to help determine the additional implants required to support the intended prosthesis. The implant abutments necessary to support the restoration are established in position, number, and size and without initial regard to the available bone conditions. The available bone is then evaluated to determine the surgical approach necessary (i.e., bone augmentation, implant insertion, or both) to support the ideal treatment plan.

Available bone describes the amount of bone in the edentulous area considered for implantation. It is measured in width, height, length, and angulation. In addition, the crown height space (CHS) is considered in relation to the remaining bone (Figure 14-7). Historically, the available bone was not modified and dictated the implant position, number, and size. Today, if the bone is inadequate to support an ideal abutment for the intended prosthesis, a bone graft is considered in the ideal site(s) or alternative sites may be considered when additional implant numbers are necessary.

Manufacturers describe the root form implant in dimensions of width and length. The implant length corresponds to the height of available bone. Therefore, this text refers to root form

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implant height or length. The width of a root form implant is most often related to its diameter because most root form implants are round. This dimension also corresponds to the mesiodistal length of available bone. Many manufacturers design implants with a crest module wider than the implant body dimension. Yet the often stated dimension of the manufacturer is the smaller implant body width. For example, the Nobel Biocare 3.75-mm-diameter implant has a 4.1-mm crest module. The clinician should be aware of all the implant dimensions, especially because the wider implant crest module is positioned next to an adjacent tooth or at the crestal dimension of bone and is usually the dimension responsible for cervical esthetics or the narrowest width region of the available bone.

As a general guideline, at least 1.5 to 2 mm of surgical error is maintained between the implant and any adjacent or opposing landmark. This is especially critical relative to implant length when the opposing landmark is the mandibular inferior alveolar nerve. However, the implant may often be placed without complication through the cortical plate of the posterior region of the maxillary sinus or inferior border of the anterior mandible. The 1.5- to 2-mm or more guideline is also suggested relative to the width of the implant adjacent to a natural tooth. Otherwise, if the implant or tooth should lose crestal bone or become mobile or affected by periimplant disease, the adjacent structure may be adversely involved.

All natural teeth are not equal when considered as abutments for a prosthesis. Restoring dentists know how to evaluate the surface area of the natural abutment roots. A healthy maxillary first molar with more than 450 mm^2 of root surface area constitutes a better abutment for a fixed prosthesis than a mandibular lateral incisor with 150 mm^2 of root support. The larger-diameter teeth correspond to the regions of the mouth with greater bite force. Likewise, not all implant body sizes are similar to each other when supporting a prosthetic load. The existing bone volume is necessary to determine, but this dimension alone should not determine the ideal implant size. The previous chapter addressed implant size related to function and esthetics. When the ideal implant size cannot be inserted into the existing available bone, bone augmentation, additional implant numbers, or both are considered.

Available Bone Height

The available bone height is first estimated by radiographic evaluation in the edentulous ideal and optional regions, where implant abutments are required for the intended prosthesis. A panoramic radiograph is the most common method for the preliminary determination of the available bone height when multiple adjacent teeth are missing. A periapical radiograph is most often sufficient for this height estimation of one or two adjacent teeth missing.

The height of available bone is measured from the crest of the edentulous ridge to the opposing landmark. The anterior regions are limited in the maxilla by the floor of the nose or in the mandible by the inferior border (Figure 14-8). The anterior regions of the jaws have the greatest height because the maxillary sinus and inferior alveolar nerve limit this dimension in the posterior regions. The maxillary canine eminence region, just lateral to the lateral periform rim of the nose, often offers the greatest height of available bone in the maxillary anterior.[35]

As a general rule, the anterior mandible has the greatest bone height. There is more bone apical to the mandibular anterior

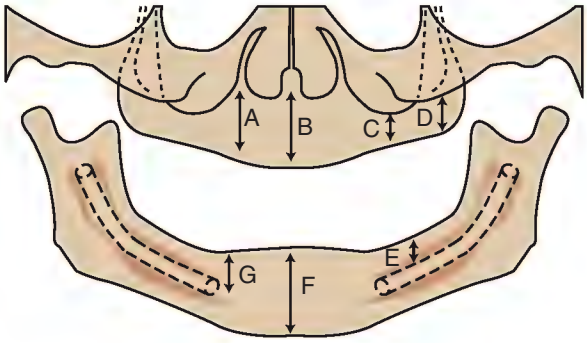


FIGURE 14-8. The height of available bone is measured from the crest of the edentulous ridge to the opposing landmark. The opposing landmark may be in the maxillary canine region *(A)*, floor of the nares *(B)*, maxillary sinus *(C)*, tuberosity *(D)*, mandibular canine region *(G)*, anterior mandible *(F)*, or bone above the inferior mandibular canal *(E)*.

teeth than any other region. Hence, even after the resorption of the residual ridge after tooth loss, there is adequate bone to insert dental implants (Figure 14-9). However, the crown height of the prosthesis may be extensive. Therefore, this region often has the most available bone but also may have the greatest CHS.

The anterior bone region in the mandible extends between the mental foramen. The foramen is most often found between (and below) the apices of the two premolars. Hence, the anterior region of bone extends beyond the canines and to the first premolar region most often. The presence of available bone in implant dentistry involves the existing anatomy of the edentulous mandible and maxilla. The initial mandibular bone height is influenced by skeletal anatomy, with angle class II patients having shorter mandibular height and angle class III patients exhibiting the greatest height.

The opposing landmarks for both the maxilla and mandible of the initial available bone height are more limiting in the posterior regions distal to the first premolar. In the maxillary posterior jaw region, there is usually greater bone height in the first premolar than in the second premolar, which has greater height than the molar sites because of the concave morphology of the maxillary sinus floor. As a consequence, the existing bone anatomy of the implant patient often requires modification to enhance long-term implant success. For example, sinus grafts in the posterior maxilla permit the placement of posterior endosteal implants into restored bone height.

The posterior height of bone in the mandibular region is reduced because of the presence of the mandibular canal, situated approximately 12 mm above the inferior border of the mandible (Figure 14-10). The height of bone in a posterior mandible (before crestal bone loss) is similar to the height of bone in the anterior maxilla (Figure 14-11). On occasion, this premolar site may present a reduced height compared with the anterior region because the anterior loop of the mandibular canal (when present) passes below the foramen and loops superiorly and then distally before its exit through the mental foramen (see Figure 14-9).

As a result, in the areas where greater forces are generated and the natural dentition has wider teeth with two or three roots, shorter implants, if any, are often used and often in insufficient number because of the anatomical limiting factors.[36] Oikarinen et al. found that more than 6 mm of bone height is found in less than 50% of posterior mandibles and 40% of

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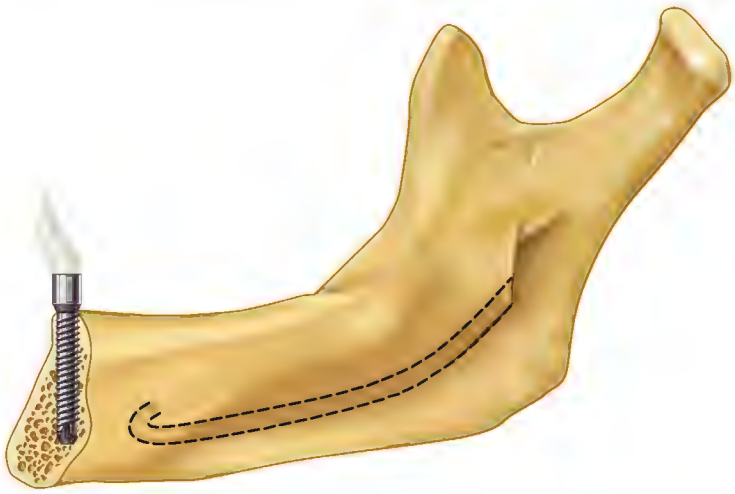


FIGURE 14-9. The anterior mandible has the greatest bone height in any region of the jaws. The incisal edge of a tooth is usually more facial, hence the implant often engages the lingual plate of bone.



FIGURE 14-10. The posterior mandible has less bone height because the inferior alveolar canal resides approximately 12 mm from the inferior molar.

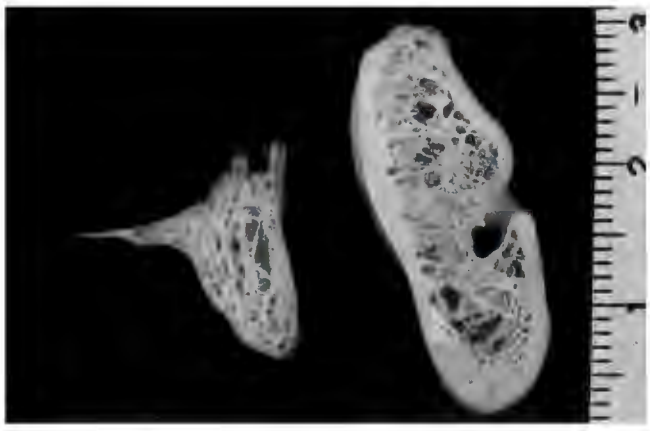


FIGURE 14-11. The available bone height (before crestal bone loss) in an anterior maxilla *(left)* is similar to the height of bone in a posterior mandible.

posterior maxillae in partially edentulous patients.[36] The author observed more than 6 mm of bone is found in less than 20% of posterior mandibles and 10% of posterior maxillae when the patient has been fully edentulous more than 5 years.

The suggested minimum bone height for predictable long-term endosteal implant survival approaches 12 mm. Failure rates reported in the literature for implants shorter than 9 mm tend to be higher independent from the manufacturer design, surface characteristic, and type of application.[37–52] The inexperienced dentist may wish to have 14 mm of bone height to place a 12-mm-long implant body before proceeding with the surgery. This precaution allows 2 mm of surgical error or permits an osteoplasty to gain additional width of bone. The 12-mm height minimum applies to most screw-shaped endosteal implant designs in good density (D2, D3) bone. This minimum implant height requirement may be reduced in the very dense bone (D1) in the symphysis of an atrophic mandible when the prosthesis has fewer forces (as an overdenture) or when the shorter dimension can be compensated by implant number, width, or design.[53–55]

The available bone height in an edentulous site is the most important dimension for implant consideration because it affects both implant length and crown height. Crown height affects force factors and esthetics. In addition, bone augmentation is more predictable in width than height, so even when the width is inadequate for implant placement, bone grafting may be used to create a site ideal for restorative and implant insertion requirements.

Available Bone Width

The width of available bone is measured between the facial and lingual plates at the crest of the potential implant site. The crestal aspect of the residual ridge in the mandible is often cortical in nature and exhibits greater density than the underlying trabecular bone regions. This mechanical advantage permits immediate fixation of the implant, provided this cortical layer has not been removed by osteoplasty.

The crest of the edentulous ridge is most often supported by a wider base in the anterior mandible. In most mandibular situations, because of this triangular-shaped cross-section, an osteoplasty provides greater width of bone, although of reduced height (Figures 14-12).

It should be noted that crest reduction affects the location of the opposing landmark, with possible consequences for

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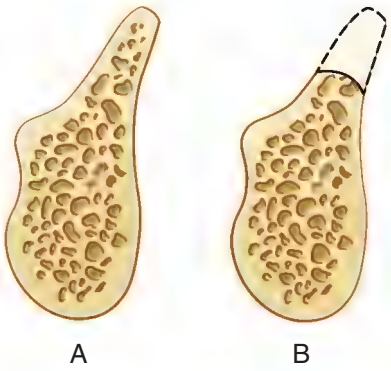


FIGURE 14-12. **A,** The anterior mandible has a wider base than the crest of the ridge and often form a triangular-shaped cross-section. **B,** An osteoplasty to the narrow ridge in the anterior mandible increases the width of crestal bone (and reduces the available bone height).

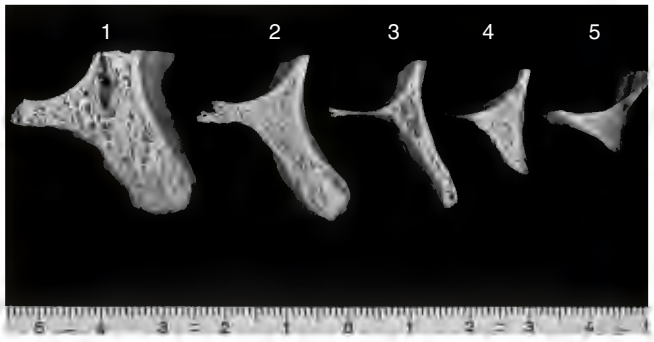


FIGURE 14-13. The anterior maxilla most often has the palatal wall of bone parallel to the facial cortical plate. Osteoplasty is less effective to increase the bone width. Augmentation procedures are most often warranted.

surgery, implant height selection, appearance, and the design of the final prosthesis. This is particularly important when a FP-1 prosthesis is planned, with the goal of obtaining a normal contour and proper soft tissue drape around a single tooth replacement.

Unlike the anterior mandible, the anterior maxilla often does not follow the triangular-shaped anatomy. The palatal plate of bone is more parallel to the facial plate in the maxilla (Figure 14-13). In addition, many edentulous ridges exhibit a labial concavity in the incisor area, with an hourglass configuration. As a result, osteoplasty does not increase the width of bone as much as in the mandible. As a consequence, bone augmentation for width is more often indicated in the maxilla.

After adequate height is available, the next most significant criterion affecting the long-term survival of endosteal implants is the width of the available bone. Root form implants with crestal diameters of 4 mm usually require more than 6 mm of bone width to ensure sufficient bone thickness and blood supply around the implant for predictable survival. This dimension provides more than 1 mm of bone on each side of the implant at the crest. Because the bone usually widens apically in the mandible, this minimum dimension rapidly increases. For root form implants, the minimum bone thickness is located in the midfacial and midlingual contours of the crestal region exclusively (Figure 14-14).

Extraction sockets with more width of bone at the crest around the socket lose less bone during initial healing than

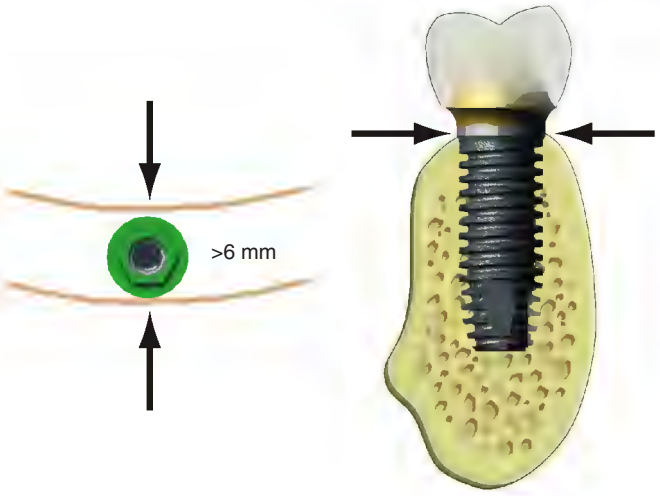


FIGURE 14-14. Minimum bone width for a 4-mm-diameter root form is 6 mm in the midfacial and lingual regions because the round implant design results in more bone in all other directions around the implant.

sockets with minimum width of cortical plates on the facial or lingual of the extraction site. The initial width of available bone is also related to the amount of crestal bone loss after implant loading. Edentulous ridges that are greater than 6 mm in width have demonstrated less crestal bone loss than when minimum bone dimensions are available.

Available Bone Length

The mesiodistal length of available bone in an edentulous area is often limited by adjacent teeth or implants. As a general rule, the implant should be at least 1.5 mm from an adjacent tooth and 3 mm from an adjacent implant. This dimension not only allows surgical error but also compensates for the width of an implant or tooth crestal defect, which is usually less than 1.4 mm. As a result, if bone loss occurs at the crest module of an implant or from periodontal disease with a tooth, the vertical bone defect will not spread to a horizontal defect and cause bone loss on the adjacent structure.[56] Therefore, in the case of a single-tooth replacement, the minimum length of available bone necessary for an endosteal implant depends on the width of the implant. For example, a 5-mm-diameter implant should have at least 8 mm of mesiodistal bone, so 1.5 mm is present on each side of the implant. A minimum mesiodistal length of 7 mm is usually sufficient for a 4-mm-diameter implant.

The diameter of the implant is also related to the width of available bone and, in multiple adjacent sites, is primarily limited in this dimension. For example, a width of bone of 4.5 mm without augmentation requires a 3.5-mm or smaller implant, with inherent compromises (e.g., as less surface area and greater crestal stress concentration under occlusal loads on abutment screw and marginal bone). Therefore, in the narrower ridge, it is often indicated to place two or more adjacent narrow-diameter implants (when possible) to obtain sufficient implant–bone surface area to compensate for the deficiency in width of the implant. Because the implants should be 3 mm apart and 1.5 mm from each tooth, 13 mm or more in available bone mesiodistal length may be required when the narrower implant dimensions are used to replace a posterior tooth.

The ideal implant mesiodistal width for single-tooth replacement is often related to the natural tooth being replaced in the

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site. The tooth has its greatest width at the interproximal contacts; is narrower at the cementoenamel junction (CEJ); and is even narrower at the initial crestal bone contact, which is 2 mm below the CEJ.[57] The ideal implant diameter corresponds to the width of the natural tooth 2 mm below the CEJ if it also is 1.5 mm from the adjacent tooth. In this way, the implant crown emergence through the soft tissue may be similar to a natural tooth. For example, a maxillary first premolar is approximately 8 mm at the interproximal contact, 5 mm at the CEJ, and 4 mm at a point 2 mm below the CEJ. Therefore, a 4-mm-diameter implant (at the crest module) would be the ideal implant diameter if it also is at least 1.5 mm from the adjacent roots (2 mm below the CEJ). The ideal width of available bone for this 4-mm-diameter size implant is 6 mm or more, and the ideal bone mesiodistal length is 7 mm or more.

Available Bone Angulation

Bone angulation is the fourth determinant for available bone. The initial alveolar bone angulation represents the natural tooth root trajectory in relation to the occlusal plane. Ideally, it is perpendicular to the plane of occlusion, which is aligned with the forces of occlusion and is parallel to the long axis of the prosthodontic restoration. The incisal and occlusal surfaces of the teeth follow the curve of Wilson and curve of Spee. As such, the roots of the maxillary teeth are angled toward a common point approximately 4 inches away. The mandibular roots flare, so the anatomical crowns are more lingually inclined in the posterior regions and labially inclined in the anterior area compared with the underlying roots. The first premolar cusp tip is usually vertical to its root apex.

The maxillary anterior teeth are the only segment in either arch that does not receive a long-axis load to the tooth roots but instead are usually loaded at a 12-degree angle. As such, their root diameter is greater than the mandibular anterior teeth. In all other regions, the teeth are loaded perpendicular to the curves of Wilson and Spee.

Rarely does the bone angulation remain ideal after the loss of teeth, especially in the anterior edentulous arch. In this region, labial undercuts and resorption after tooth loss often mandate greater angulation of the implants or correction of the site before insertion.[12,15,16] For example, in the anterior mandible, the implant insertion often engages the lingual cortical plate, rather than the inferior border of the mandible, as a consequence of the position of the incisal edge and the angulation of bone (see Figure 14-9). In the posterior mandible, the submandibular fossa mandates implant placement with increasing angulation as it distally progresses. Therefore, in the second premolar region, the angulation may be 10 degrees to a horizontal plane; in the first molar areas, 15 degrees; and in the second molar region, 20 to 25 degrees.

The limiting factor of angulation of force between the body and the abutment of an implant is correlated to the width of bone. In edentulous areas with a wide ridge, wider root form implants may be selected. Such implants may allow up to 30 degrees of divergence with the adjacent implants, natural teeth, or axial forces of occlusion with minimum compromise. The angled load to an implant body increases the crestal stresses to the implant components and bone, but the greater–diameter implant decreases the amount of stress transmitted to these structures. In addition, the greater width of bone offers some latitude in angulation at implant placement. The implant body may often be inserted so as to reduce the divergence of the abutments without compromising the permucosal site. Therefore, an acceptable bone angulation in the wider ridge may be as much as 30 degrees.

The narrow yet adequate width ridge often requires a narrower design root form implant. Compared with larger diameters, smaller-diameter designs cause greater crestal stress to the system (abutment screws, crestal bone) and may not offer the same range of custom abutments. In addition, the narrower width of bone does not permit as much latitude in placement regarding angulation within the bone. This limits the acceptable angulation of bone in the narrow ridge to 20 degrees from the axis of the adjacent clinical crowns or a line perpendicular to the occlusal plane.

Crown Height Space

The CHS is defined as the vertical distance from the crest of the ridge to the occlusal plane. It affects the appearance of the final prosthesis and may affect the amount of moment force on the implant and surrounding crestal bone during occlusal loading. Esthetically, the prosthesis is less likely to replace the sole anatomical crowns of natural teeth when a greater CHS is present.

The CHS may be considered a vertical cantilever. Any direction of load that is not in the long axis of the implant will magnify the crestal stresses to the implant–bone interface and to the abutment screws in the restoration. The greater the CHS, the greater the moment force or lever arm with any lateral force or cantilever (Figure 14-15).

The absence of a periimplant ligament means that the bone–implant stresses cannot be reduced by increasing the implant height. Therefore, as the CHS increases and a cantilever or a lateral load is planned on the restoration, a greater number of implants or wider implants should be inserted to counteract the

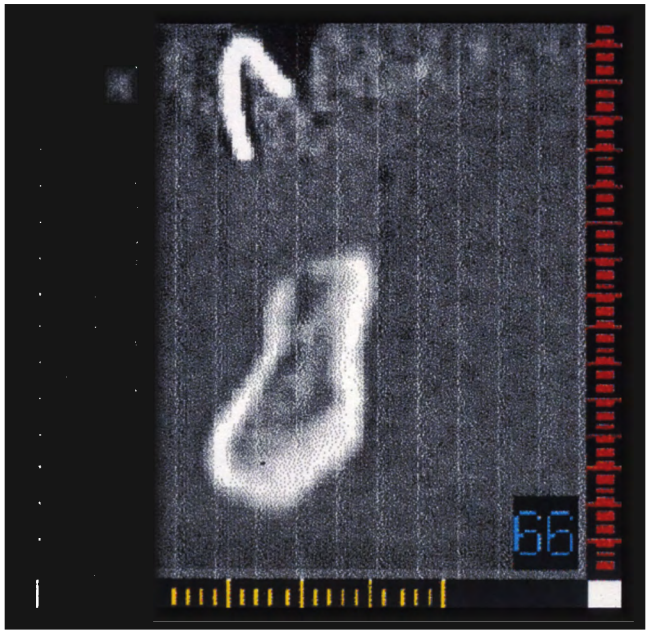


FIGURE 14-15. The angulation of bone may not be in the long axis of the missing tooth, especially in the anterior regions of the mouth. The crown height space (CHS) is measured from the occlusal plane to the crest of the ridge. The computed tomography scan was obtained with a barium sulfate radiopaque template over the edentulous site of a lower anterior denture tooth. The available bone trajectory diverges 30 degrees from the tooth's angulation and the CHS is less than 15 mm.

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increase in stress. For an ideal treatment plan, the CHS should be equal to or less than 15 mm under ideal conditions.

Divisions of Available Bone

Division A (Abundant Bone)

Division A abundant bone often forms soon after the tooth is extracted. The abundant bone volume remains for a few years, although the residual bone height is slowly reduced and the original crestal width is usually reduced by more than 30% within 2 years.[12] Division A bone corresponds to abundant available bone in all dimensions.

The height of available bone for division A is 12 mm or more. It should be emphasized that the available bone height may be 20 mm for division A, but this does not mean the implant length must be equal to the bone height. Because the stresses to the implant interface in good-density bone are captured within the coronal two thirds of the implant, an implant of 12 mm has been shown to be without compromise for long-term success even though the implant does not engage the opposing cortical plate.

The width of available bone for division A is 6 mm or more. The division A width of more than 6 mm is predicated on an implant diameter of at least 4 mm at the crest module because abundant long term data have been published regarding this implant size. In abundant bone width of greater than 7 mm (A+ bone), a wider (5-mm-diameter) implant may be inserted, provided that at least 1 mm of bone remains around the buccal and lingual aspects of the implant. Osteoplasty may often be performed to obtain additional bone width in the mandible when a larger diameter implant is desired.

The mesiodistal edentulous span for division A bone is 7 mm or more. This is adequate for a 4-mm-diameter implant. The angulation of the bone in reference to the occlusal plane is within 30 degrees. Hence, even when an angled abutment is necessary to restore the patient, the direction of load is not excessive. The CHS for division A is less than 15 mm. This is an ideal dimension for a fixed implant prosthesis (Box 14-1).

The implant choice in division A bone is a division A root form that is 4 mm or greater in diameter and 12 mm or longer in height (length). A larger-diameter implant is suggested in the molar regions (5 to 6 mm in diameter). Longer implants are suggested in immediate loading treatment options or when an implant is immediately inserted after the extraction of the tooth. As a general rule, division A bone should not be treated with smaller-diameter implants for the final prosthesis (Figure 14-16). There are several advantages to the use of implants equal to or greater than 4 mm in diameter compared with smaller diameter implants (Box 14-2).

Prosthetic Options

The prosthetic options for division A span the full gamut. A FP-1 restoration demands a division A ridge. However, a FP-2 prosthesis most often also requires a division A bone. A FP-2 restoration is the most common posterior restoration supported by multiple adjacent implants in partially edentulous patients

BOX 14-1 Division A Bone Dimensions

- Width >6 mm
- Height >12 mm
  - Mesiodistal length >7 mm
  - Angulation of occlusal load (between occlusal plane and implant body) <30 degrees
  - Crown height space ≤15 mm



FIGURE 14-16. **A,** A panoramic radiograph of seven division A root form implants in the anterior and posterior mandible, with a FP-3 prosthesis. **B,** The full-arch fixed FP-3 prosthesis from **A**.

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BOX 14-2 Division A Root Form Implant Advantages

- The larger the diameter of an implant, the greater the surface area and the less stress distributed through the crestal bone region.
- The larger-diameter implants are closer to the lateral cortical plates of bone, which have greater density and therefore increased strength, modulus of elasticity, and bone–implant contact percentages.
- The larger-diameter implants are less likely to fracture because the strength of the material is increased by a power of four related to the radius of the implant (e.g., a 4-mm-diameter implant is 16 times stronger than a 2-mm-diameter implant).
- The smaller-diameter implants are often one-piece implants to decrease the risk of fracture.
- The one-piece implants require an immediate restoration rather than a submerged or one-stage approach. As such, micromovement may occur at the bone–implant interface, with an increased risk of crestal bone loss and implant failure.
- The emergence profile angle of the crown is related to the implant diameter. The larger-diameter teeth can be most esthetically restored with a wider-diameter implant.
- The larger the implant diameter, the less stress applied to the abutment screw, and therefore complications such as screw loosening or fracture are less likely.
- The larger-diameter abutment provides greater cement retention for the final restoration crown.
- Oral hygiene procedures are more compromised around smaller-diameter implants restored with greater emergence profile angles and over contoured restorations.
- The crest module and crestal portion of many two-piece, small-diameter implants are smooth metal to increase the interbody wall thickness, thus creating shear loads to the crestal bone and an increased risk of bone loss.
- Implant costs to the patient are related to implant number, not diameter. Therefore, increases in implant numbers for smaller-diameter implants increase the cost to the patient (and the doctor).
- Division A root form implants can provide the greatest range of prosthetic options.

because of either bone loss or osteoplasty before implant placement. A FP-3 prosthesis is most often the option selected in the anterior division A bone when multiple adjacent teeth are missing and the maxillary smiling lip position is high or a mandibular low lip line during speech exposes regions beyond the natural anatomical crown position.

For removable implant overdentures in division A bone, the final position of the tooth and superstructure bar must be evaluated before surgery. A limited CHS is more common in division A bone, and a RP-4 or RP-5 restoration may require osteoplasty before implant placement. Division A bone may represent a contraindication for high profile O-ring attachments or superstructures placed several millimeters above the tissue for hygiene considerations because of a compromised CHS to accommodate prosthetic components (Figure 14-17).

A patient with division A bone should be notified that this is the most ideal time to restore the edentulous condition with implants. All too often, the doctor fails to educate the patient about the rapid decrease in bone volume width and the consequences of delaying treatment. When the bone volume is division A, there is a decrease in treatment costs, with a reduction in the number and complexity of surgeries to the edentulous area with significant benefits to the patient. Unfortunately, these patients may not have significant problems with their existing restoration and therefore may not be motivated to address the situation. As the bone resorbs and the problems arise, a greater appreciation for the benefits of implant-supported restorations is realized. Just as the restoring dentist explains the need to replace a single tooth before tipping and extrusion of adjacent teeth and the risk of additional tooth loss, the patient should be educated as to the benefit of implant treatment while the edentulous site presents abundant bone.

BOX 14-3 Division B Dimensions

- 2.5–6 mm wide
  - B+: 4–6 mm
  - B–w: 2.5–4 mm
- Height >12 mm
  - Mesiodistal length >6 mm
  - Angulation <20 degrees
  - Crown height space <15 mm

Division B (Barely Sufficient Bone)

As the bone resorbs, the width of available bone first decreases at the expense of the facial cortical plate because the cortical bone is thicker on the lingual aspect of the alveolar bone, especially in the anterior regions of the jaws. There is a 25% decrease in bone width the first year and a 40% decrease in bone width within the first 1 to 3 years after tooth extraction.[12,13,16] The resulting narrower ridge is often inadequate for many 4-mm-diameter root form implants. Slight to mild atrophy is often used to describe this clinical condition. After this division B bone volume is present, it may remain for more than 15 years in the anterior mandible.[5] However, the posterior mandibular height resorbs four times faster than the anterior region. The posterior maxillary regions exhibit less available bone height (as a consequence of sinus expansion) and have the fastest decrease of bone height of any intraoral region. As a result, the posterior regions of the jaws may become inadequate in height (C–h) earlier than the anterior regions.

Division B bone offers sufficient available bone height (Box 14-3). The division B available bone width may be further classified into ridges 4 to 6 mm wide and B minus width (B–w) 2.5 to 4 mm wide, where bone grafting techniques are indicated (see Figure 14-6). The mesiodistal length of available bone is related to the implant diameter. A division B root form implant is narrower in diameter than a division A root form implant. Therefore, the minimum mesiodistal length of a division B ridge is less than that of division A. Because the ridge width and implant diameter are narrower, and forces increase as the angle of load increases, the angulation of occlusal load is also less and should be within 20 degrees from the axis of the adjacent teeth or occlusal plane. A CHS of 15 mm or less (similar to division A) is necessary in division B to decrease the moment of forces with lateral or offset loads, especially because of the smaller width dimension.

Three treatment options are available for the division B edentulous ridge:

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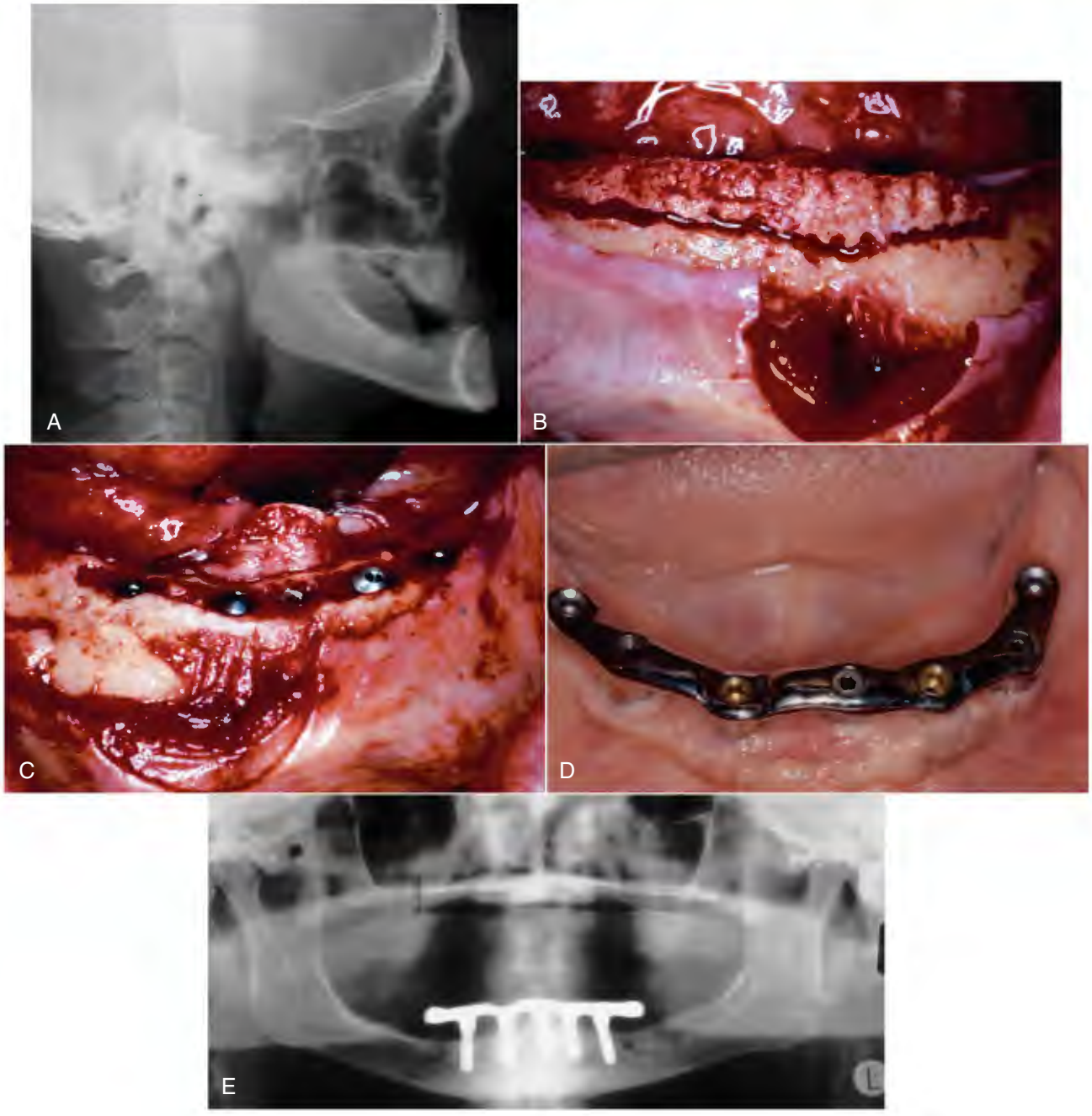


FIGURE 14-17. **A,** A lateral cephalogram of a patient with division A anterior bone in the mandible. When planning implants in the anterior mandible for an overdenture, the following factors must be considered: crown height space (CHS) for the denture teeth, acrylic, bar, and attachments. In division A bone, the crestal bone may require osteoplasty to increase the crown height. **B,** An osteoplasty is performed to increase the CHS because the final restoration is an overdenture. **C,** Five anterior implants are positioned above the foramen. **D,** Intraoral view of an overdenture bar for a RP-4 restoration. The low-profile design is more common for division A bone situations. **E,** A panoramic radiograph of a division A anterior mandible with five implants and an overdenture bar.

1. Modify the existing division B ridge to another division by osteoplasty to permit the placement of root form implants 4 mm or greater in width (see Figure 10-12). When more than 12 mm of bone height remains after osteoplasty, the division B bone is converted to division A. When less than 12 mm of bone height results, the division B bone is converted to division C–h.
2. Insert a narrow division B root form implant (3–4 mm diameter and 12 mm or more in length) (Figure 14-18).
3. Modify the existing division B bone into division A by augmentation (Figure 14-19).

To select the proper approach to this division B bone category, the final prosthesis must first be considered. When a division B ridge is changed to a division A by osteoplasty procedures, the final prosthesis design has to compensate for the increased CHS. For example, before surgery, the available bone height may be compatible with a FP-1 prosthetic design. If, at the time of surgery, the ridge is found deficient in width for implant

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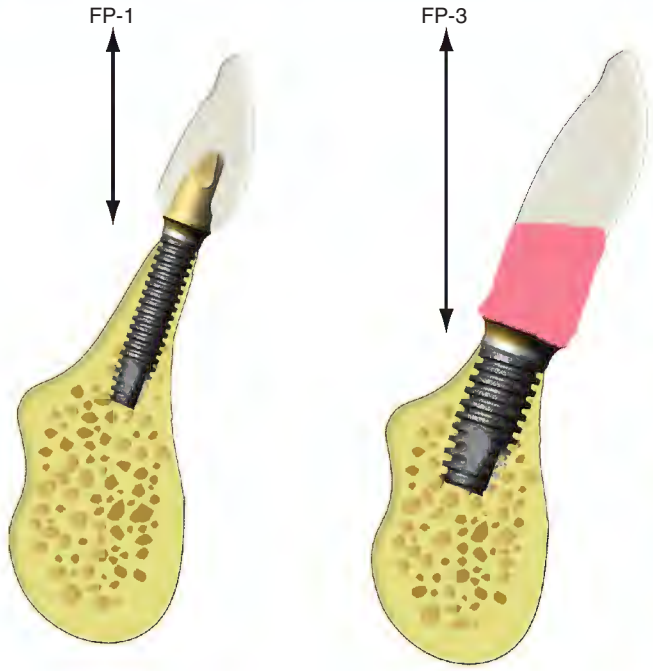


FIGURE 14-18. Options to treat a division B ridge in the anterior mandible include a narrow implant with a final prosthesis closer to anatomical dimensions (FP-1) *(left)* or osteoplasty with division A root forms and extended crown heights (FP-2 or FP-3) *(right)*.

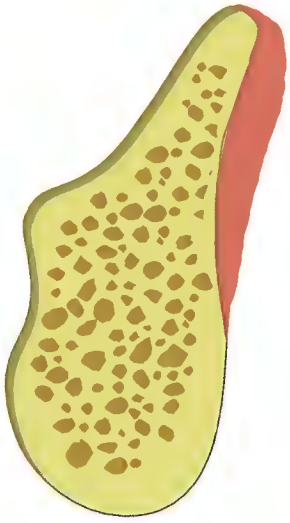


FIGURE 14-19. A division B bone may be modified to division A by doing a bone augmentation.

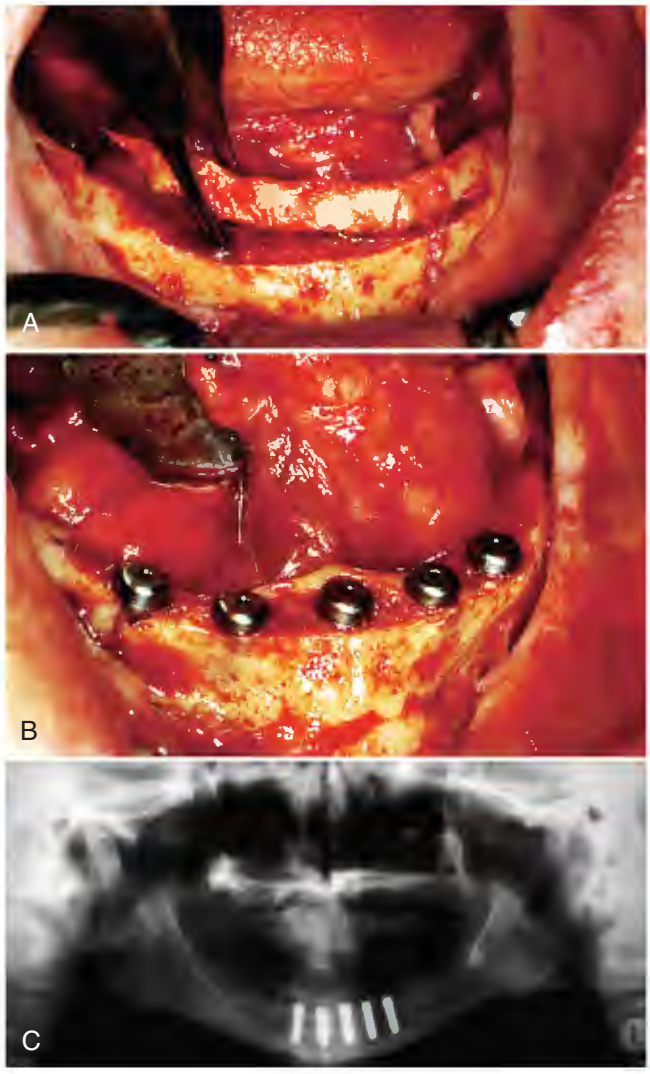


FIGURE 14-20. **A,** A division B bone ridge may be modified by osteoplasty to increase the width of bone. The osteoplasty increases the crown height space for the prosthesis. **B,** Five 4-mm-diameter anterior implants were placed after the osteoplasty. These implants were positioned with regard to the final restoration. **C,** A panoramic radiograph of the division B ridge modified to a division A by osteoplasty and five root form implants between the mental foraminae.

placement, it is not unusual to remove 3 mm of crestal bone before reaching a division A width. This means the final restoration will require an additional 3 mm in height. Therefore, it may result in an extended tooth (FP-2, FP-3) restoration. The osteoplasty option is less likely the treatment of choice for a FP-1 prosthesis with a B–w ridge because even greater bone height reduction is required during the osteoplasty.

The most common approach to modify the narrower division B ridge into another bone division by osteoplasty is when the final restoration is a mandibular implant overdenture (Figure 14-20). The edentulous ridge crest may be reduced, thereby increasing the width of the ridge. If the CHS is less than 15 mm, the ridge division becomes division A with a greater width than 6 mm. If the ridge height is reduced so that the CHS is greater than 15 mm, the bone division is not changed to a division A. Instead, it has been altered to a division C–h bone volume, and when cantilevers or lateral forces are present on the prosthesis, it is not as predictable for long-term success or increases mechanical problems with the prosthesis compared to division A. RP-4 or RP-5 restorations most often require option 1—osteoplasty—where adequate CHS is required to permit the fabrication of the overdenture and superstructure bar with attachments without prosthetic compromise.

The second main treatment option for the available bone division B is the small-diameter root form implant. Smaller-diameter root form implants (3.0–3.5 mm) are designed primarily for division B available bone. The division B bone is narrower, so the implant body of the implant must bisect the bone and implant angulation is less flexible. The division B root form implants present several inherent disadvantages compared

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with the larger-diameter implants (Box 14-4).[58] As a result of these concerns for the division B root form, this option is most often used for single-tooth replacement of a maxillary lateral incisor or mandibular incisors where the restricted available bone is in mesiodistal width or with multiple implants in the posterior mandible where bone density is good and esthetic requirements are limited.[59,60]

The third alternative treatment for division B bone is to change the division B ridge into a division A by grafting the edentulous ridge with autogenous bone or a combination of allograft and alloplast with or without guided bone regeneration techniques. If this graft is intended for implant placement, a healing period of at least 4 to 6 months is advantageous for maturation of the graft before endosteal implants are placed. A FP-1 restoration most often mandates option 3: augmentation. The emergence profile angle of the final crown, which does not compromise hygiene, requires a division A root form implant (with the exception of maxillary lateral incisors or mandibular incisors). Stress factors may also dictate the augmentation approach to division B bone in order to place larger-diameter implants. In the presence of unfavorable stress factors, the number and width of abutments should be increased without increasing the CHS to provide a greater surface area of resistance to the magnified forces. To accomplish this goal, augmentation is most ideal in division B bone.

An alternative for the augmentation approach for division B bone is bone spreading. A narrow ostotomy may be made between the bony plates, and bone spreaders are tapped into the edentulous site. The division B ridge may be expanded to a division A with this technique and allow a division A implant or an alloplast to be inserted for augmentation.[61]

BOX 14-4 Disadvantages of Division B Root Forms

1. Almost twice the stress is concentrated at the top crestal region around the implant.
2. Less overall surface areas means that lateral loads on the implant result in almost three times greater stress than division A root forms.
3. Fatigue fractures of the abutment post are increased, especially under lateral loads.
4. The crown emergence profile is less esthetic (except for maxillary lateral or mandibular incisors).
5. Conditions for daily care are compromised around the cervical aspect of the crown.
6. The implant design is often poor in the crestal region. To increase implant body wall thickness to reduce fracture, no threads or compressive force design are present, but this further increases stress and the amount of shear loads to bone.
7. The angle of load must be reduced to less than 20 degrees to compensate for the small diameter.
8. Two implants are often required for proper prosthetic support unless anterior single-tooth replacement for maxillary laterals or mandibular incisors, so surface area ends up being greater because of implant number, *not* size.
9. Implant costs are not related to diameter, so an increase in implant number results in greater cost to the doctor and patient.

Division B–w (B Minus Width)

The success of alloplastic materials for augmentation correlates with the number of osseous walls in contact with the graft material.[62] Therefore, a five-wall bony defect (as a tooth socket) forms bone more predictably with an alloplast than a one-wall defect (as an onlay graft).

The distinction between B and B–w is especially important when augmentation is the method of choice. Bone augmentation is more predictable when the volume to augment is minimal and is for width and least predictable when additional bone height is desired. For example, a width increase of 1 to 2 mm may be obtained with an alloplast and guided bone regeneration, but more than 2 mm of width is more predictable with autologous bone as part of the graft.

The division B–w ridge requires more than 2 mm of width increase, and therefore autologous bone is beneficial to predictably grow the additional bone width. If the division B–w ridge contour should be altered for improved prosthodontic relationships, an onlay particulate or block graft of autogenous bone is indicated. The autograft may be harvested from an intraoral region (e.g., the mandibular symphysis or ramus) and placed along the lateral aspect of the ridge that corresponds to ideal arch form (Figure 14-21). The implant placement should usually be delayed for 4 to 6 months after the augmentation process, to permit ideal implant placement and to ensure complete bone formation before placing the implant.[63–65]

The patient delaying treatment with a division B bone situation should be notified of the future bone volume resorption. The augmentation of bone in height is much less predictable and requires more advanced techniques than augmentation of bone width alone (Figure 14-22). For example, the patient may not be experiencing problems with a maxillary denture, but the division B bone will resorb in height and decrease the stability and retention of the removable soft tissue–supported prosthesis. When treatment is delayed until patient problems begin, the overall result may be more difficult to achieve and more costly to the patient.

The final prosthesis type for division B ridges is dependent on the surgical option selected. Whereas grafted ridges will more often be used when a fixed prosthesis is desired, ridges treated with osteoplasty before implant placement are likely to be supporting removable prostheses. The treatment option may be influenced by the region to be restored. For example, in a partially edentulous anterior maxilla, augmentation is most often selected because of esthetics, and the parallel bony anatomy of the residual ridge is not conducive for osteoplasty to gain bone width. In the edentulous anterior mandible, osteoplasty is common. In the premolar region of the posterior mandible, division B root form implants are often used because the bone density is adequate, available bone height is limited and may be reduced after osteoplasty, and esthetics are often not a major factor.

Division C (Compromised Bone)

The division C ridge is deficient in one or more dimensions (width, length, height, or angulation) (Box 14-5) regardless of the position of the implant body into the edentulous site. The resorption pattern of bone occurs first in width and then in height. As a result, the division B ridge continues to resorb in width, although height of bone is still present, until it becomes inadequate for any design of endosteal implant. This bone category is called division C minus width (C–w) (see Figure 14-6). The surgical approach for C–w is augmentation in width

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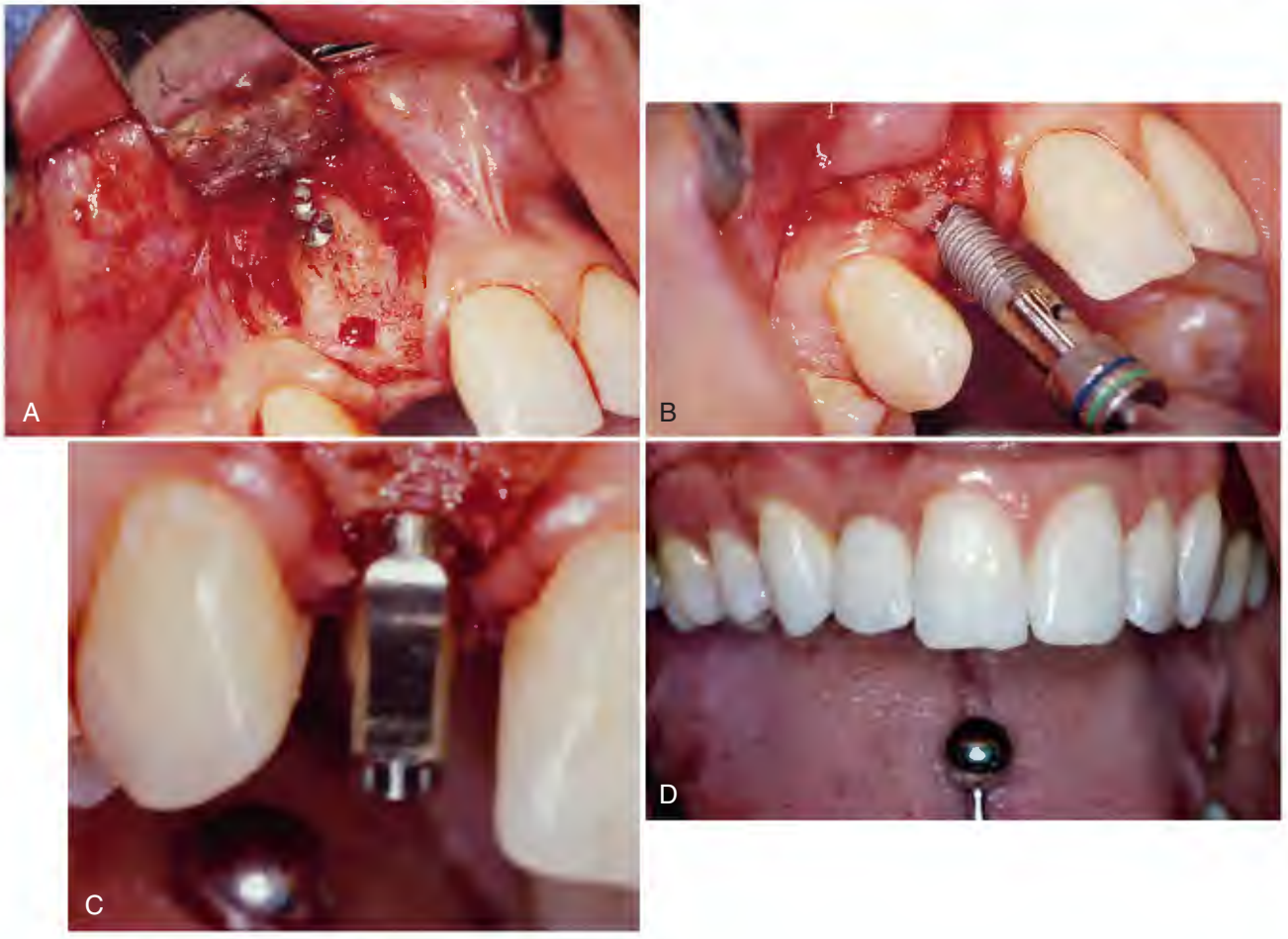


FIGURE 14-21. **A,** A division B ridge anatomy may be modified to division A by an augmentation procedure. A reentry of an onlay ramus bone graft to a division B–w ridge. The ridge is now converted to division A. **B,** A root form implant may now be inserted without compromise of implant width. **C,** The implant is not compromised relative to implant position. **D,** After bleaching the natural teeth, the implant crown was fabricated to replace the lateral incisor.

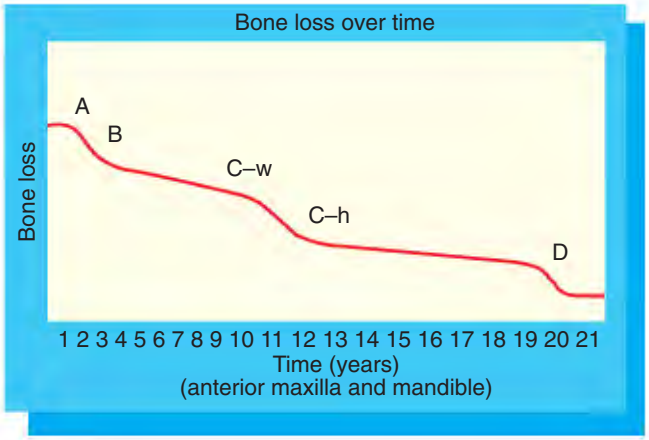


FIGURE 14-22. Bone rapidly resorbs from division A to division B then plateaus for many years before it is division C-w. From division C–w to C–h, it resorbs rapidly. Long plateaus are found for both division B and division C–h.

BOX 14-5 Division C Bone

- Width (C–w bone): 0–2.5 mm
- Height (C–h bone) <12 mm
  - Angulation of occlusal load (C–a bone) >30 degrees
  - Crown height space >15 mm

(usually both facial and lingual) or osteoplasty to convert the ridge to C–h (in adequate height).

On occasion, the C–w ridge may be treated by osteoplasty in the anterior mandible. An osteoplasty converts the ridge to C–h and, in the anterior mandibular region, most often to a width suitable for root form implants. The most common available bone division after osteoplasty of C–w is C–h available bone, not division A, because the CHS is greater than 15 mm. On occasion, the C–w osteoplasty may convert the ridge to division D, especially in the posterior mandible or maxilla. Care should be taken not to let this occur because bone grafting procedures will be more challenging after the height has been reduced.

Another treatment option is to alter the division C–w by bone grafting. After the ridge is augmented, it is treated with the options available in the acquired bone division. A patient who

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desires a fixed prosthesis often requires an autogenous graft before implant placement to acquire proper lip support and ideal crown height.

Augmentation of C–w is most often used when prosthetic guidelines require a fixed restoration or excess force factors require greater surface area implants and improved biomechanics for the prosthesis. The C–w augmentation is more difficult than for division B bone because the need for bone volume is greater, yet the recipient bed is more deficient. Therefore, block bone grafts are usually indicated[63–65] (Figure 14-23). Soft tissue complications, such as incision line opening, are also more common in C–w augmentations than division B.

The doctor must appreciate that the C–w bone will resorb to a C–h ridge as fast as the A resorbs to B and faster than B resorbs to C–w. In addition, without implant or bone graft intervention, the C–h available bone will eventually evolve into division D (severe atrophy) (see Figure 14-22).

The vertical height of bone for C–h is 7 to 9 mm, or the crown height space is greater than 15 mm. The resorption process continues, and the available bone is then reduced in height (C–h). Moderate to advanced atrophy may be used to describe the clinical conditions of division C. The posterior maxilla and mandible have a division C–h bone volume more rapidly than the anterior regions because the maxillary sinus or mandibular canal limits vertical height sooner than the opposing cortical plates in the anterior regions.

Many completely edentulous patients are treated with implants in the mandible and conventional dentures in the maxilla, primarily because the mandibular C–h arch is more often the cause of patient complaint (Figure 14-24). However, the patient should be educated about the future maxillary bone loss that will render maxillary implant treatment almost impossible without advanced bone graft procedures before placement.

The division C edentulous ridge does not offer as many elements for predictable endosteal implant survival or prosthodontic management as divisions A or B. Anatomical landmarks to determine implant angulations or positions in relation to the incisal edge are usually not present; therefore, greater surgical skill is required. The doctor and patient should realize that division C ridge implant-supported prostheses are more complex and have slightly more complications in healing, prosthetic design, or long-term maintenance. On the other hand, the patients usually have greater need for increased prosthodontic support. Despite the reduced bone volume, altered treatment plans that decrease stress can provide predictable, long-term treatment. When the anterior mandible is C–h, the floor of the mouth is often level with the residual mandibular crest of the ridge. During swallowing, it may prolapse over the residual crest and implant sites, causing constant irritation of the permucosal implant posts and impairing proper design of the prosthetic superstructures.

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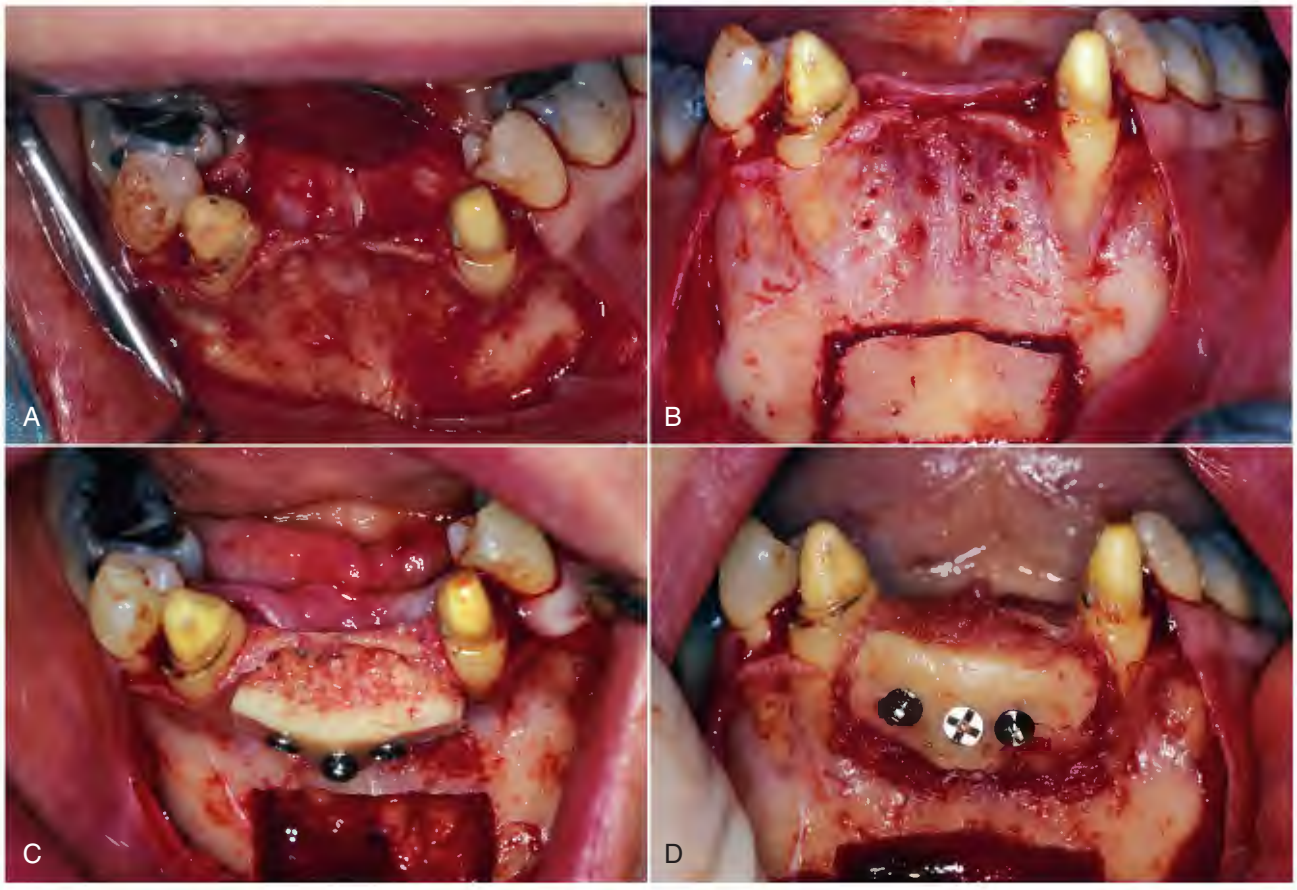


FIGURE 14-23. **A,** An anterior mandible with a partially edentulous C–w ridge in the incisor region. **B,** A block of autograft is being harvested from the mandibular symphysis. **C,** The symphysis block graft is shaped and fixated to the C–w ridge with three bone screws. **D,** The division C–w ridge is converted to division A by bone augmentation.

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FIGURE 14-24. **A,** Panoramic radiograph of a division C–h anterior mandible with five root forms opposing a maxillary denture. The patient should be informed of the continued maxillary and posterior mandibular bone loss over time. **B,** The overdenture bar often has less cantilever for a division C–h ridge because the CHS is greater.

There is one less common subcategory of division C, called C–a. In this category, available bone is adequate in height and width, but angulation is greater than 30 degrees regardless of implant placement (Figure 14-25). The limitations of anatomy for root form implants may be bone angulation or inadequate bone height. When the anterior bone angulation is unfavorable, root form implants may be positioned too far lingually for prosthodontic support, speech, or hygiene.

Mraiwa et al. found that 28% of edentulous anterior mandibles had an angulation of 67.6 ± 6.5 degrees.[66] Hence, almost 10% of patients may have a greater than 30 degree angle to the occlusal plane. When present, this condition is most often found in the anterior mandible. Root form implants placed in this bone category may have the abutments positioned within the floor of the mouth and compromise prosthetic reconstruction, speech, and comfort (Figure 14-26). Other less observed regions for C–a include the maxilla with severe facial undercut regions or the mandibular second molar with a severe lingual undercut.

Implant treatment planning for the completely edentulous C–h arch is more complex than in division A or B. There are seven implant treatment options for division C bone (Box 14-6). All of these options require greater skill than similar treatment modalities in division A or B.

Various implant approaches are used in the division C–h available bone. Shorter endosteal implants are the most common options.[54,55] A C–h root form implant is usually 4 mm or greater in width at the crest module and 10 mm or less in height. Several studies indicate that implant survival is decreased when an implant is less than 10 mm in height.[37,67,68] For example, a large multicenter study of 31 different sites and six different implant designs observed 13% failure with 10-mm implants, 18% failure with 8-mm implants, and 25% failure with 7-mm implants.[37] The implant failure did not occur after



FIGURE 14-25. Lateral cephalogram of an anterior mandible with a 45-degree trajectory to the occlusal plane. This is a C–a anterior mandible.

BOX 14-6 Division C Treatment Options

- Osteoplasty (C–w)
- Root form implants (C–h)
  - Subperiosteal implant (C–h, C–a partial, or completely edentulous mandible)
  - Augmentation procedures before implant insertion
  - Disk design implants (posterior mandible, anterior maxilla)
  - Ramus frame implant (C–h completely edentulous mandible)
  - Transosteal implant (C–h anterior mandible)

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surgery but rather after prosthetic delivery. This loading failure is a result of inadequate implant support combined with a magnification of force resulting from excessive CHS.

When endosteal root form implants are used in division C–h bone with greater crown heights, additional implants should be placed to increase the overall implant–bone surface area, and the prosthesis should load the implants in an axial direction. Because the CHS is greater than 15 mm, the design of a removable prosthesis should often reduce or eliminate cantilever length and incorporate a stress relief mechanism. Reduced long-term predictability is usually expected if additional implants or less stressful prostheses are not used because a greater moment force is transmitted to the implants.



FIGURE 14-26. A C–a anterior mandible with four root form implants. The implants encroach on the floor of the mouth, complicate prosthesis fabrication, and impair speech and comfort during function.

Posterior Regions

The C–h posterior maxilla is a common and unique edentulous condition. The residual ridge resorbs in width and height after tooth loss, similar to other regions. However, because of the initial ridge width dimension, a decrease of 60% in dimension still is adequate for 4-mm-diameter implants. In addition to the residual alveolar bone resorption, the maxillary sinus expands after tooth loss. As a result, the available bone height is decreased from both the crestal and apical regions.

Sinus grafts, which elevate the maxillary sinus floor membrane and then graft the previous sinus floor region, were developed by Tatum in the mid 1970s.[61] This area is the most predictable intraoral region to augment in excess of 10 mm of vertical bone. Even alloplasts may be used for this technique. Therefore, sinus grafting is often prescribed before placing endosteal implants in the C–h posterior maxilla (Figure 14-27).



FIGURE 14-27. **A,** A panoramic radiograph of a maxillary first molar region with C–h bone. **B,** A Tatum lateral wall approach to the sinus floor permits an augmentation for apical height. **C,** The implant is inserted at the same time as the sinus graft.

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FIGURE 14-27, cont'd. **D,** A postoperative radiograph of the implant and sinus bone graft. **E,** An abutment is inserted into the implant after 6 months. **F,** A crown restores the maxillary first molar implant. **G,** A 5-year postoperative radiograph of the implant and crown.

Alternative approaches to endosteal implants in the posterior mandibular edentulous division C–h arch are subperiosteal and disk design implants. Disk implants have a circular disk 7 to 10 mm in diameter with a connected 3-mm-diameter permucosal post, which supports the prosthesis. These implants may be used in C–h bone because it is inserted from a lateral approach, which allows the wider disk to engage facial or lingual cortical bone (or both) (Figure 14-28).[69,70] Because the disk design implant engages the lateral aspect of the cortical bone, it may be used in available bone height of 5 to 7 mm (or more). As a general rule, these implants are used in addition to other root form implants. Their inclusion in the treatment plan for C–h posterior sections of edentulous mandibles eliminate cantilevers in full-arch restorations.[69]

Subperiosteal implants are snow-shoe designs that rest on the lateral aspects and crest of a ridge. Subperiosteal implants are more predictable in the mandibular arch than in the maxilla. The superstructure and abutment posts for the subperiosteal implant are designed and cast before implant placement. The permucosal posts may be designed with greater latitude than endosteal implants. When anterior root forms are placed in an edentulous mandible with a square arch form, the superstructure may not be cantilevered distally because of the poor anteroposterior distance. As a result, a fixed restoration or RP-4 overdenture prosthesis is contraindicated with anterior root forms in a square arch form. A subperiosteal implant may provide anterior and posterior bone support, and the square arch form does not contraindicate a RP-4 or fixed prosthesis.

Autogenous grafts or nerve repositioning may be necessary to place endosteal implants in the posterior division C–h mandible. The increase in treatment time, surgical risks, and

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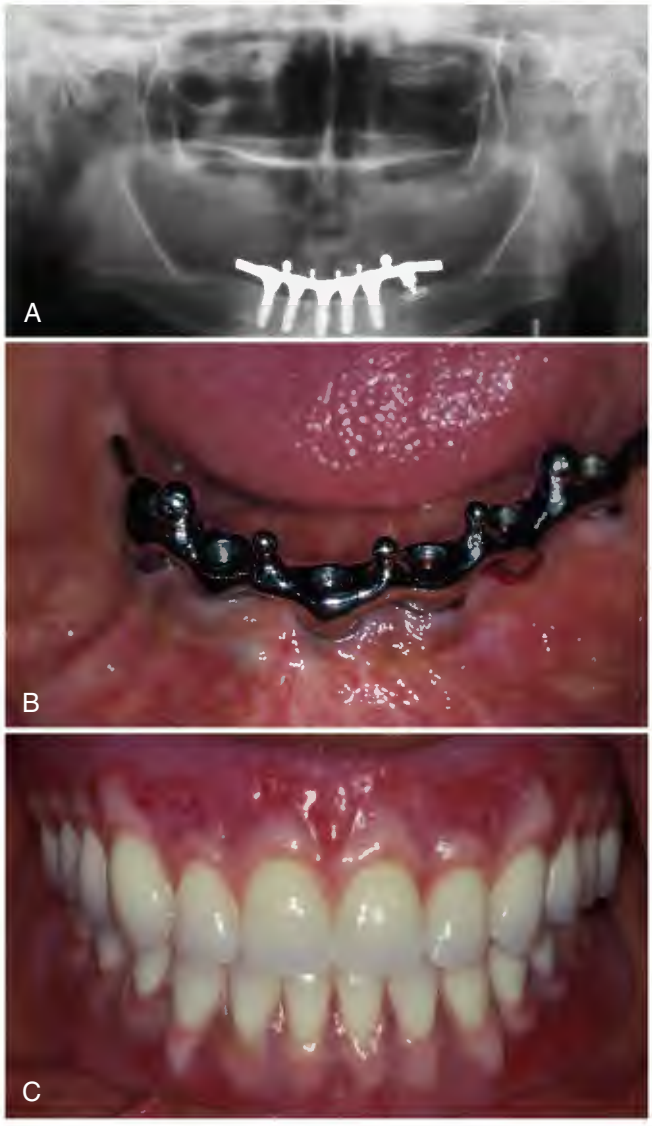


FIGURE 14-28. **A,** A panoramic radiograph of an edentulous C–h mandible with a disk implant in the posterior left connected to five anterior root form implants with an overdenture bar. **B,** An intraoral view of the overdenture bar for a RP-4 prosthesis in a C-h mandible. **C,** The five root forms and disk implant support a bar for a mandibular RP-4 overdenture opposing a conventional maxillary denture.

postoperative complications (e.g., paresthesia) are to be thoroughly discussed with the patient. Circumferential or unilateral subperiosteal implants permit the placement of posterior prosthodontic units without risks of paresthesia from nerve repositioning or lengthened treatment time associated with autogenous bone grafts and endosteal implants[71] (Figure 14-29).

Prosthetic Options

The prosthetic options for division C ridges more often consist of removable prosthesis in the completely edentulous maxillary arch. A maxillary overdenture in a division C ridge supports the upper lip without hygiene compromise. In the division C mandible, the greater CHS often mandates an overdenture design with some soft tissue support (RP-5). A fixed restoration in the division C mandible may require both anterior and posterior implant support when force factors are greater than usual. The fixed prosthesis in division C bone with greater than 15 mm CHS is most often a hybrid device, with denture teeth attached to a precious metal substructure with acrylic resin. In this way, the complications and costs of a porcelain–metal fixed restoration may be reduced.

In general, division C–h presents less favorable biomechanical factors to the implant support. Therefore, additional implants, cross-arch stabilization, soft tissue support, or an opposing removable prosthesis often need to be considered in the prosthetic design to improve the long-term prognosis. Treating the division C ridge requires greater experience, caution, and training than does the previous two bone divisions; however, excellent results may be achieved.

A completely edentulous patient who does not have implant treatment should be well educated that the bone resorption process will continue, with significant increased risks for the conventional removable restoration. Waiting to treat the patient until irreparable problems develop is a poor treatment alternative that results in the need for more advanced procedures (e.g., iliac crest grafts) and significant risks of associated complications.

In conclusion, as in all other bone divisions, the final prosthesis determines the treatment option. For mandibular RP-4 restorations, five root forms in the anterior mandible may be used (if the other dental criteria permit). However, the greater CHS or a square arch form may mandate a RP-5 prosthesis with anterior root form implants. The combination of anterior root forms and posterior subperiosteal implants (or disk implants) is a treatment option for RP-4 or fixed prosthesis in the mandibular arch. Augmentation is often required for a fixed prosthesis in either of the division C complete edentulous arches if stress factors are high and cannot be reduced.

Division D (Deficient Bone)

Anterior Regions

Long-term bone resorption may result in the complete loss of the residual ridge accompanied by basal bone atrophy (Figure 14-30). *Severe atrophy* describes the clinical condition of the division D ridge. At one time, it was believed only the alveolar process would resorb after tooth loss and the basal bone would remain. However, bone loss may continue beyond the previous roots of teeth and even include the bone over the inferior mandibular nerve or the nasal spine of the maxilla. The division D maxilla occurs when 6 mm or less of bone exits in the anterior maxilla below the floor of the nose or less than 6 mm posterior bone is present below the maxillary sinus. In the anterior mandible, the division D ridge has 6 mm or less of bone between the mental foramen or the posterior mandible has less than 6 mm of bone above the inferior alveolar canal. In the maxilla, basal bone loss eventually results in a completely flat maxilla.

In the mandible, the superior genial tubercles become the most superior aspect of the ridge. The mentalis muscle has lost much of its attachment even though the superior portion of the muscle attaches near the crest of the resorbed ridge. In the posterior mandible, the buccinator muscle may approach the mylohyoid muscle and form an aponeurosis above the body of the mandible. The mandibular arch also presents with mental foraminae and portions of the mandibular canal dehiscent. Therefore, it is not infrequent that these patients complain of paresthesia of the lower lip, especially during mastication. The CHS is greater than 20 mm, which is a significant force multiplier and can rarely be reduced enough to render long-term success of the prosthesis (Figure 14-31; Box 14-7).

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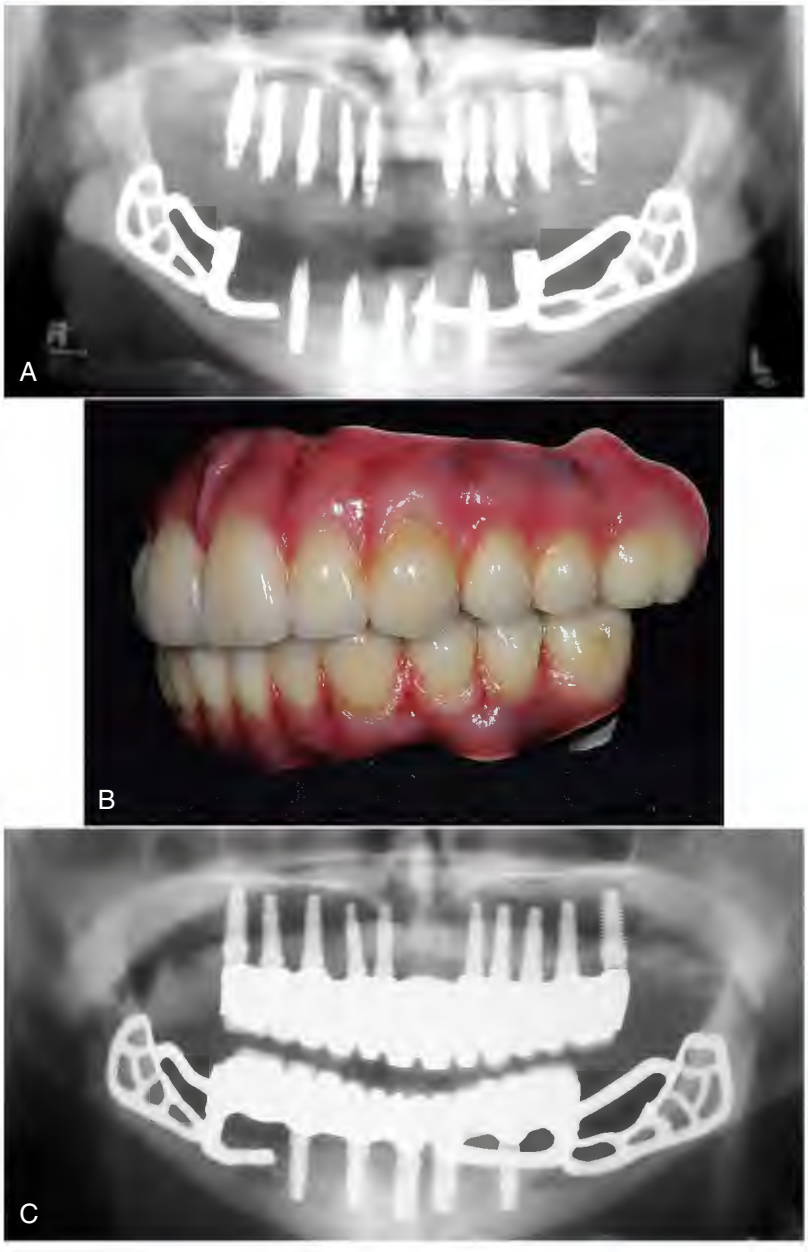


FIGURE 14-29. **A,** A panoramic radiograph of 10 implants inserted into an edentulous maxilla after bilateral sinus grafting. The mandible has five endosteal implants in a C–h anterior mandible. The posterior mandible has bilateral subperiosteal implants inserted for posterior prosthetic support. **B,** The maxillary and mandibular FP-3 restoration. **C,** A panoramic radiograph of the FP-3 prostheses in situ.

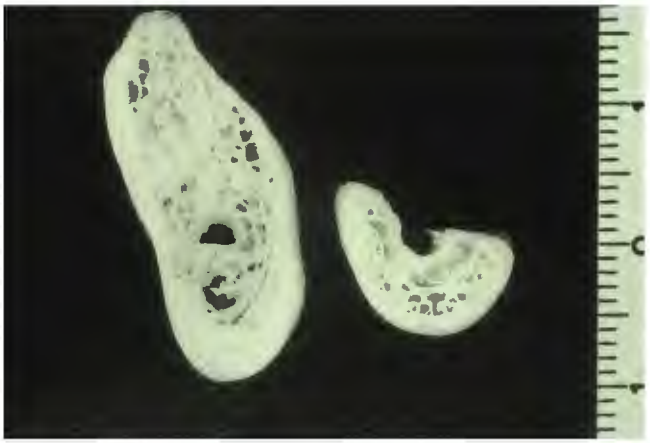


FIGURE 14-30. The *left* posterior mandible is division A, with abundant bone in height and width. The residual ridge on the *right* is a division D bone volume with a dehiscent mandibular canal.

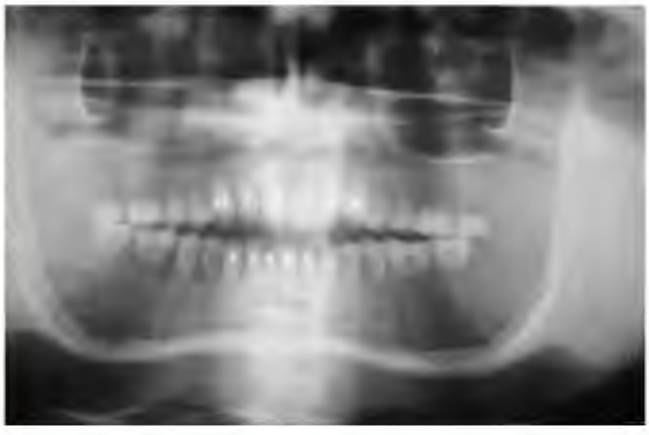


FIGURE 14-31. A panoramic radiograph of a patient with a division D mandible wearing a complete denture. Paresthesia of the mental nerve and fractures of the mandible are frequent complications.

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BOX 14-7 Division D Bone

- Severe atrophy
- Basal bone loss
- Flat maxilla
- Pencil-thin mandible
- >20 mm crown height

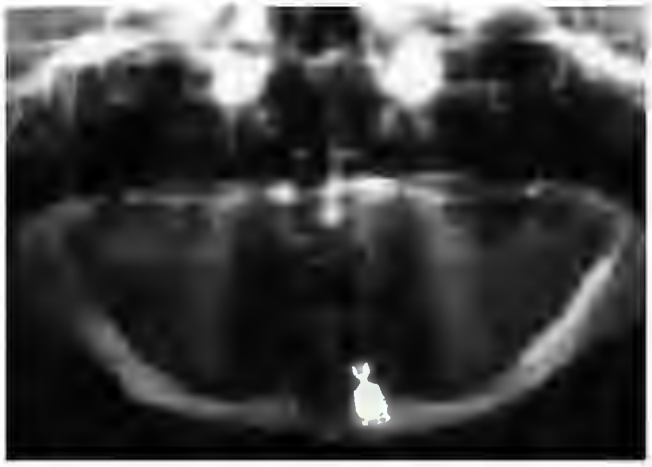


FIGURE 14-32. Two anterior root form implants were placed in a division D mandible. As a result of the failure of one implant, the mandible has fractured and has a discontinuity defect.

The prosthetic result for anterior ridges with division D without augmentation is the poorest treatment outcome of all the divisions of bone. Fixed restorations are nearly always contraindicated, because the CHS is so significant. When treated without augmentation, completely implant-supported overdentures are indicated whenever possible to decrease the soft tissue and nerve complications. A RP-5 restoration is not suggested, because bone loss will continue in the soft tissue–supported region of the overdenture. Bone augmentation in the anterior regions for division D is difficult to improve the CHS enough to warrant a fixed restoration.

The mandibular completely edentulous division D patient is the most difficult to treat in implant dentistry. Benefits must be carefully weighed against the risks. Although the practitioner and patient often regard this condition as the most desperate, these patients do not usually have deviated facial features after mandibular fracture before treatment. If implant failure occurs, the patient may become a dental cripple—unable to wear any prosthesis. Idiopathic fracture during surgery or from implant failure or removal is a more likely complication than in other bone division (Figure 14-32). Therefore, practitioners treating anterior division D mandibles should be able to manage future complications, which may be extensive.

Endosteal root form implants without autogenous grafts may be used on rare occasions in the anterior division D mandible when the remaining bone is dense and the opposing arch is edentulous. Care must be taken during placement because mandibular fracture at insertion or during postoperative healing is a possible complication.[72] Under these conditions, the CHS is very great, and the number of implants is often four or fewer. Implant failure after loading is a greater risk. Implant failure results with circumferential bone loss, which may be associated with mandibular fracture through the implant site. A RP-5 removable restoration is usually indicated for division D with only anterior implants. However, the RP-5 restoration allows continued bone resorption and atrophy to continue in the posterior regions. Therefore, the prudent therapy is to educate the patient as to the risks of the situation and offer an autologous bone graft and implants to support a RP-4 restoration. The choice to render treatment is the doctor's, not the patient's. The implant support should not be compromised when implant failure may result in significantly greater risks (Figure 14-33).

The anterior maxilla rarely provides sufficient support in the division D ridge for implants of any design. Autogenous iliac crest bone grafts to improve the anterior division D are strongly recommended before any implant treatment is attempted.[73] After autogenous grafts are in place and allowed to heal for 5 or more months, the bone division is usually division C–h (or even division A), and endosteal implants may be inserted (Figure 14-34).

The autogenous bone grafts are not intended for improved denture support in either arch. If soft tissue–borne prostheses are fabricated on autogenous grafts, 90% of the grafted bone resorbs within 5 years as a result of accelerated resorption.[74] Additional augmentation to compensate for this resorption is not indicated. Repeated relines, highly mobile tissue, sore spots, and patient frustration are all consequences. On the other hand, autogenous bone grafts are maintained long term in conjunction with implant placement. The completely flat anterior division D maxilla should not be augmented with only hydroxyapatite to improve denture support. Inadequate ridge form exists to guide the placement of the material. As a result, migration of the graft at the time of surgery or in the future after soft tissue loading is a frequent sequela.

Posterior Regions

The partially or completely edentulous patient with a posterior division D maxilla and healthy anterior teeth or implants may undergo sinus graft procedures with a combination of local autogenous bone, demineralized freeze-dried bone, and calcium phosphate bone substitutes.[61] The CHS may be insufficient for onlay grafts in the posterior maxilla despite a lack of available bone height because the sinus expands faster than the crest of the ridge resorbs. Endosteal implants of adequate height can rarely be positioned in the posterior maxilla with division D bone without a sinus graft. After 6 months post sinus graft, the division D posterior maxilla is restored to division A or C–h, and root form implants may be inserted for posterior prosthodontic support (Figure 14-35).

If adequate mandibular anterior bone is present with division D posterior bone, root form implants, tripodal subperiosteal implants, mandibular staple implants, or ramus frame implants may be used cautiously in the anterior edentulous mandible.

The division D arch requires greater doctor training and results in more frequent complications related to grafting, early implant failure, and soft tissue management; therefore, treatment options include a more guarded prognosis. It should be the goal of every dentist to educate and treat the patient before a division D bone condition develops. The profession treats periodontal diseases before pain in the region occurs, and carious lesions are removed from teeth before abscess formation. The profession monitors bone loss around teeth in millimeters and offers continued care to reduce the risks of future

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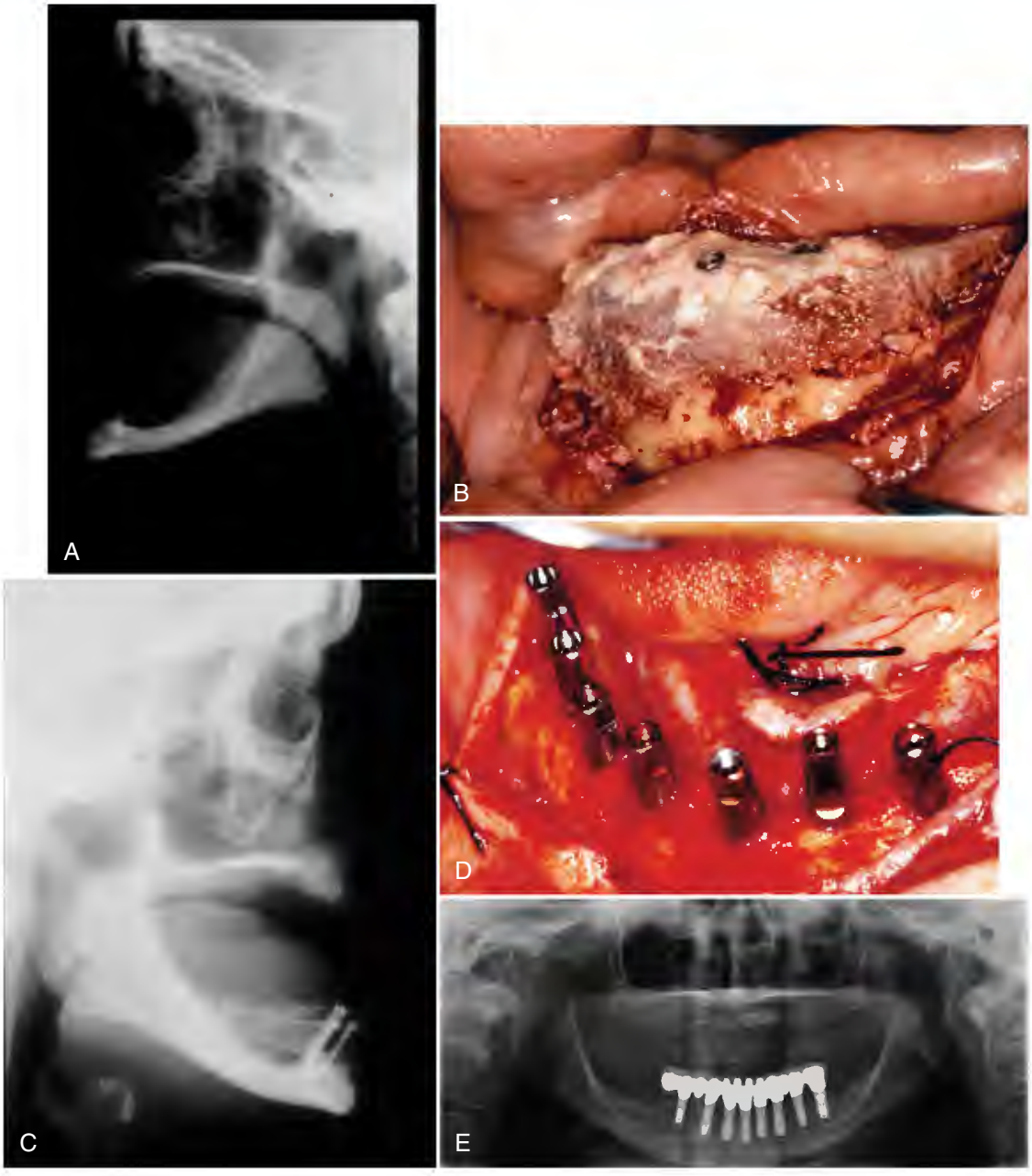


FIGURE 14-33. **A,** A lateral cephalogram of a division D mandible and maxilla. **B,** An autologous iliac crest bone graft in situ. The block graft is fixated with screws between the foramina and projects over the posterior canals. **C,** Lateral cephalogram of the block graft in **A** and **B**. The residual anterior mandible was angled more than 30 degrees lingually, so the bone graft is contoured facially toward the incisal edge of the final restoration. **D,** Reentry into the iliac crest block graft and placement of seven implants (4 mm in diameter and 12 mm long). The residual ridge was restored to division A dimensions in the anterior and posterior regions. **E,** A panoramic radiograph of the mandible restored with seven mandibular implants. In the maxilla, a dense hydroxyapatite graft was performed to improve the contour for a maxillary denture and delay the continued resorption.

tooth and bone loss. Likewise, prudent practitioners monitor bone loss in edentulous sites and offer education and treatment before deleterious effects.

Summary

In implant dentistry, the prosthesis is designed at the onset of treatment to satisfy the patient's needs and desires and obtain optimal results. This may range from a completely fixed prosthesis to one with primarily soft tissue support. After the final prosthesis type has been established, the key implant positions, patient force factors, bone density in the implant sites, and implant number and size are determined. The primary criterion for proper implant support is the amount of available bone. Four divisions of available bone, based on the width, height, length, angulation, and CHS in the edentulous site, have been presented. Consistent implant treatment plan procedures elaborated for each category of bone may be followed.

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FIGURE 14-34. **A,** A panoramic radiograph of a division D maxilla opposing unsalvageable mandibular teeth. An iliac crest bone graft is fixated to the edentulous maxilla. **B,** Ten endosteal implants are inserted into the iliac crest bone graft 6 months later. **C,** A fixed maxillary prosthesis was fabricated after integration of the implants. **D,** A panoramic radiograph of the implants and final restoration in the maxilla and mandible.

The division A edentulous ridge offers abundant bone in all dimensions. Division A root form implants are optimally used and most often as independent support for the prosthesis. Division B bone may provide adequate width for narrower, small-diameter root from endosteal implants.

The decreased width and surface area usually require additional implants to be included in the final prosthesis design. Division B may be changed to division A by augmentation or osteoplasty. The treatment options may be selected in light of the area to be treated. For example, in the anterior maxilla, augmentation is most often selected because of esthetics. In the anterior mandible, osteoplasty is common because of the available bone height and low esthetic concerns. In the posterior mandible, multiple division B implants may be used because the bone density is good, the available bone height is limited, and esthetics are not a primary factor. When stress factors are greater, bone augmentation precedes division A root form implants regardless of the anatomical location.

The division C edentulous ridge exhibits moderate resorption and presents more limiting factors for predictable endosteal implants. The decision to restore with endosteal implants or to upgrade the bone division by augmentation before implant placement is influenced by the prosthesis, patient force factors, and patient's desires.

The division D edentulous ridge corresponds to basal bone loss and severe atrophy, resulting in dehiscent mandibular canals or a completely flat maxilla. The patient often requires augmentation with autogenous bone before implant and prosthodontic reconstruction.

If the existing conditions do not qualify for a predictable end result, the patient's mind or mouth must be modified. For example, the expectations of the patient must be reduced so the

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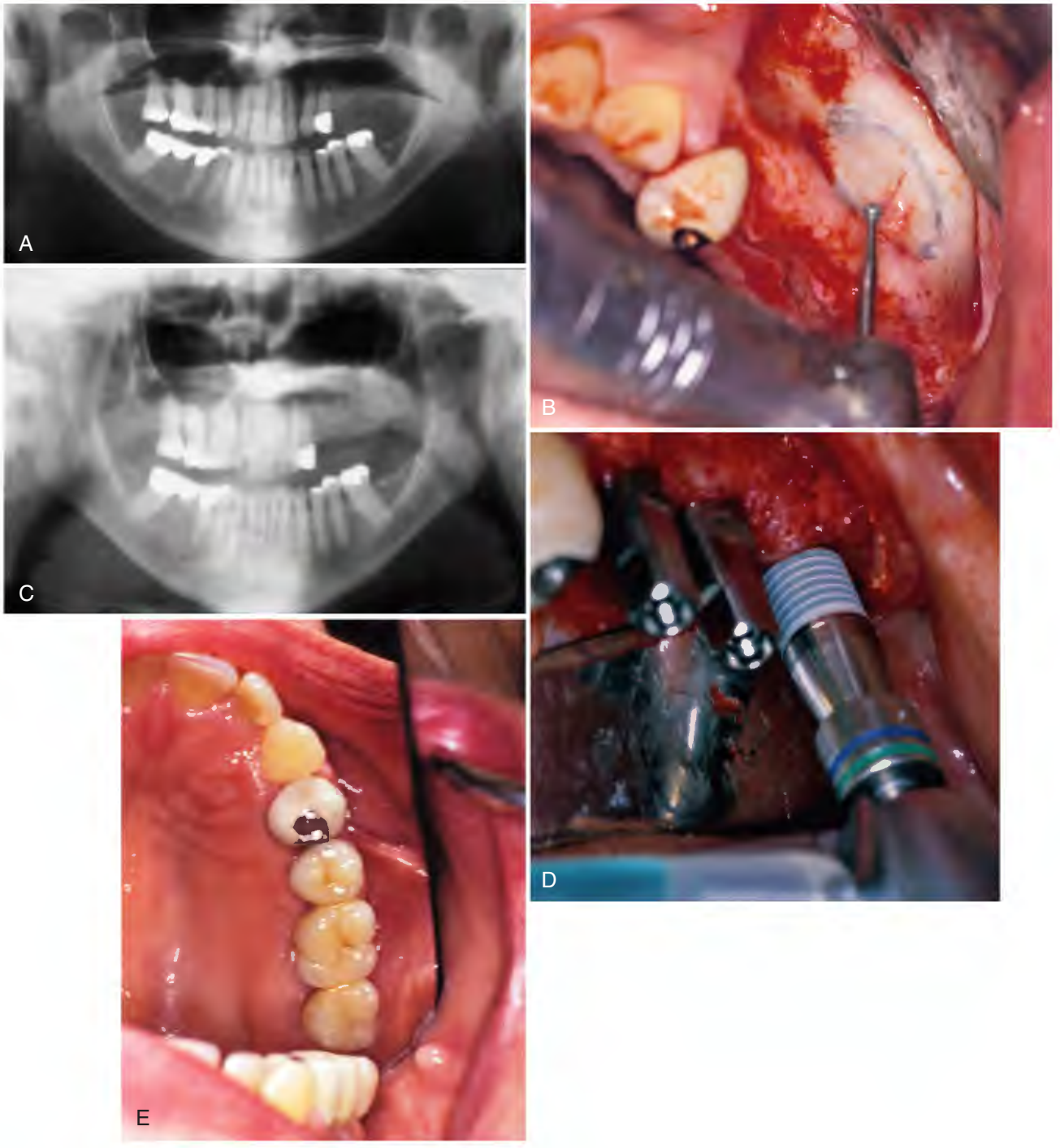


FIGURE 14-35. **A,** A panoramic radiograph with a unilateral posterior maxilla missing a premolar and molars. The bone division is C–h in the premolar and division D in the molar region. **B,** A Tatum lateral wall approach is prepared with a round diamond. The sinus mucosa will be elevated, and a sinus graft will be placed to augment the bone height. **C,** Six-month postoperative radiograph of **A** and **B**. The posterior maxilla has been modified to division A height requirement. **D,** After the sinus graft matured, three implants are inserted at reentry into the posterior maxilla. The second premolar implant is 4 mm in width; the molar sites are 5-mm-wide implants. **E,** The three-unit fixed final restoration (FP-1) is cemented into position over the three implants.

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prosthesis may be changed from FP-1 to RP-4, or the bone must be augmented to improve the height and width and change the division so that long-term implant support and prosthetic design will be compatible.

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CHAPTER 15

Scientific Rationale for Dental Implant Design

Carl E. Misch, J. Todd Strong, and Martha Warren Bidez

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The treatment planning sequence for implant dentistry begins with the design of the final restoration.[1] After the position and number of teeth replaced and type of prosthesis are determined, the patient force factors are evaluated.[2,3] The greater the force factors, the greater the implant support required. The bone density in the region of the implant abutments is then considered, with poorer bone densities requiring a greater amount of implant support.[4] The key implant positions and additional implant number are then determined followed by the ideal implant size.[5] The available bone in the edentulous sites is then evaluated.[6] When the bone available is present for the size, number, and position of the implants for the planned prosthesis, the treatment proceeds with little compromise.

When the available bone is not present, a modification of one or more factors of the treatment plan is necessary. These modifications include (1) bone augmentation to fulfill the ideal treatment plan, (2) consideration of optional implant locations, (3) additional implants, (4) an increase in implant size, and (5) optimization of implant design (Table 15-1). A favorable implant design may help compensate for risk of occlusal loads in excess of normal, poor bone densities, less than ideal implant position or number, or less than an ideal implant size.[7]

Many different implant body designs are available in implant dentistry. They may be categorized as a cylinder type, screw type, press fit, or a combination of features (Figure 15-1). Dental implants are often designed to answer a primary focus or belief that implant failure may stem from (1) implant surgery, (2) bacterial plaque complications, (3) biologic width bone loss, or (4) loading conditions.

Implant Design

Surgical Prospective

In the past, implant body design was driven by the surgical ease of placement. A surgically driven implant design will tend to have a tapered, short implant body or a press-fit insertion. These features permit the implant site preparation and implant to be surgically most easily placed. A cylinder or press-fit implant has a friction-fit insertion and may have less risk of pressure necrosis from too tight an insertion pressure, has no need to bone tap (even in dense bone), and may have the first-stage cover screw already in place because no rotational force is required to insert the implant. As a result, cylinder or press-fit implants are the easiest to insert, were very popular in the 1980s, and were reported to have high initial success rates.[8,9] However, after 5 years of loading, reports of the cylinder implant more often include loss of crestal bone and implant failure. For example, in a report by Scortecci et al., the 3-year survival of a press-fit cylinder design with a rough surface condition reported a success rate of almost 100%. However, after 10 years of loading, the implant failure was approximately 50%[10] (Figure 15-2). Most likely, this was related to a fatigue overload condition and harmful shear loads on the bone, causing large bone turnover rates and ultimately less bone–implant contact percent and higher risk of overload failure.

The most predictable aspect of implant dentistry appears to be the surgical success. After many years of clinical studies and evaluations, the surgical success rate from implant insertion to uncovery of the implant is usually higher than 98% regardless of the implant design or size.[8,9,11–14] As such, designing an implant for surgical ease does not appear to be the most important aspect of the long-term overall implant-prosthetic–related process to reduce the incidence of complications.

Crest Module Considerations

An implant body may be divided into a crest module, the body, and the apex. The crest module of an implant body is the transosteal region, which extends from the implant body and often incorporates the antirotation components of the abutment implant connection (Figure 15-3). The crest module of the implant has a surgical influence, a bacterial plaque concern if bone loss occurs, biological width influence, a loading profile consideration (characterized as a region of highly concentrated mechanical stress), and a prosthetic influence. Therefore, this area of the implant body is a major determinant for the overall implant body design.

Surgical Aspects

During the surgical phase, the crest module design primarily benefits the crestal implant interface. The crest module of an implant should be slightly larger than the outer thread diameter of the implant body. In this way, the crest module seals completely the osteotomy, providing a barrier and deterrent for the

TABLE 15-1
Inadequate Available Bone for Ideal Treatment Plan

Bone augmentation
Optional implant locations
Additional implants
Increase implant size
Optimize implant design

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FIGURE 15-1. Dental implant bodies may be categorized by their design as cylinder type *(top row)*, screw type *(middle row)*, press fit *(bottom row)*, or a combination of features *(upper row, far right)*.

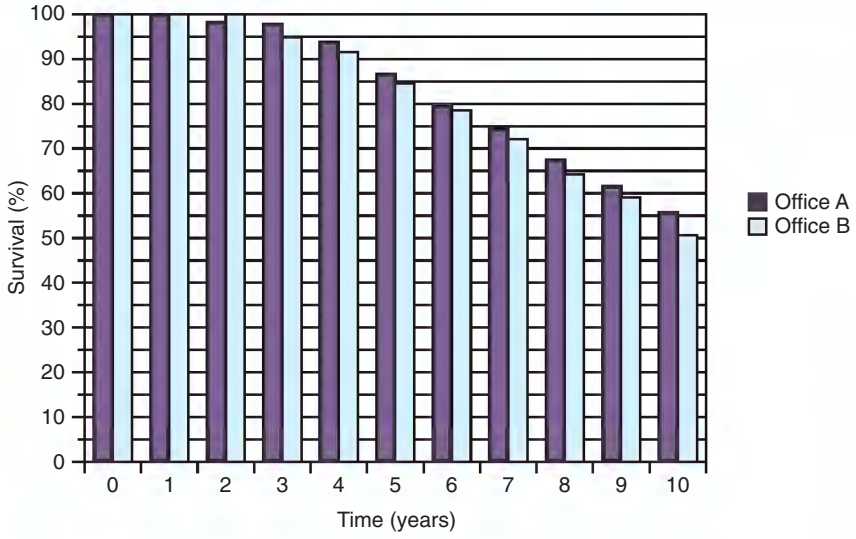


FIGURE 15-2. The hydroxylapatite-coated cylinder implant had almost 100% success in two different offices for the first 3 years. After 5 years, 20% failure rates were observed, and at 10 years, almost 50% failure rates were reported.

ingress of bacteria or fibrous tissue during initial healing. The seal created by the larger crest module also provides for greater initial stability of the implant after placement, especially in softer unprepared bone, because it compresses the crestal bone region.[15]

"Biologic Width" Designs

There are at least six causes of marginal bone loss at the crestal bone region of implants, including the formation of a "biological width" and occlusal overload after the implant is in function.[16,17] The biological width of an implant is related to marginal bone loss before, or separate from, occlusal loading influences. Both of these entities have increased bone loss risk when smooth metal is placed below the bone.

In an animal study, Hermann et al. placed one-piece implants with a 1.5-mm smooth crest module below the bone and compared it with a roughened crest module of similar design level at the bone crest in dogs[18] (Figure 15-4). The two implant

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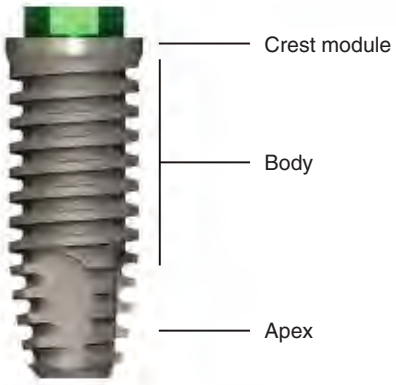


FIGURE 15-3. An implant body may be divided into a crest module, body, and apex.

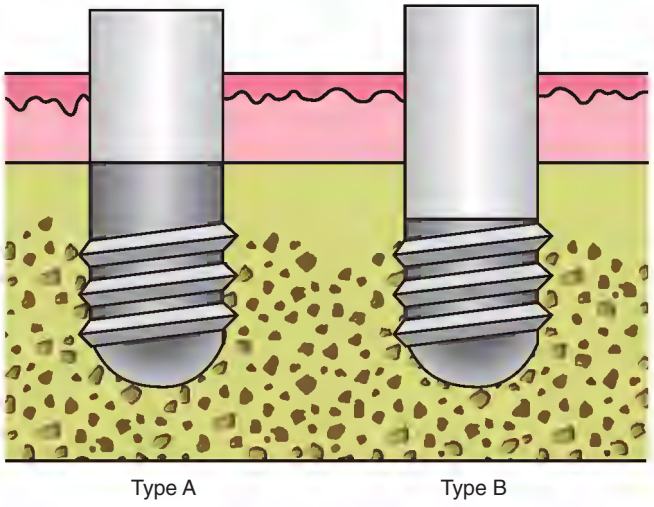


FIGURE 15-4. Hermann et al. evaluated the initial unloaded healing of 12 one-piece transgingival implant designs in dogs. The implant on the *left* (type A) had roughened metal placed at the crestal region. The implant on the *right* (type B) had a smooth metal collar of 1.5 mm placed below the crestal bone.[18]

designs were followed for 6 months, with no occlusal load. Within 1 month after the implant insertion and extension through the soft tissue, marginal bone loss occurred on the smooth region 1.5 mm below the crestal region. No bone loss occurred when the implant crest module was rough and placed at the level of the crestal bone (Figure 15-5). Hammerle et al. inserted similar implant designs in human patients and found a similar crestal relationship to smooth metal below bone.[19] Hanggi et al. also compared two different crest module designs in patients and found the longer smooth metal collar had more crestal bone loss.[20] The "biologic width" of initial bone loss appears to be directly related to the amount of smooth metal placed below the bone. Therefore, the crest module of the implant should not have an extended smooth metal area placed below the bone.

A "biological width" of 0.5 mm has been reported apical to the abutment-to-implant connection in most implant crest module designs, whether or not the crest module is rough. A 0.5-mm-length smooth collar may provide for a desirable smooth surface close to the perigingival area while preserving the biomechanical performance of the remaining portion of the crest module (Figure 15-6). The "microgap" between the implant crest module and abutment may also be eliminated when polished surfaces are approximated.

The soft tissues surrounding a dental implant in several ways are similar to a natural tooth. Both entities have a junctional epithelial "attachment" zone below the sulcus region. The actual "attachment" to the tooth or implant is a hemidesmosome with a layer of glycoaminoglycin. It is not a true attachment because plaque may destroy it, and a dental probe may penetrate through the region. However, in health, it can prevent bacteria in the sulcus from invading the underlying tissues. Below this region on a natural tooth is a connective tissue (CT) attachment zone. The CT attachment is a physical barrier because Sharpey's fibers of collagen insert into the cementum of the tooth. An implant does not typically have this zone of attachment (Figure 15-7).

Smooth implant surfaces on an implant crest module encourage fibroblast growth and spreading of the cells over the surface, which encourage a fibrous capsule that restricts bone formation. On the other hand, ridge-groove widths similar to the size of cells may guide cell migration and orientation.[21] It

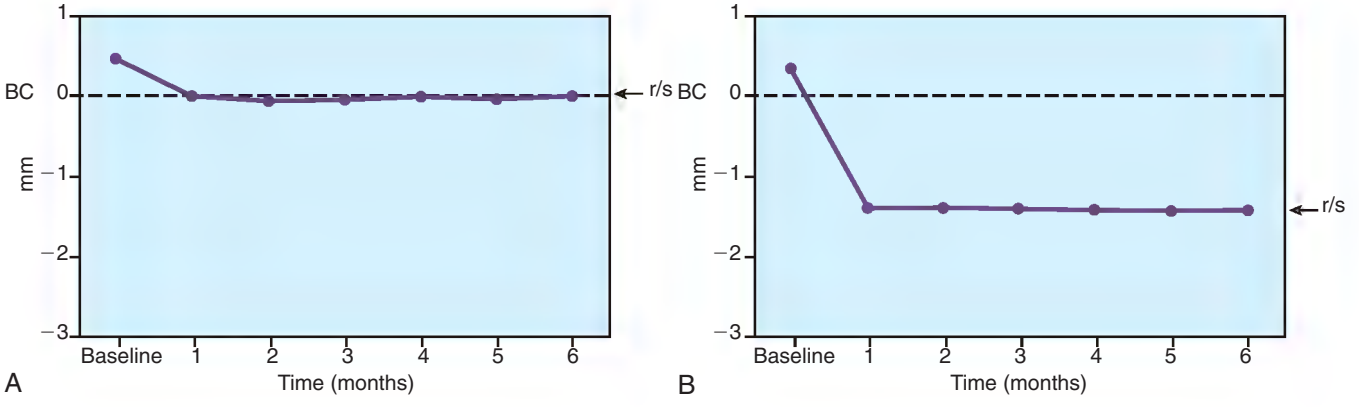


FIGURE 15-5. **A,** The implants with a rough surface at the crestal bone (type A) lost no bone during an unloaded 6-month period. **B,** The implants with a 1.5-mm smooth metal collar below the bone (type B) lost 1.5 mm of bone the first month during an unloaded 6-month period.

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FIGURE 15-6. An implant crest module may have up to a 0.5 mm smooth region to improve the abutment-to-implant connection. (BioHorizons, Birmingham, AL.)

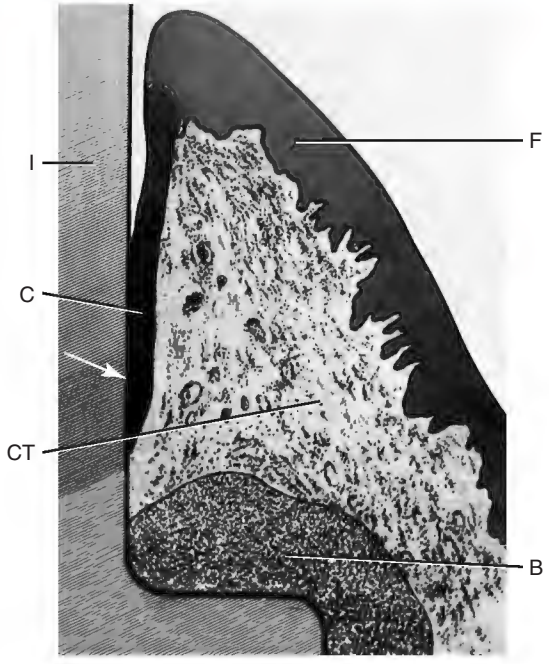


FIGURE 15-7. An implant does not have a connective tissue (CT) attachment zone, as with a natural tooth. Hence, the only connection between the soft tissue and implant is a hemidesmasome approximation. *B,* Bone; *C,* hemidesmosome approximation; *F,* free gingival margin.

has been observed from in vitro studies that an 8- and 12-micron microgrooved architecture affects cellular attachment, spreading, orientation, and growth of the fibroblasts and osteoblast cell types. An 8-micron groove was the most effective to inhibit cell migration across the groove, in effect acting as a migration barrier. The 12-micron groove was found to inhibit fibrous tissue growth and permit bone cell growth.

Animal and human histology has observed collagen connection of the soft tissue to microchannels that have three-dimensional structure.[22,23] This soft tissue "attachment" zone acts to restrict apical migration of gingival epithelial cells and fibroblasts in the smaller grooves and permit bone tissue to

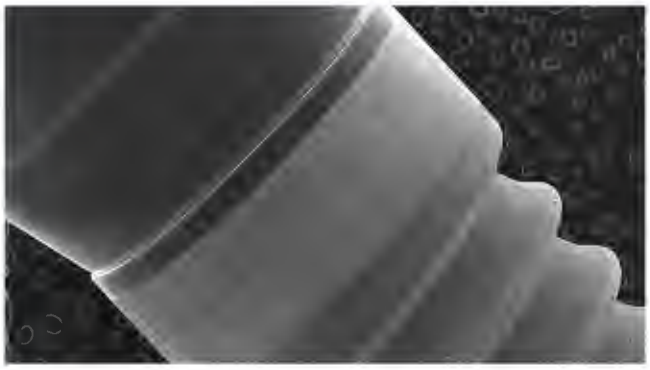


FIGURE 15-8. Microchannels (8 and 12 microns) may be placed on the crest module of the implant to guide soft and hard tissue attachment. (Laser-Lok, BioHorizons Dental Implants, Birmingham, AL.)



FIGURE 15-9. These three-dimensional microchannels are formed by a computer-controlled laser ablation technique.

establish attachment to the larger microtextured surface. As a consequence of these studies, three-dimensional microchannels of 8 and 12 microns have been introduced on the crest module (or implant abutment) of an implant(Laser-Lok, BioHorizons Dental Implants) and permit a physical attachment of CT fibers above the bone to the implant surface (Figure 15-8). These three-dimensional microstructures are formed by a computer-controlled laser ablation technique (Figure 15-9). An advantage of the three-dimensional microchannel architecture is that the soft tissue has a base of connection to the implant, similar to a tooth (Figure 15-10). The CT around the implant may physically attach to the implant surface (Figure 15-11). Hence, the soft tissue drape, including the interimplant papilla, may be more stable and improve the soft tissue esthetic regions around an implant prosthesis. This may be particularly advantageous when implants are adjacent to each other and the interimplant papilla is in the esthetic zone (Figure 15-12).

Occlusal Loading Design. The next consideration of the crest module is related to occlusal loading.[17] Most of the occlusal stress occurs at the crestal region of an implant design.[16,24] A larger crest module diameter compared with the implant body increases surface area, which can further decrease stress at the crestal region. A crest module height of 2 mm, which is 4.2 mm in diameter compared with a 3.7 mm diameter, has 9% greater surface area ($\pi \times$ Diameter $\times$ Height).[5] Because the stresses are highest in this region, the greater surface area

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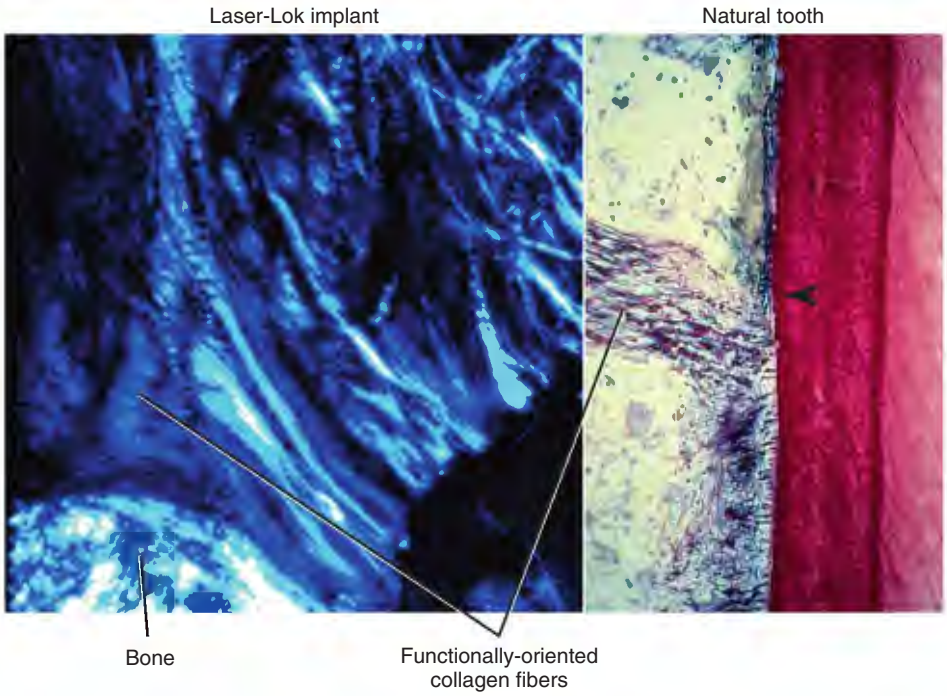


FIGURE 15-10. The natural tooth *(right side)* has perpendicular Sharpey's fibers, which insert into the cementum of a tooth. The Laser-Lok implant *(left side)* may develop a perpendicular mechanical connection of the soft tissue above the bone to act as a physical attachment to the implant. (From Nevins M, Nevins ML, Camelo M, et al: Human histologic evidence of a connective tissue attachment to a dental implant, *Int J Periodontics Rest Dent* 28:111–121, 2008.)

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decreases stress to the bone. In addition, the increase in the diameter of the crest module also affects the strength of the implant body. The crest module diameter increases the strength of the implant more than the surface area because the bending fracture resistance is related to the radius of the crest module times the power of 4.[7]

In addition to the "biologic width" bone loss before occlusal loading, the cylinder smooth metal reduces the bone cell contact compared with a roughened surface after loading.[25] When the surface condition of the implant is rough, the bone–implant contact (BIC) is increased during initial healing. The stress applied to an implant interface with bone may be related to the BIC because stress equals force divided by the area of contact. Reverse torque tests after initial healing observe consistently higher values when roughened surfaces are compared with machined or polished surface conditions.[25] Significant loss of crestal bone after loading has been reported for implants with machined (smooth) coronal regions, and the amount of the bone loss is directly related to the length of the smooth crest module.[26]

Cylinder crest module (or implant) designs promote shear stresses in the adjacent bone interface after loading, regardless of the surface condition[27] (Figure 15-13). Bone is 65% weaker to shear loads compared with compression loads and 35% weaker compared with tensile loads[28] (Figure 15-14). Hence, a crest module design to limit shear loads is in order. A roughened surface, but a parallel-sided crest module, maintains the bone through the biological-width bone healing period. However, it often loses the marginal bone during the occlusal load conditions because it loads the bone in shear.

The concept of rough surface condition and shear loads are two different entities, which may act together. Although more bone contact during initial healing is most often evident to the cylinder design rough surface, the stress to the bone after loading is still a shear force. For example, Straumann ITI has a roughened crest module, which is a cylinder below the bone. The initial bone loss before loading is minimal. However, a clinical report on human patients demonstrated almost 30% of the implants lost more than 5 mm of bone. and 22% lost more than 6 mm during a 10-year prospective study[29] (Table 15-2). DeBruyn et al. followed clinical outcomes of implants with an internal hex and long rough-cylinder crest module).[30] Crestal bone loss was consistently found at least to the first thread, which accounted for more than 2 mm of bone loss. In other words, a rough crest module with a cylinder design may not be sufficient to stop crestal bone loss after the implant is loaded.

TABLE 15-2
Success Rates Using 5 mm as Borderline Compared with Clinical Survival

Implant Type (Clinical Survival)	Number of Implants Placed	<5 mm Bone Loss
Hollow screw (95.4)	112	101 (74%)
Hollow cylinder (85.7%)	9	7 (63%)
Angulated hollow cylinder (91.7%)	18	6 (61%)
All implants (92.4%)	179	154 (69.8%)

Data from Karoussis IK, Bragger U, Salvi GE, et al: Effect of implant design on survival and success rates of titanium oral implants: a 10-year prospective cohort study of the ITI Dental Implant System, *Clin Oral Implants Res* 15:8–17, 2004.

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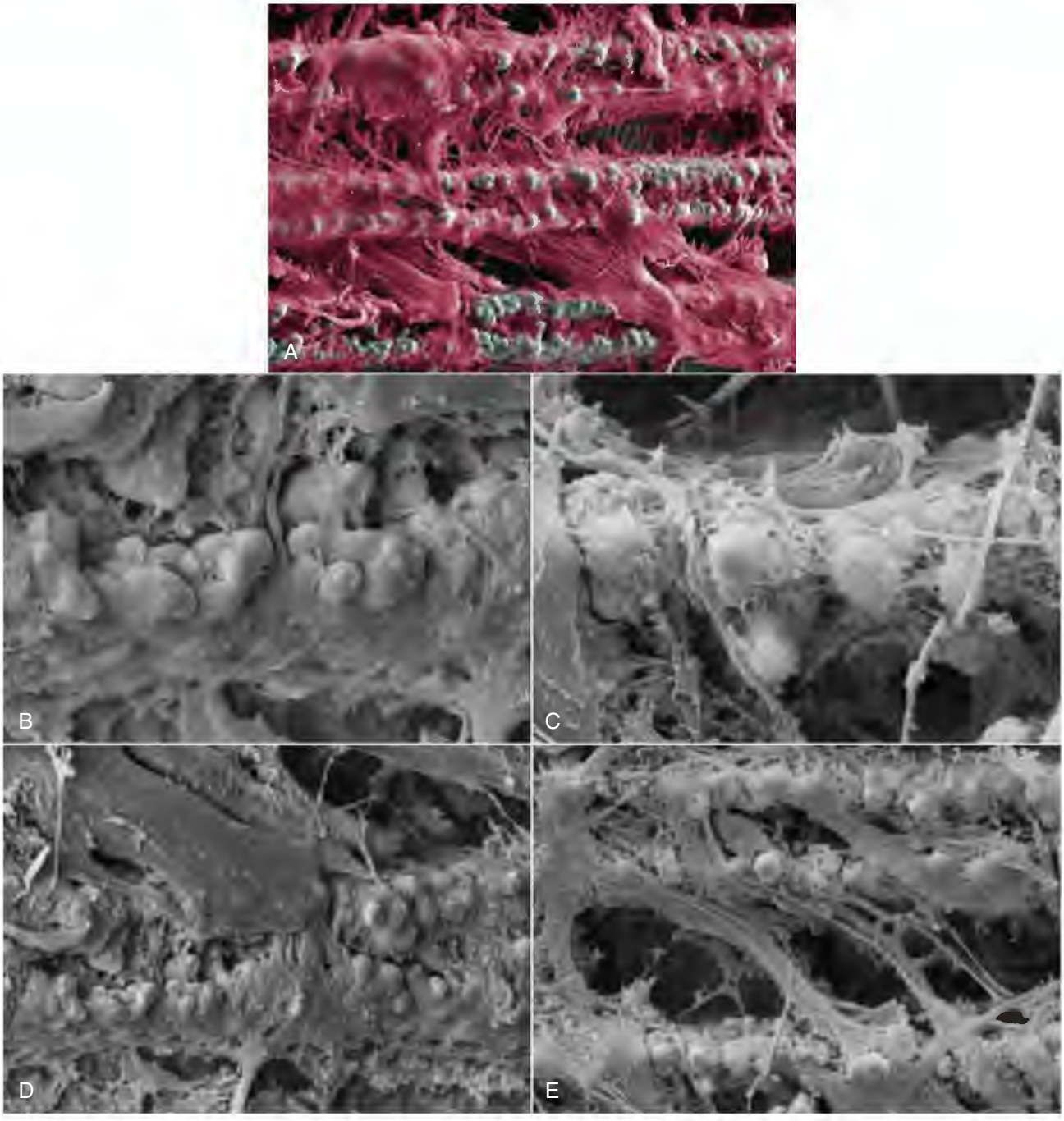


FIGURE 15-11. The connective tissue may physically attach to the laser-developed microgrooves. (From Nevins M, Nevins ML, Camelo M, et al: Human histologic evidence of a connective tissue attachment to a dental implant, *Int J Periodontics Rest Dent* 28:111–121, 2008.)

It has been a common clinical observation that bone is often lost to the first thread after loading, regardless of the manufacturer type or design. Bone grows above the threads during initial healing, but after prosthesis loading, bone loss is often observed to this landmark. However, the amount of crestal bone loss is different for different implant designs and related to the length of the crest module. For example, the first thread is 1.2 mm below the platform of the Nobel Biocare Mark IV implant, 2 mm below the platform on the Nobel Replace design, and 3.5 mm on internal hex Zimmer implant designs. The magnitude of the crestal bone loss is often directly related to the distance between the crest module and the first thread distance (regardless of whether the surface condition is smooth or rough above the thread) (Figure 15-15). Therefore, the bone loss cannot be related to a specific "biological width" but may be in part caused by crest module design. The bone loss often stops at the first thread because the first thread changes the shear load created by the cylinder crest module to a component of compressive loading (and the bone is 65% stronger). Instead of designing the crest module for shear, an improved design that loads the bone in compression can reduce the crestal bone loss risk after occlusal loading.

Prosthetic Attachment Designs. The original external hex design of Brånemark Nobel Pharma used the hex of the implant

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FIGURE 15-12. Two adjacent implants in the esthetic zone with an interimplant papilla.

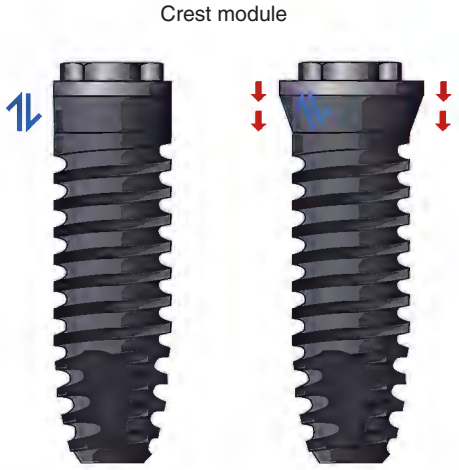


FIGURE 15-13. The crest module with a cylinder collar transfers primarily shear forces (⇅) to the bone *(far left)*. An angled crest module or one with grooves may load the bone with a compressive component (↓) *(right)*.

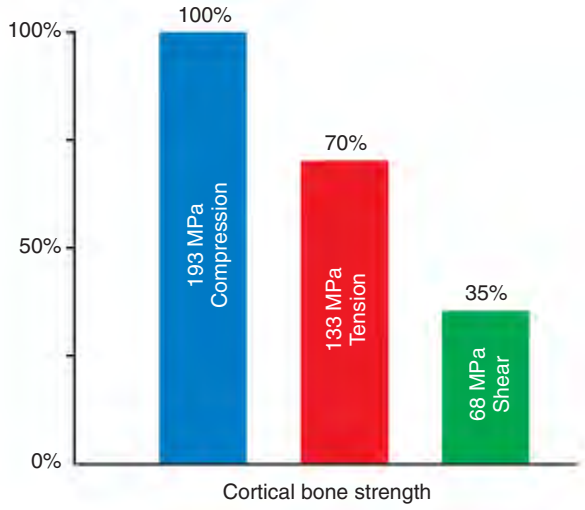


FIGURE 15-14. Cortical bone is strongest when loaded in compression, 30% weaker to tensile loads, and 65% weaker to shear loads.[53]

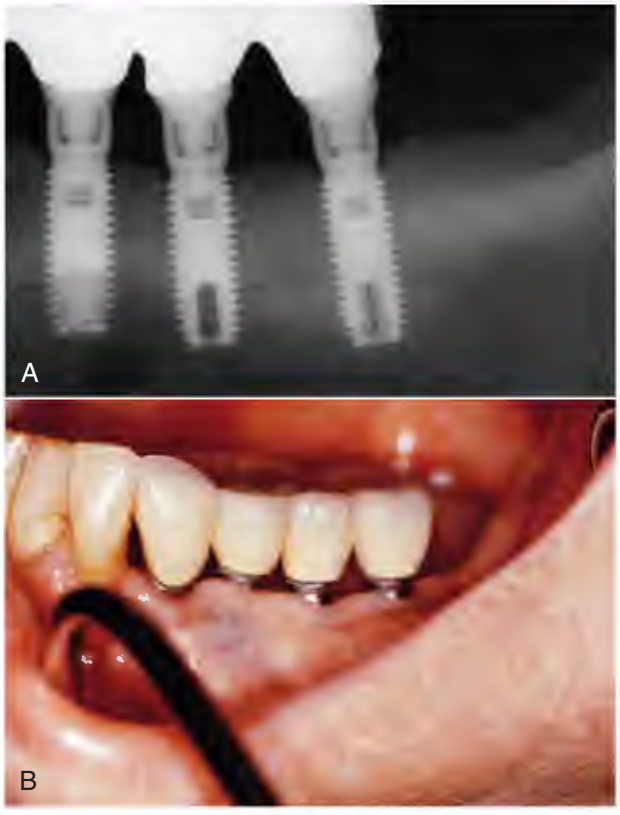


FIGURE 15-15. **A,** The three implants in the periapical radiograph have a 4-mm acid-etched collar above the first thread. The bone loss after loading is to the first thread. **B,** The tissue receded after the bone loss, and the implant crest modules are now exposed.

crest module only during surgery to engage an insertion tool, and allowed the implant to be threaded into the bone.[12] The prosthetic components did not engage the hex. Instead, they only rested on the outer periphery of the crest module (Figure 15-16). These original designs were advantageous when the implants were splinted together for complete arch prosthesis because the implant bodies did not have to be completely parallel to each other. However, after implants were used for single tooth replacement or when angled abutment were developed to allow abutments to be more parallel to each other (circa 1986), the hex components of the crest module were engaged by the abutment and fixated together with an abutment screw.

As a general rule, the abutment attaches to an implant body with an internal extension (usually a hex or trilobe design) or an external dimension (i.e., external hex) (Figure 15-17). After the attachment and implant are fixated together with an abutment screw, the overall crest module, abutment, and connections are similar regardless if they are in external or internal hex (Figure 15-18). Therefore, the restoration results relative to esthetics, retention, and so on are similar. However, the consequences of the connection do affect the implant crest module design.

In most internal hex implant designs, the antirotational feature of the abutment is designed within the crest module. As a result, the implant is lower in profile when placed at the crest of the ridge and easier to cover with soft tissue during surgery. In addition, the antirotational feature is often deeper within the implant body compared with the height of external hex implants. The deeper (or higher) the hex profile, the less force

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FIGURE 15-16. The original Nobel Pharma Brånemark implant had an external hex. The prosthetic components did not engage the hex but rested on the periphery of the implant crest module.

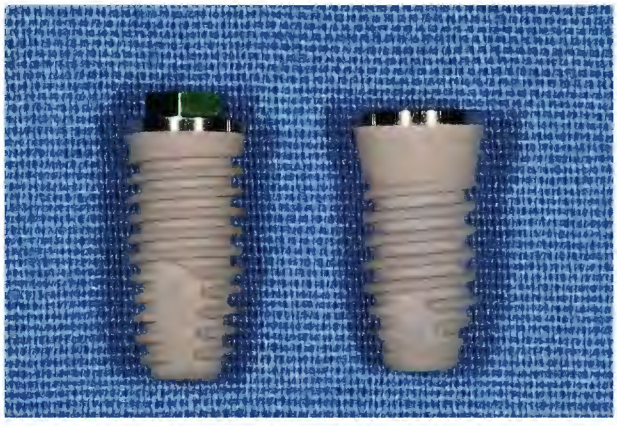


FIGURE 15-17. The implant on the *left* has an external hex prosthetic connection. The implant on the *right* has an internal hex connection. The threads on the external hex are closer to the crestal bone region.

is applied to the attachment screw during loading. Hence, abutment screw loosening is reduced when the hex is deeper. It should be noted that if the external hex height was as tall as the internal hex depth, the force on the abutment screw would be similar.

The larger in diameter the crest module, the larger the diameter of the platform dimension of the abutment connection. There is a corresponding stress reduction to the abutment screw during lateral loading related to the platform dimension. In fact, the platform width dimension is more critical to the stress applied to the abutment screw than is the height (or depth) of the antirotational hex of the implant body connection.[31]

The internal antirotation feature of an implant body is wider than an abutment screw; therefore, the body wall dimension at the crest module is reduced compared with an external hex design. As a result, the threads on the outside of the implant



FIGURE 15-18. When the abutments are connected to the implant crest module, the antirotational hex (internal shown on the *left* and external on the *right*) is covered, and the location of the abutment margin is the same. Therefore, there is no difference in the esthetic aspect of the implant crown.

body often cannot be designed at or above the antirotational feature of the internal hex implants. Therefore, internal hex implant bodies more often have cylinder crest module designs, and shear forces are observed above the first implant body thread. The threads on the implant body may progress more crestally with the external hex implant design because the abutment screw diameter is narrower than an internal hex dimension, and the outer body wall of the implant is thicker. Therefore, the thread depth may approach farther toward the crestal region of the implant (see Figure 15-17).

In summary, a crest module design that incorporates an angled geometry or grooves to the crest module, coupled with a surface texture that increases bone contact, will impose a more compressive component to the contiguous bone and decrease the risk of bone loss after loading. By way of example, implants designed with stress transfer features (i.e., Astra, BioHorizons) often exhibit less bone loss after loading in clinical reports[14] (Figure 15-19).

Plaque-Related Crest Module Designs. A focus of several implant designs is to reduce the plaque-related complications of treatment. Implant plaque accumulation is less on smooth metal than rough metal, similar to less plaque adherence on enamel than a rough tooth root.[32] With this concept in mind, many crest module designs feature smooth metal surfaces (Figure 15-20). A smooth crest module of the implant is easier to clean related to oral hygiene methods and collects less plaque than rougher surfaces. Therefore, the rationale is that if bone loss occurs at the marginal regions of the implant, the smooth implant surface will harbor less plaque and be easier to clean.

The crest module is initially placed below the bone in most two-piece implant designs. Therefore, the need for daily hygiene and plaque control is not relevant to the crest module unless

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FIGURE 15-19. Implant designs with threads closer to the crest of the ridge and wider crest modules report less crestal bone loss after loading. (BioHorizons, Birmingham, AL.)

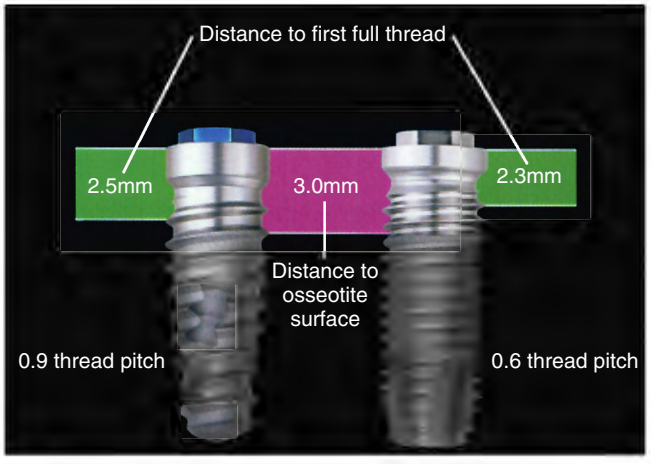


FIGURE 15-20. Several manufacturers design a crest module with a machined or smooth surface to reduce plaque accumulation if bone loss occurs after surgery (Biomet 3i implants).

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crestal bone loss occurs. The initial sulcular soft tissue thickness approximates 3 mm above the bone. A toothbrush bristle only extends 0.5 to 1 mm into the sulcus during oral hygiene procedures. Therefore, unless the tissue recedes, even when bone loss occurs on the implant crest module, the gingival sulcus depth prevents access by hygiene procedures to the crest module after crestal bone loss, especially because the gingival sulcus usually increases in depth after marginal bone loss.

The problem with the reduced plaque philosophy is that the smooth crest module is often initially placed below the crest of the bone and is a design that encourages marginal bone loss from the extension of a biological width after implant uncovery and from shear forces after occlusal loading.[16,17] As a result, this plaque-reducing design feature increases the periimplant sulcus depth. After the sulcus or pocket is greater than 5 mm, the incidence of anaerobic bacteria increases. Paradoxically, the feature designed to decrease bacteria complications actually increases the risks. In addition, the increase in pocket depth may also result in shrinkage of the tissue and may even expose the implant crest module. This complication then causes poor esthetics of the soft tissue drape.

Implant Body Design

Most implant body complications in the literature are related to early implant failure after loading and marginal bone loss after the loading of the implant–bone interface. Implant failures are most often observed as early loading failures in softer bone types or shorter implant lengths. A review of the literature by Goodacre et al. between 1981 and 2003 found that, after the implant was loaded, failure rates increased to an average of 16% in soft bone.[33] Misch reviewed the literature between 1981 and 2004 and found an overall 18% failure rate in implants shorter than 10 mm.[34] For example, in a multicenter study of 6 years, Weng et al. reported implant initial healing survival higher than 98%, but 7-mm implants failed 25% of the time within 18 months of loading, and short implants in the posterior maxilla had the highest early loading failure of any intraoral region.[35] Therefore, implant body designs should attempt to primarily address the primary causes of complications (i.e., the factors that address the loading conditions of the implant after the implants are placed in function).

Many dentists have stated that "all implants integrate and act the same." In this concept, the cost of an implant is therefore a major determinant to the selection of an implant. Although almost all implants integrate after initial surgical healing, the bone loss after loading is not similar for all designs. In fact, different implant survival rates and different marginal bone loss after loading have been reported for different implant body designs. For example, a report by Zechner et al. evaluated the periimplant bone over a 3- to 7-year period around functionally loaded, screw-type implants with a machined surfaced V-thread and a sandblasted, acid-etched, square-thread design.[36] Both of these implant types had a similar crest module and external hex connection, and all implants were inserted into the anterior mandible (Figure 15-21, *A*). The range of bone loss in the study was 0.1 to 8.5 mm for the machined V-thread and 0.2 to 4.8 mm for the rough-surface, square-threaded implant. Almost one third of the machined, V-threaded implants lost more than 4 mm of bone compared with fewer than 10% of the square-threaded rough implants. Bone loss of less than 1 mm was reported for almost half of the rough-surface implants compared with only 5% of the machined-surface implants (Figure 15-21, *B*). The range of bone loss and the incidence of bone loss both indicate implant design and surface condition made a difference in bone loss.

A prospective report by Karoussis et al. also indicated that different implant designs yield different incidences of survival and crestal bone loss.[29] Three different implant designs from the same manufacturer (Straumann ITI Dental Implant Systems, Basel, Switzerland) were evaluated with a prospective study over 10 years (see Table 15-2). The survival rate of each design over this time was 95.4% versus 85.7% versus 91.2%. Whereas the implant with the highest survival rate (hollow screw design) lost more than 5 mm of bone in 26% of the implants, the two other designs reported 37% and 39% incidence of greater than 5 mm bone loss. More than 6 mm of marginal bone loss occurred in 22% of implants with the first design and in 35% and 33% for the other two designs.

In summary, several reports indicate implant survival and marginal bone loss after loading were related to implant design. The design of the implant does not affect the surgical healing period (when two-stage implant insertion is used). However, different implant designs influence not only the implant survival but also the amount of early crestal bone loss after loading.

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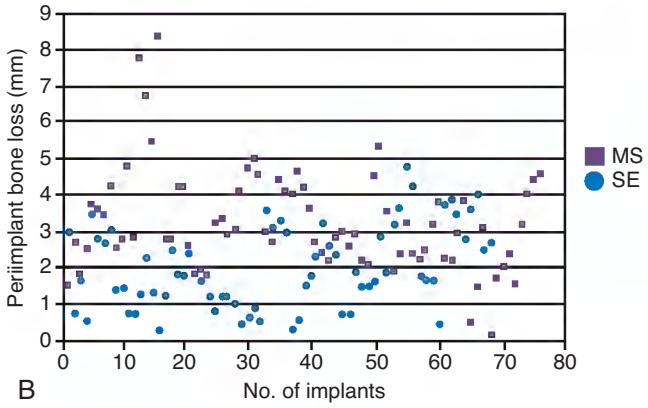


FIGURE 15-21. **A,** Two different implant designs were evaluated over a 3- to 7-year period in the anterior mandible.[36] The crest module and microgap position were similar. The implant on the *left* was a machined, V-shaped thread. The implant on the *right* was a roughened, square-threaded design. **B,** Almost one third of the V-thread design implant (MS) lost more than 4 mm of bone over a 3- to 7-year period. In the square-threaded implant (SE) design group, almost half of the implants lost less than 1 mm of bone during this time frame compared with 5% of the MS implants.

The crest module and implant body design both may affect clinical success rates for optimum health.

Functional versus Theoretical Surface Area

An implant body–crest module design can affect the amount of bone loss because the bone loss may be related to biomechanical stress.[17] Hence, understanding factors that affect the surface area and type of load to the bone is a benefit to reduce the biomechanical-related complications.

The surface area over which the forces are applied is relevant to bone loss or implant survival and is inversely proportional to the stress observed within the implant system (Stress = Force ÷ Surface area). To reduce risk of biomechanical stress, the force that is applied to the system should decrease or the surface area over which the force is dissipated should increase. This concept is supported by the reduced implant survival reports with short implants.

For a given bone volume, implant surface area should be optimized for functional loads. Thus, an important distinction is made between theoretical total surface area and functional surface area of an implant. Because bone is 65% weaker to shear forces and 35% weaker to tensile forces, functional surface area is defined as the area that actively serves to dissipate compressive loads to the implant–bone interface.[37] Functional thread surface area, therefore, is that portion of the implant that participates in compressive load transmission under the action of an axial (or near-axial) occlusal load.

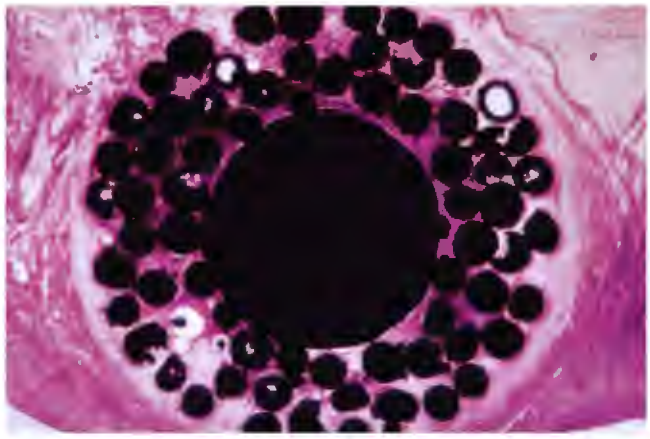


FIGURE 15-22. The functional surface area of an implant design does not include spaces too small for bone to grow into and act as a stress transfer medium. (From Steflik D, Corpe RS, Young TR et al: Light microscopic and scanning electron microscopy retrieval analysis of implant biomaterials retrieved from humans and experimental animals, *J Oral Implantol* 27:5–15, 2001.).

Surface Condition versus Design

In contrast to functional surface area is total theoretical surface area, which may include a "passive" area on the implant that does not participate in load transfer, or has a feature so small that bone cannot adapt to load transfer. An implant has a macroscopic body design and a microscopic component to implant design. Both design features (although independent) are relevant for the clinical behavior. The microscopic features are most important during initial implant healing. The macroscopic implant body design is most important during early loading and mature loading periods. For example, plasma spray coatings are often reported to provide up to 600% more total surface area for the potential BIC.[38,39] The roughed surface can increase initial BIC during healing. However, the size of each plasma spray particle is less than 8 microns, and the 120-micron bone cell does not receive a transfer of mechanical stress during loading from this feature. As a result, the amount of actual BIC that can be used for compressive loading may be less than 30% of the total theoretical (microscopic) surface area (Figure 15-22).

Smooth or rough surface, cylindrical implants provide ease in surgical placement; however, the bone–implant interface is subject to significantly larger shear conditions. A cylinder crest

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FIGURE 15-23. The macrodesign of a cylinder implant places shear loads on the bone interface. As such, the surface conditions must be rough to compensate for the implant body design. In situations that compromise the integrity of the surface coating, the load-bearing capabilities of this design are greatly compromised, and bone loss may result.

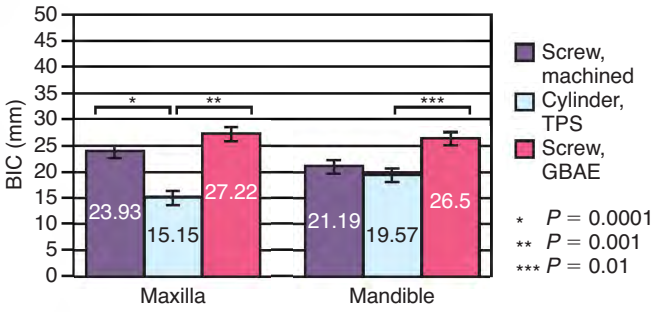


FIGURE 15-24. Comparison of a cylinder and two screw-type implant designs used in baboons. The bone–implant contact (BIC) is greater in the maxilla and mandible for screw-type designs.[44] The rough-surface screw (GBAE) had more BIC than the machined-surface screw.

module or a cylinder implant body has similar types of force transferred to the bone after loading. A cylinder implant body results in essentially a shear load at the implant–bone interface. Bone grows to a cylinder-shaped implant during initial healing. However, this type of body geometry must rely on a microscopic retention system, such as roughening or coating (e.g., acid etch, mechanical etch, or coatings such as titanium plasma spray or hydroxyapatite [HA]) for the initial loading period.[40] The integrity of the implant interface during initial loading is therefore dependent on the shear strength of the implant surface-to-bone bond. The quality of the coating (e.g., HA) is absolutely paramount in such applications.[41] If the HA is altered from friction during implant surgical insertion, infection, mechanically removed during treatment of periimplantitis or from bone remodeling over years of function, the remaining smooth-sided cylinder is severely compromised for healthy load transfer to the surrounding tissues[42] (Figure 15-23).

The surface conditions of an implant may enhance BIC and adhesion qualities to the bone–implant interface at initial healing. However, the surface coatings on cylinders do not permit compressive forces to be effectively transmitted to the bone cells because the microfeatures of the coating are too small for the cells to be loaded in compression.[43] Therefore, the surface area–bone contact percentage is greater during initial healing, but the functional surface area over which loads are effectively dissipated during long-term loading to the surrounding bone is most dependent on the macroscopic design of the implant body. For example, Watzek et al. evaluated machined and rough-surface screw-shaped and rough-surface cylinder implants with histologic and histomorphometric analysis after 18 months of occlusal loading in baboons.[44] There was a significant difference in BIC, with screw-type implants having higher values in both the maxilla and mandible (Figure 15-24). The rough-surface screw had slightly more BIC than the machined-surface screw. In addition, the trabecular bone pattern was irregular around the cylinder implants, but the bone was organized and perpendicular to the threads around the screw implants (Figure 15-25). Therefore, the bone trabeculae pattern and the higher BIC resulted in a superior support system for threaded implants.

An implant retrieval human clinical report by Bolind et al. evaluated cylinder implants compared with threaded implants from functioning prostheses.[45] Consecutively retrieved oral implants from 117 patients, with 85 cylinder implants and 85 threaded implant designs were evaluated. Greater BIC was found around threaded implants, and greater marginal bone loss was observed around cylinder implants (Figure 15-26). It should be noted that whereas the cylinder implants in this report had a roughened surface condition, the threaded implants had a machined surface. Numerous reports demonstrate roughened surfaces have higher BIC compared with machined surfaces during initial healing. In this human retrieval report, therefore, implant body design was more important than the surface condition of the implant for crestal bone loss and overall BIC after loading. In Figure 15-27, an HA-coated cylinder is splinted to two HA-coated threaded implants. After 5 years of loading, more crestal bone loss was observed on the cylinder implant. Hence, implant design may be more important after loading than implant surface condition.

Any shear surface on an implant body increases the risk of bone loss after loading because of inadequate load transfer.[25] Figure 15-28 depicts one such example characterized by extensive crestal resorption adjacent to a long, shear surface on the two implant bodies (Core-Vent/Paragon implant). The crestal bone loss contributes to an increase in crown height (which further magnifies stress from bending moments) and the fracture of two abutments. The implant body next to these cylinder-type implants was loaded in the same prosthesis, yet the plateau implant body design (which is a compressive load design) maintained bone height over the years of loading.

Functional Implant Dimension

Another rationale related to functional surface area is related to implant length. An improved functional surface area per *unit length of the implant* (in contrast to *total* surface area) is beneficial to reduce the mechanical stress to bone. Most stress to the implant–bone interface in D1 to D2 bone is in the crestal 5 to 9 mm of the implant; therefore, the design of the implant body in the coronal 9 mm is most important to appropriately distribute occlusal stresses to the bone.[35,37] For example, a conventional 20-mm V-shaped or reverse buttress–threaded implant of a constant thread depth may have more *total* surface area compared with a 13-mm square-threaded or plateau design implant. The *functional* area, however, that is available to resist compressive biomechanical loads in the crestal 5- to 9-mm zone of

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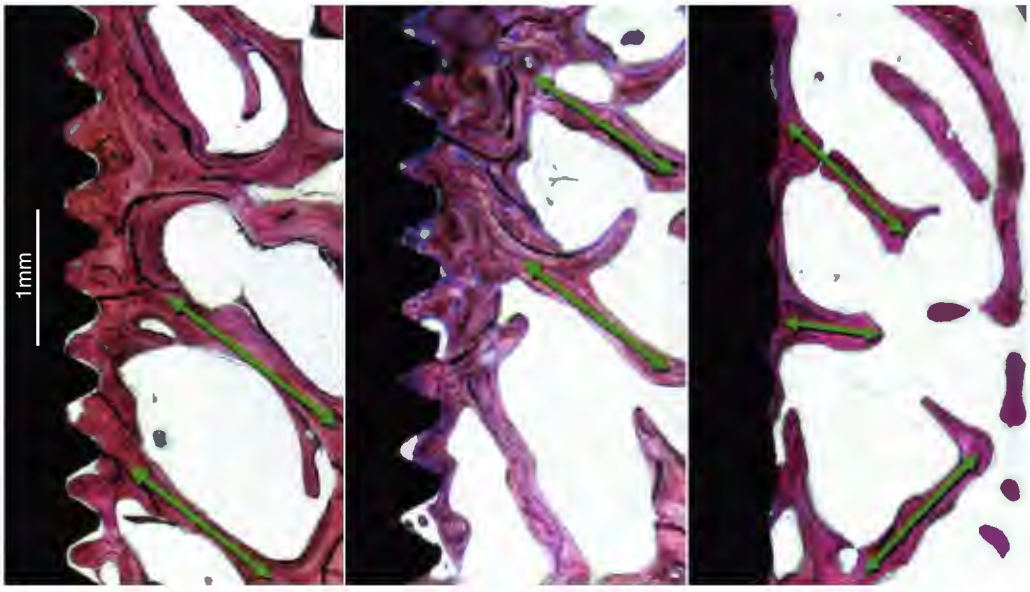


FIGURE 15-25. Trabecular bone has a more organized form to resist occlusal stresses for screw-type implants compared with cylinder implants. (From Watzek G, Zechner W, Ulm C, et al: Histologic and histomorphometric analysis of three types of dental implants following 18 months of occlusal loading: a preliminary study in baboons, *Clin Oral Implants Res* 16:408–416, 2005.)

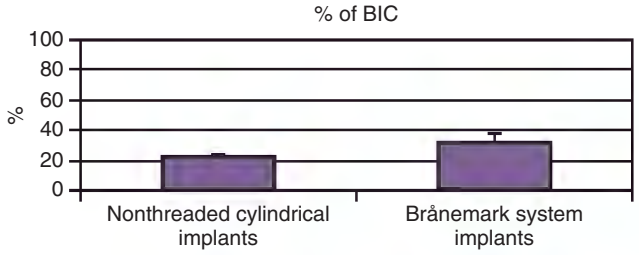


FIGURE 15-26. Evaluation of human retrievals of 85 rough-surface cylinder implants and 85 threaded (machined) implants.[45] The bone–implant contact (BIC) was greater in threaded implants (Brånemark system).



FIGURE 15-27. A rough hydroxyapatite-coated cylinder implant was splinted to two hydroxyapatite screw implants. After a 5-year period, more crestal bone loss was observed on the cylinder implant.



FIGURE 15-28. Two cylinder-neck design implants were splinted to a plateau implant design. After several years of loading, the crestal bone loss on the two cylinder-neck designs led to implant abutment fracture.

greatest stress to the BIC may be significantly higher in the 13-mm implant because of the thread geometry.

The diameter of an implant may also affect functional surface area because the length requirements of the implant body are affected by the width of the implant.[46] However, the higher bite forces and lower bone density of the posterior regions of the mouth may not always be able to be addressed adequately by only implant diameter. For example, in 1999, Ivanoff et al. found that 6-mm-long implants with a 5-mm diameter had a failure rate of 33% in the mandible and 10% in the maxilla.[47]

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The 8-mm-long, 5-mm-diameter implant yielded 33% and 25% failure rates in the mandible and the maxilla, respectively. On the other hand, the longer 10-mm and 12-mm implants that were 5 mm in diameter yielded no mandibular failures and a 10% failure rate in the maxilla. In other words, the increase in implant diameter alone was not sufficient to improve implant survival. In this report, the 5-mm implant diameter was not enough to compensate for the shorter implants.

Functional Surface Area

Functional surface area is also affected by the variable of initial BIC zones related to bone density upon initial loading. D1 bone, the most dense bone found in the jaws, is also the strongest; has the stiffest modulus of elasticity; and has the highest initial BIC percent, which approximates 80%. D2, D3, and D4 bone have progressively decreasing percentages of bone at the initial implant interface, with D4 bone ranging around 25% interface contact at the initial healing and uncovery of a machined titanium implant.[4,48]

In addition, the stress transfer to an implant body is affected by the bone density. In D1 and D2 bone with a greater bite force on the implant, the stresses are greatest at the crest and then reduced along the implant body for approximately 5 to 9 mm. In D3 bone, the high crestal stresses with a greater amount of occlusal force may extend farther along the implant body and reduced straining level and extend up to 12 mm of implant length. D4 bone has higher strain conditions and may extend for 12 to 15 mm of implant length, with a high bite force (Figure 15-29).

Therefore, bone density is related to the functional surface area. In more compromised bone sites (i.e., D4 bone), longer implants are required to resist off-axis and moment loads because of cantilevers, improper occlusion, or parafunction.[37] Recall that mechanical stress is equivalent to the applied load divided by the surface area over which the load is dissipated. D4 bone has the weakest biomechanical strength and the lowest BIC area to dissipate the load at the implant–bone interface. The functional surface area requirements would increase from a minimum for an implant in D1 bone to a maximum for implants in the D4 bone.[7]

In summary, bone density, implant diameter, implant length, and implant surface condition may all affect functional surface area; however, the overall implant design may be most effective to decrease biomechanical-related complications. An ideal treatment plan would include an implant length of 12 mm or greater and a 4 mm diameter for most anterior implant sites and 5 mm or greater in the molar regions.[5] When the ideal implant size cannot be inserted because of inadequate bone, an alternative to bone augmentation may be to increase the functional surface area of the implant by increasing the implant number or modifying the implant body design.

Bone–Implant Contact Related to Occlusal Load

Different implant survival rates and amounts of marginal bone loss may be directly related to the BIC of different implant body designs. The macrodesign of an implant has an important bearing on the overall surface area to resist the load to the bone. Protruding elements of the implant surface, such as ridges, crests, teeth, ribs, or the edge of threads, may act as stress transfers to the bone when load is applied. Hoshaw et al. applied tensile loads to titanium V-threaded implants (Nobel Biocare Brånemark) in the cortical bone of canine tibiae[49] (Figure 15-30). The osteons in the tibia are usually oriented parallel to the long axis of the bone to resist the weight of the animal.

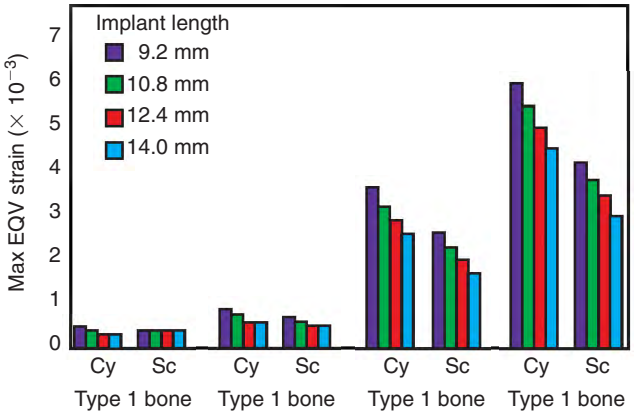


FIGURE 15-29. The required functional surface area is less for implants in D1 bone *(far left)* and greatest for implants in D4 bone *(far right)*. Screw-type implants have more functional surface area, which is an advantage, especially in softer bone types. *Cy,* Cylinder implant; *Sc,* screw-type implant. (From Tada S, Stegiaroiu R, Kitamura E, et al: Influence of Implant design and bone quality on stress/strain distribution in bone around implants: a 3-dimensional finite element analysis, *Int J Oral Maxillofac Implants* 18:357–368, 2003.)

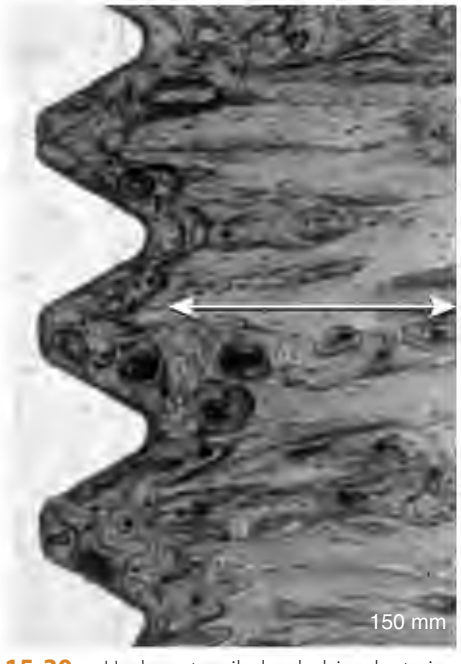


FIGURE 15-30. Hoshaw tensile-loaded implants in dog tibiae. The osteons in the tibia of the dog run parallel to the long axis to resist the weight and axial forces of the animal. When the implants were inserted perpendicular to the long axis and tensile loaded for 5 days, the osteons 4 to 5 mm around the implants reoriented to encircle the implant to resist the tensile loads rather than remain parallel to the long axis of the tibiae. (From Hoshaw SJ, Brunski JB, Cochran GVB: Mechanical loading of Brånemark fixtures affects interfacial bone modeling and remodeling, *Int J Oral Maxillofac Implants* 9(3):345–360, 1994.)

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However, around the implants with tensile loads, osteons were oriented encircling the implants, and secondary osteons appeared oriented around the depth of the implant threads. This bone orientation was observed 3 to 4 mm around the implant bodies. The cortical bone remodeling observed around endosteal implants may be an attempt to improve strain orientation of the bone in relation to the functional loads.

In an animal study using a square thread, microscopic observation noted that when the bone did not fully occupy the threads, greater bone volume was observed on the lower aspect compared with the upper aspect of the square threads[50] (Figure 15-31). In addition, bone bridges were found from one square thread to another. The square thread shape of the tested implants was designed to enhance compression loads and reduce shear loads delivered to the implant interface. Duyck et al. found in an animal model that the bone density was equally distributed above and below a threaded implant after initial bone healing.[51] However, after dynamic loading, the bone implant density was greater on the bottom of the thread face angle (pressure side) and less on top of the thread (tensile side) (Figure 15-32). Kohn and Hollister demonstrated that when the implant (Nobel Biocare Brånemark) was loaded laterally, no bone remained at the tip of the thread, and a bone bridge formed from the depth of one thread to another[52] (Figure 15-33). The local strain field within the bone–implant interface under this condition is inhomogeneous. During a lateral load, the strain was more concentrated at the tip of the thread, and the strain was decreased from the exterior to the interior regions of the thread. They speculated that because the strains were highest at the tip of each thread, bone was resorbed, and where strains were reduced at the depth of the thread, bone was maintained.

A retrieval report by Bolind et al. confirmed a consistent pattern of BIC location in humans.[45] The bone contact was least at the tip of each thread (where the highest strain occurs) and was the greatest under the thread face angle (where the bone is loaded more in compression). Therefore, it appears the design of the implant not only governs the initial stability of the implant, but as important, also determines the BIC percent and location of contact available for effective load transfer to the bone after occlusal loading.

Implant Body Design Related to Occlusal Forces

Dental implants function to transfer loads to surrounding biological tissues. Thus, the primary functional design objective is to manage (dissipate and distribute) biomechanical loads to

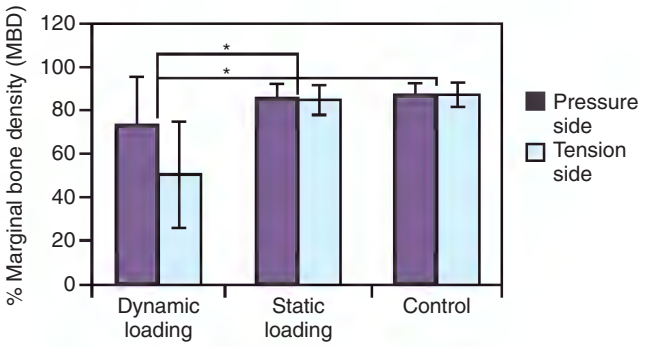


FIGURE 15-32. There was more bone on the bottom of a V-threaded implant (pressure side) compared with the top of the thread (tensile side) for dynamic-loaded implants. The static loaded and unloaded implants had a similar bone contact on the top and bottom of the thread.[51]



FIGURE 15-31. Bone bridges formed from one square thread to another, and a higher bone contact percent was found on the bottom of the square thread, which is the part of the thread which loads the bone in compression.



FIGURE 15-33. Lateral loads were placed on V-shaped implants, and bone bridging was found from the depth of one thread to another. Because the strain would be highest at the peak of a thread and lowest at the depth, the bone contact point is related to lower strain positions.

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optimize the implant-supported prosthesis function. Biomechanical load management is dependent on two factors: the character of the applied force and the functional surface area over which the load is dissipated. More than 90 dental implant body designs are available. A biomechanical rationale of dental implant design may evaluate these designs as to their efficacy to manage biomechanical loads. Fundamental scientific principles related to force and surface area may then be combined with engineering principles to pursue the desired clinical goals.

Force Type and Influence on Implant Body Design

Three types of forces may be imposed on dental implants within the oral environment: compression, tension, and shear. As previously stated, bone is strongest when loaded in compression, 30% weaker when subjected to tensile forces, and 65% weaker when loaded in shear[53] (see Figure 15-14). An attempt should be made to limit shear forces on bone because it is least resistant to fracture under these loading conditions. This is most important in regions of decreased bone density because the strength of bone is also directly related to its density.[54]

Unlike a cylinder (parallel-walled) implant body, a cylindrical, tapered implant provides for a component of compressive load to be delivered to the bone–implant interface, depending on the degree of taper.[38] The greater the taper, the greater the component of compressive load delivered to the interface. Unfortunately, the amount of taper cannot be greater than 30 degrees or the implant body length is significantly reduced along with the immediate fixation required for the initial healing. As a negative feature, the greater the taper of a cylinder implant, the less the overall surface area of the implant body under load and the less initial stability provided by that implant at an immediate extraction and implant insertion.

In contrast to a tapered cylinder design implant, a tapered, threaded implant serves no functional surface area advantage because the threads of a screw bear the compressive and tensile loads to the bone. The tapered, threaded implant provides some surgical advantage during initial insertion because it is positioned within the osteotomy halfway before engaging bone. However, the less surface area of a tapered implant increases the amount of stress at the crestal portion, as demonstrated in three-dimensional finite element studies.[46] In addition, in a tapered, threaded implant, threads at the apical half are often less deep because the outer diameter of the implant body continues to decrease (Figure 15-34). This limits the initial fixation of the implant and further reduces the functional surface area.

Force Direction and Influence on Implant Body Design

Bone is weaker when loaded under an angled force.[55] The greater the angle of load, the greater the stresses to the implant–bone interface. The noxious effect of angled loads to bone is further exacerbated because of the anisotropy of bone.[56] Anisotropy refers to how the character of bone's mechanical properties, including ultimate strength, depends on the direction in which the bone is loaded. A 30-degree angled load will increase the overall stress by 50% compared with a long-axis load, especially around the crestal portion of the implant.[57] Therefore, under ideal conditions, the implant body long axis should be perpendicular to the curve of Wilson and curve of Spee to apply a long-axis load to the implant during occlusal load in centric occlusion (where the occlusal forces are usually the greatest).



FIGURE 15-34. A threaded, tapered implant body often has less deep threads at the apical portion of the implant body (Nobel Biocare). This may reduce initial fixation and reduce overall surface area.

As the angle of load to the implant–bone interface increases, the stresses around the implant increase. As a result, virtually all implants are designed for placement perpendicular to the occlusal plane. Additionally, axial alignment places less shear stress on the overall implant system (i.e., porcelain, cement, abutment and abutment screw components, crestal bone, implant body, and implant–bone interface) and decreases the risk of complications such as screw loosening and fatigue fractures.

Implant body designs with threaded features have the ability to convert occlusal loads into more or less favorable compressive, tensile, or shear loads at the bone interface; therefore, thread shape is particularly important when considering long-term load transfer to the surrounding bone interface. Under axial loads to a dental implant, a V-thread face angle (typical of implants from Zimmer, LifeCore, 3i, and some Nobel Biocare designs) loads the bone at a 30-degree angle, which results in more shear loads to the bone (Figure 15-35, *A*). The reverse buttress thread (typical of some Nobel BioCare designs) is similar to the V-thread face because of the similarity in the inferior portion of the thread face angle. Under axial loads to an implant–bone interface, a buttress or square-shaped thread (typical of BioHorizons, Biocon, and Ankylos) would primarily transmit compressive forces to the bone (Figure 15-35, *B*).

A reduction in shear load and subsequent shear stresses at the thread–bone interface reduces the risk of bone failure and possible reduced BIC percent after loading of the implant if all of the other factors are equal. This is particularly important in compromised bone densities or shorter implant lengths.[37] The thread shape (macroscopic design) is independent from the surface coating (microscopic design). For example, any threaded implant surface may also be textured with HA coating or other roughened surface conditions to enhance initial osseointegration and increase the BIC percent during initial healing.

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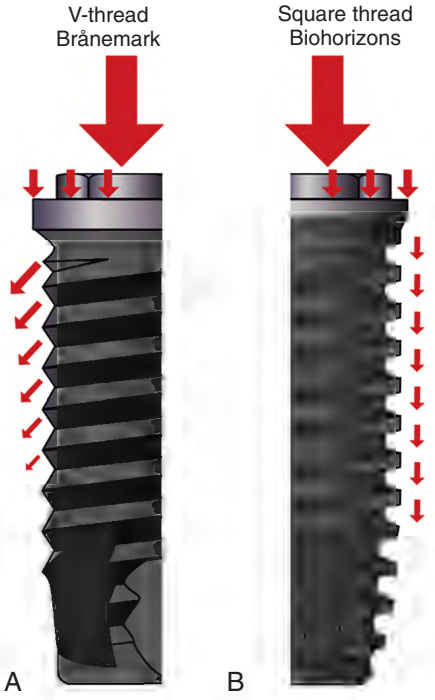


FIGURE 15-35. **A,** An axial load on the prosthesis may result in an axial load to the implant platform. However, the implant body design may convert the primary compressive forces to the prosthesis, resulting in a 30-degree angled force with more tensile and shear loads to the implant–bone interface *(left)*. **B,** A plateau or square-thread implant body design can deliver a compressive force to the bone when the implant is loaded in the long axis. The implant body design determines the type of force transmitted to the implant–bone interface.

Bone Cell Response to Implant Body Design

Cortical and trabecular bone are modified by modeling or remodeling.[58] Modeling is the result of independent sites of formation and resorption that change the shape or size of bone. Remodeling is a process of resorption and formation at the same site that replaces previously existing bone and is primarily responsible for the change in bone quality or the ability of bone to respond to an occlusal load. Bone modeling and remodeling are primarily controlled by the mechanical environment of strain.

There are four histologic description of bone: lamellar bone, woven bone, composite bone, and bundle bone.[59] The first two of these bone types are often found next to an osseointegrated dental implant. Lamellar bone is the most organized, highly mineralized, and strongest of the bone types. It has been called *load-bearing bone* and is most desired next to an implant. Woven bone is also called *immature bone* because it is unorganized, less mineralized, and has less strength than the other types. It is the bone type that is formed to repair the bone. These histologic terms may be used to describe the microscopic bone types in the macroscopic description of cortical and trabecular bone.

Nicolella et al. found that a 0.15% deformation in a bone specimen may have microstructural level strain values as large as 3.5% at various regions within the cellular microstructure.[60,61] Microstrain levels 100 times less than the ultimate strength of bone may be responsible for remodeling rates within the structure because the bone cell membranes are able to act as a mechanosensory system in bone.[62] In other words, the cellular behavior of bone cells is largely determined by the mechanical environment of strain or deformation of the bone cells.[63–65] It is speculated that the source of energy to open the ion membrane channels in the bone cell membrane is the microstrain in the cells as a result of the load applied to the bone.[66,67]

Frost described four microstrain zones for compact bone and related each of these categories to the mechanical adaptation to strain.[68] These four zones include the pathologic overload zone, the mild overload zone, the adapted window, and the acute disuse window (Figure 15-36). Briefly stated, the pathologic overload zone and the acute disuse window are the two extremes of bone reaction to strain conditions. Each of these conditions, however, may result in a similar condition of less bone. Pathologic overload could lead to microfractures, which require repair and may result in net bone resorption. The disuse zone also increases remodeling, which decreases bone mass.

The remodeling rate, or bone turnover, is the time needed for new bone to replace the existing bone and allows for the adaptation of bone to its environment (e.g., next to a dental implant).[69] The bone remodeling rate (BRR) also has been expressed as a percentage or volume of new bone within a specific time period. Whereas lamellar bone forms at a rate of 1 to 5 microns each day, woven bone can form at rates of more than 60 microns each day.[70,71] Therefore, a higher BRR is directly related to an increase in the amount of woven bone formation. The mild overload zone is more likely to have a higher BRR than the adapted window zone and more reactive woven bone formation (less organized, less mineralized, and weaker) to create and maintain bone mass in response to the mechanical challenge.[28] The adapted window zone is most likely to be organized, highly mineralized, lamellar bone. Misch et al. stated the adapted window would be the ideal strain condition next to a dental implant, providing bone that is more mature and more resistant to periodic changes in strain conditions.[72] Therefore, the BRR may be directly related to the strength of the implant interface and the degree of risk for the implant–bone interface. The higher risk is related to higher bone turnover rates because the bone is less mineralized, less organized, and less strong at the interface.

Interface remodeling allows a viable bone interface to form between the dental implant and the original bone after the implant has been surgically inserted.[71] Before implant insertion, the bone is usually mature lamellar bone. The surgical trauma causes the bone to repair, with primarily woven bone formation. By the end of 4 months of a maturation phase next to an implant interface, osteoblasts have deposited about 70% of the mineral found in mature vital bone and have reformed lamellar bone. The remaining 30% of mineral deposition occurs during secondary mineralization over the next 8-month period.[59]

After the bone has healed and the implant is then loaded, the interface again remodels, as influenced by its local strain environment.[58] If woven bone forms as a result of mechanical loading, it is called *reactive woven bone* and is very similar in structure and properties to the "repair" woven bone from surgical trauma. The long-term maintenance of the implant involves a continuous remodeling of the interface. In part, this allows new bone to replace bone, which may have sustained microfractures or fatigue as a result of cyclical loading. In vivo microdamage in bone and an elevated remodeling activity to repair those regions have been identified by Frost.[73] To date, the BRR

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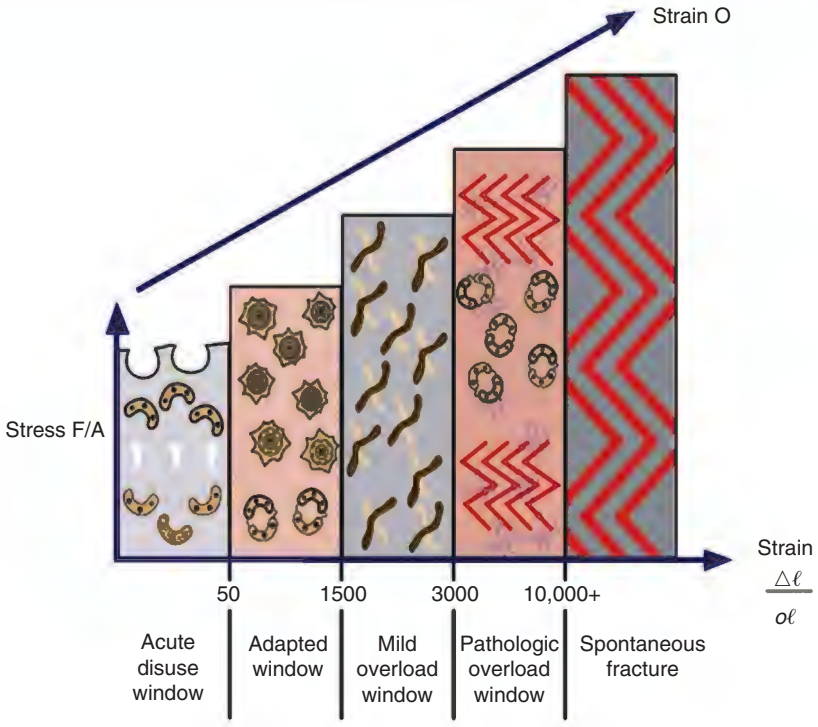


FIGURE 15-36. Four microstrain zones for bone relate to the cellular responses (before fracture). The greater the stress to the bone, the greater the strain. The ideal stress–strain relationship for an implant–bone relationship is the adapted window zone. *F,* Force; *A,* area; *D,* strain.

of the bone in the jaws for humans is not well documented; however, it appears to reach 40% each year.[74]

Microdamage in cortical bone surrounding screw-type implants has been reported during both insertion and with pullout forces, and the amount of microdamage was related to the thread design of the implants.[75] Microdamage acts as a key step in signaling increases in remodeling and replacement of skeletal tissue and is similar to the local tissue remodeling response to physical injury in other tissues.[76] Mori and Burr provided evidence of an increased BRR in regions of microfracture from fatigue damage.[77] Verborgt et al. found that in the ulnae of rats, fatigue loading produced a large number of terminal dUTP nick-end labeling to detect apoptotic cells (TUNEL)–positive osteocytes in bone surrounding microcracks.[78] The intracortical resorption was almost 300% greater than in the control rats. The authors noted a strong association between microdamage, osteocyte apoptosis, and subsequent bone remodeling.

In addition to the increased BRR at the interface that is related to the trauma induced during the implant surgery, there may be heightened remodeling of bone some distance beyond the surgical interface after loading. Hoshaw et al. found an increase in bone remodeling next to threaded dental implants in dog tibiae when loaded for 5 consecutive days after a 12-month initial healing period.[49] Hoshaw et al. also found titanium-threaded implants with axial tensile loading have higher remodeling rates and less mineralized bone than control implants that did not receive a load after healing.[79] The increase in the BRR found in the overload zone of Frost and the increase in BRR from the microfracture are directly related.

Barbier and Schaper investigated implant-supported prostheses under nonaxial and axial loads.[80] A higher cellular response, including osteoblasts and inflammatory cells, was observed next to implants under nonaxial shear loading conditions compared with axial loads (Figure 15-37). These authors found that nonaxially loaded implants exhibited a greater BRR compared with axially loaded implants in animals with the same implant design. It appears the implant design, direction of load may, or both affect the bone at the implant interface, which affects the bone turnover rate at the interface. Because bone in the jaws usually remodels at 40% per year, this most likely represents the adapted window zone. The higher the BRR, the more likely the bone is in an overload condition.

Thread Geometry and Functional Surface Area

Threads on an implant body are designed to maximize initial fixation and bone contact, enhance surface area, and facilitate dissipation of loads at the bone-implant interface.[37] Functional surface area per unit length of the implant may be modified by varying nine different parameters, including three geometric thread parameters: thread pitch, thread shape, and thread depth[15,37] (Figure 15-38).

Thread Pitch

Thread pitch is the distance measured parallel between adjacent thread form features of an implant.[37] The length of the threaded portion of the implant body divided by the pitch equals the threads per unit length. The smaller (or finer) the pitch, the more threads on the implant body for a given unit length and thus the greater surface area per unit length of the implant body if all other factors are equal. Restated, a decrease in the distance between threads will increase the number of threads per unit length. The greater number of threads, the greater the surface area if all other factors are the same (Figure 15-39). Because stress is directly related to the magnitude of the force and indirectly related to the area over which the force is applied, the implant pitch may be made smaller when the magnitude of the force is greater than usual in order to obtain a reduced stress magnitude.[37] Roberts et al. observed in an animal model that the thread number may affect the BIC percentage.[71] When two different implant thread pitch designs were placed in the same

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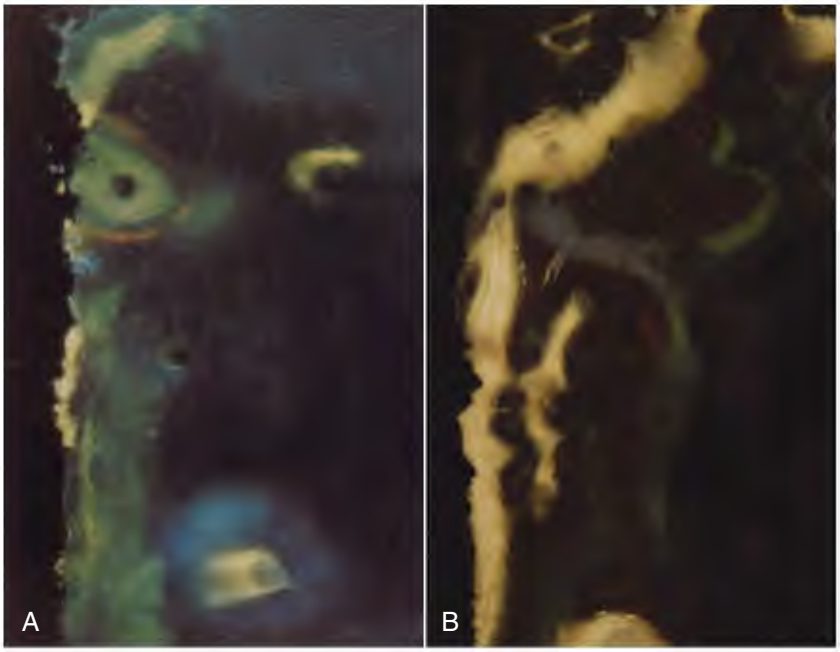


FIGURE 15-37. **A,** In this study of loaded implants in an animal (dog), axially loaded implants have lamellar bone more often at the interface. **B,** Implants with nonaxial loading have primarily woven bone at the interface, a higher bone remodeling rate, and osteoclasts and inflammatory cells. (From Barbier L, Schepers E: Adaptive bone remodeling around oral implants under axial and nonaxial loading conditions in the dog mandible, *Int J Oral Maxillofac Implants* 12:215–223, 1997.)

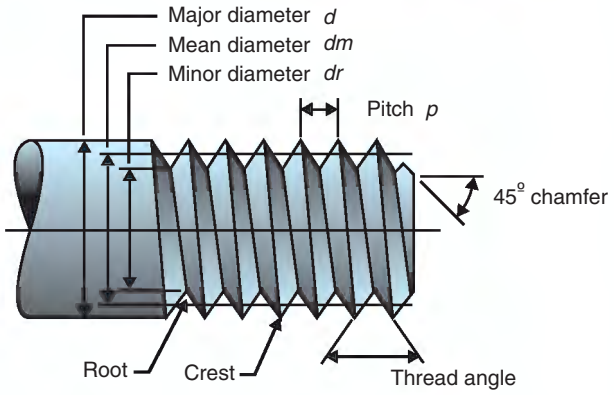


FIGURE 15-38. There are nine thread form parameters of an implant that may alter the functional surface area. Three of these include thread pitch, thread shape, and thread depth.[37]

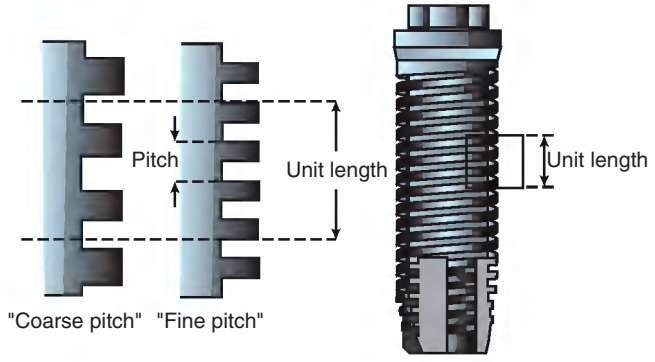


FIGURE 15-39. The thread pitch describes the number of threads per unit length of an implant. Whereas the implant on the *right* has a smaller thread pitch and greater surface area, the implant on the *left* has a larger thread pitch and less overall surface area.

animal, a higher BIC was observed with the implants with the greater thread number (Figure 15-40).

It is interesting to note that of all the design variables, pitch has the most significant effect on changing the surface area on a threaded implant. This is a major point to consider when looking at the anatomical dimensional limitations presented in the oral environment. For example, when an ideal implant length cannot be planned without advanced bone augmentation, an implant with greater thread numbers may improve the functional surface area for the height dimension compromise.[25]

The thread pitch may also be used to help resist the forces to bone with poorer quality.[37] Because the softest bone types are 58% or more weaker than ideal bone quality, the implant thread number may be increased to increase the overall surface area and reduce the amount of stress after occlusal loading to the weaker bone trabeculae. Therefore, if force magnitude is increased, implant length is decreased, or bone density decreased, the thread pitch may be decreased to increase the thread number and increase the functional surface area.

Most manufacturers provide implant systems with a fixed pitch and fixed surface area per unit length regardless of the implant size, character of forces, or the bone density of the anatomical site. However, different popular implant designs often have different thread pitches. For example, whereas the distance between the threads for one implant design is 1.5 mm (Straumann ITI), a thread pitch of 0.6 mm exists for others (Zimmer Screw-Vent, Biomet 3i). Hence, the first implant has less than half the threads compared with the other. Each implant pitch has a different number of threads per unit length and a different amount of functional surface area. Hence, when ideal implant length and width are not used in the prosthetic support system, an implant with more threads may decrease the risk of overload conditions.

The thread number is most significant for the shorter-length implants in softer bone types. For example, the Straumann ITI 6- and 8-mm-long implants may only have three threads to carry the compressive load (Figure 15-41). On the other hand, the thread pitch of other implant designs (e.g., BioHorizons External Hex) may feature seven to 10 threads for a similar

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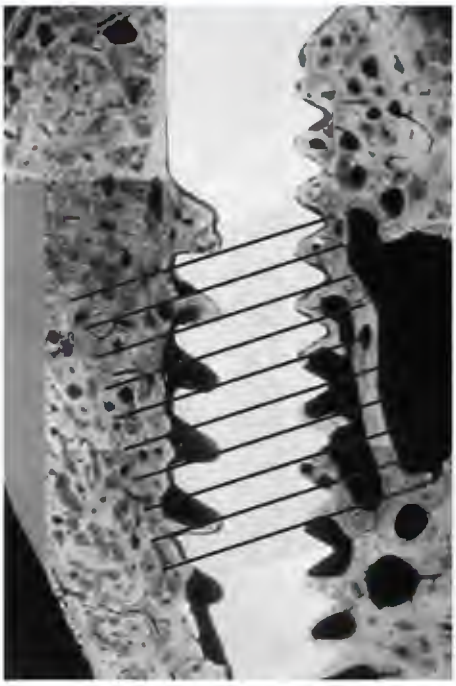


FIGURE 15-40. There is a higher bone–implant contact (BIC) with implants of greater thread number compared with implants with fewer threads. A composite of a typical result demonstrates a higher BIC on the right side compared with the left side of the implant.



FIGURE 15-41. The Strauman, ITI implant length on the *left* is 6 mm, and the one on the *right* is 8 mm. Each implant only has three threads for surgical fixation and load bearing after healing.



FIGURE 15-42. The BioHorizons Maestro implant on the *left* (7 mm long) has seven threads. The implant on the *right* (9 mm) has 10 threads. The greater the number of threads, the greater the functional surface area.



FIGURE 15-43. The internal hex implant design on the *left* (Zimmer Screw-Vent) features an internal hex. The implant on the *right* (BioHorizons Maestro) has an external hex crest module. The implant on the left is 1 mm longer but has fewer threads than the implant on the right. The implant on the left is manufactured with triple thread lead; the one on the right has a single thread lead. However, the overall surface area is not affected by the thread lead.

length (Figure 15-42). The greater the thread number, the greater the initial fixation and, more important, the greater the overall functional surface area after loading.

The thread number may be affected by the implant crest module design. When the implant body has an extended cylinder crest module, the number of the threads to support the occlusal load is reduced. For example, whereas some implant designs have a cylinder crest module of 3 mm or more, other designs have only a 0.7-mm area above the first thread. When the thread pitch is 0.5 mm, there are four fewer threads for every 2 mm of a cylinder crest module. Therefore, a 7-mm-long implant may have 28% fewer threads with an extended smooth crest module (Figure 15-43).

Several manufacturers advertise implant bodies with double or triple thread leads (e.g., Zimmer, Nobel Biocare). These terms relate to the manufacturing process and do not increase functional surface area. Rather than machining one thread at a time with one cutting instrument, a double thread uses two cutting blades, and a triple thread uses three blades to manufacture the threads. As a result, when a one thread-lead implant rotates 1 rpm, the implant inserts a distance of one thread. A double-thread implant at 1 rpm inserts two threads into the bone. If the revolutions per minute on a single thread lead is doubled (e.g., 30 rpm vs. 15 rpm), both implants thread into the bone at the same rate. In any case, no functional surface area change is found between a single, double, or triple thread lead.

The surgical ease of implant placement is related to thread number. The fewer the threads, the easier to insert the implant. If fewer threads are used in denser bone, the ease of placement is improved, because hard bone is more difficult to tap threads

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and insert several threads compared to an implant which more resembles a cylinder implant.

Thread Depth

The thread depth is the distance between the major and minor diameter of the thread[37] (Figure 15-44). Conventional implants provide a uniform thread depth throughout the length of the implant. A straight minor diameter, which is used in almost every screw-type dental implant, results in uniform cross-sectional area throughout a parallel-walled implant length. A tapered implant often has a similar minor diameter, but the outer diameter decreases in relationship to the taper, so the thread depth decreases toward the apical region. As a result, a tapered implant design has overall less surface area, which is more critical in shorter implant lengths. The tapered, threaded implant may have less ability to fixate the bone in the apical region at initial insertion and has less functional surface area. The implant body taper may result in higher stresses, especially in shorter-implant lengths.[46,81]

The greater the thread depth, the greater the surface area of the implant if all other factors are equal. Different manufacturers use different thread depths. Some threaded implants have a 0.24-mm thread depth (Nobel Replace), the thread depth of Straumann ITI is 0.3 mm, and the thread depth of many V-shaped threads is 0.375 mm (Biomet 3i and Zimmer Screw-Vent). The BioHorizons square thread of the 4-mm-diameter implant body has a 0.42-mm thread depth. Therefore, if all other factors were equal, each type of implant in these examples would have a different functional surface area directly related to the depth of the thread, with BioHorizons having the most surface area and Nobel Replace the least (Table 15-3).

The more shallow the thread depths, the easier it is to thread the implant in dense bone and the less likely bone tapping is required before implant insertion. Because implant surgeons often decide what implant they will insert based on ease of surgical insertion, it is not unusual that an implant with fewer threads and less deep threads is selected because both conditions facilitate implant insertion. However, after the implant is placed into the bone, the conditions that make implant surgical insertion easier create less functional surface area and increase the risk of occlusal overload to the bone–implant interface.

In the conventional implant design, the implant body design remains identical, regardless of the implant diameter. As a consequence, the implant increases in surface area by 15% to 25% for every 1-mm increase in diameter.[5] However, as the implant becomes wider, the depth of the thread may be deeper without decreasing the body wall thickness between the inner diameter and the abutment screw space within the implant. For example, the 4-mm-diameter implant of BioHorizons has a thread depth of 0.42 mm, but the 5-mm-diameter implant has a thread depth of 0.8 mm. Therefore, the thread depth may be modified relative to the diameter of the implant, and thereby the overall surface area may be increased by 150% to 200% for every 1-mm-diameter increase (Figure 15-45). For example, the Biomet 3i 4.0-mm-diameter implant body has 200 mm^2 surface area, and the 5.5-mm implant has 245 mm^2 surface area (when the implant is 12 mm long). The 4.0-mm-diameter BioHorizons implant has a 215 mm^2 surface area, and the 5-mm implant has a 356 mm^2 surface area.[15,37]

The overall functional surface area of an implant body is therefore related to both the thread pitch and thread depth. Tables 15-3 and 15-4 illustrate the difference in several popular

TABLE 15-3
Surface Area of Implant Designs (4 mm in Diameter)*

Implant Type	Implant Size	Square Millimeters
BioHorizons (external)	4 × 12	214.9
BioHorizons (internal)	4 × 12	206.5
Replace Select	4 × 12	167.1
Straumann ITI	4 × 12	161.3

*The finer the thread pitch [more threads] and deeper thread depth equals more functional surface area.

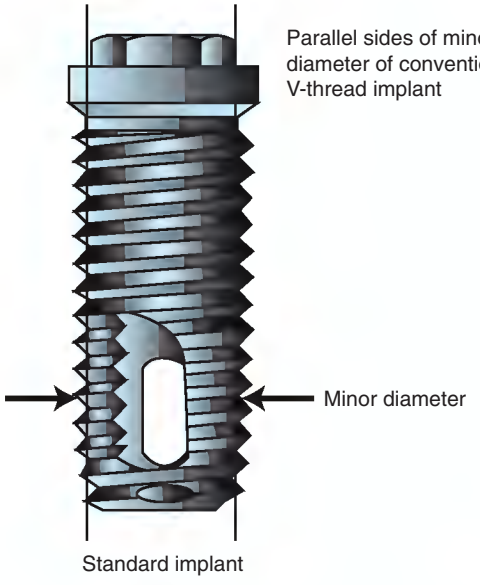


FIGURE 15-44. The thread depth of an implant refers to the distance between the outer (or major) diameter and the inner (or minor) diameter of the thread. The deeper the thread depth, the greater the functional surface area.



FIGURE 15-45. The BioHorizons implant on the left is 4 mm in diameter and has a thread depth of 0.42 mm. The *center* and *right* implants are 5 and 6 mm in diameter, respectively, and have a thread depth of 0.78 mm. As a result, the surface area of the two implants on the right increases by implant diameter and thread depth and has more than 200% more surface area than the implant on the left.

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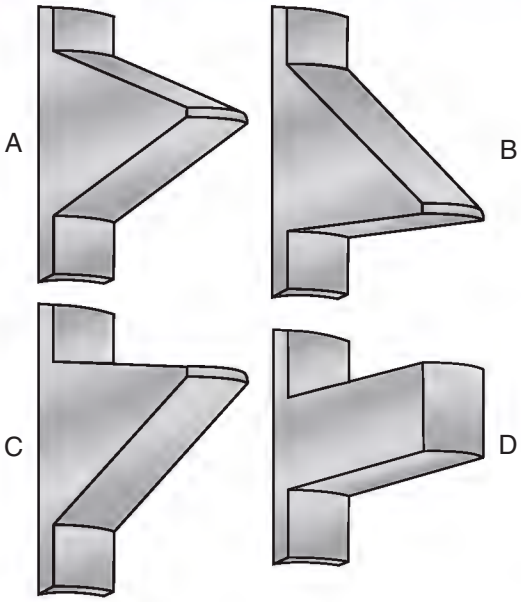


FIGURE 15-46. The four basic thread shapes for implant design include V-thread (**A**), reverse buttress thread (**B**), buttress thread (**C**), and square thread (**D**).

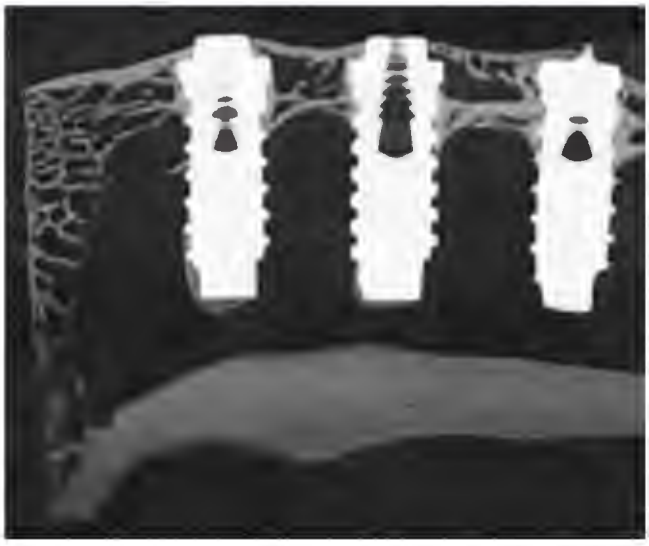


FIGURE 15-47. In this animal study, three different thread designs were evaluated for initial bone healing. The thread number, depth, and surface condition (resorbable blast medium) were kept identical. The implant length and diameter were also the same. The crest module designs of the implants were also similar.[83,84] The square thread resulted in a higher bone–implant contact and a great reverse torque test value.

TABLE 15-4
Surface Area of Implant Designs (5 mm in Diameter)

Implant Type	Implant Size	Square Millimeters
BioHorizons (external)	5 × 13	356.2
BioHorizons (internal)	5 × 12	332.5
3i	5 × 12	245.4
Straumann ITI	5 × 12	207.1
Replace Select	5 × 12	193.6

implant designs when the implant body is 12 mm long. Note the difference between the 4- and 5–mm-diameter implants. It is interesting to note the molars of natural teeth have 200% more surface area than the premolars. Natural teeth not only increase their diameters, but they also modify their design to cope with the higher bite forces in the posterior regions of the mouth. Yet most implant designs only increase surface area by 10% to 30% with a larger-diameter implant body.

Thread Shape

The thread shape is another important characteristic of overall thread geometry.[37] As described previously, thread shapes in dental implant designs include square, V shaped, buttress, and reverse buttress (Figure 15-46). In conventional engineering applications, the V-thread design is called a *fixture* and is primarily used for fixating metal parts together.[82] The angle of the V-shaped thread is 30 degrees, so it can apply in tensile and shear load to the metal and stretch the components to fit more tightly together. This thread shape is the most common in the industry (e.g., Nobel BioCare, Biomet, Zimmer, Astra). It is interesting to note that the original Brånemark implant of Nobel BioCare was called a "fixture" rather than being referred to as an implant.

The buttress thread shape was initially designed for pullout loads by Krupp.[82] This buttress design was used to secure cannons to concrete bunkers so that the discharge forces during firing of the cannon would not pull the screws out of the foundation. Hence, this thread design is improved for pullout loads. However, the force transfer for occlusal loads to the bone is similar to that of the V-thread design. This thread design for dental implants is less used in the implant industry (Nobel BioCare).

Dental implant applications dictate the need for a thread shape optimized for long-term function (load transmission) under occlusal, intrusive (the opposite of pullout) load directions. The square thread (called a power thread in engineering) provides an optimized surface area for intrusive, compressive load transmission.[82] Most automobile jacks or engineering designs built to bear a load use some form of a square thread design. Yet few implant designs have incorporated a square thread design (BioHorizons, Ankylos). A buttress thread shape may also load the bone with primarily a compressive load transfer (e.g., BioHorizons, BioLok, Straumann).

The thread shape has primarily design applications for loading conditions but may also contribute to the initial healing stage for the direct bone interface. An animal study by Steigenga et al. compared three thread shapes with identical implant width, length, thread number, thread depth, and surface condition[83,84] (Figure 15-47). The V-shaped and buttress thread shapes had similar BIC percent. The square thread had the highest BIC percent (Table 15-5). Whereas the square-thread design had a higher BIC percent and a greater reverse torque test value, the buttress and V-shaped thread had similar values (Table 15-6). Therefore, it appears that thread shape may also be a parameter in an implant design for the initial healing phase of osseointegration.

A consistent loading profile approach is warranted in implant dentistry. In general, materials are strongest under compressive

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TABLE 15-5
Percentage of Bone to Implant Comparing V-Shaped, Reverse Buttress, and Square-Threaded Implant Designs ($N = 12$; $n = 69$)

Square Thread	V-Shaped Thread	Reverse Buttress
74.37	65.46	63.05

n, number of implants evaluated; *N*, Number of rabbits.

TABLE 15-6
Reverse Torque Removal Values (N-cm) Comparing V-Shaped, Reverse Buttress, and Square-Threaded Implant Designs ($N = 12$, $n = 36$)

V-Shaped Thread	Reverse Buttress	Square Thread
15.58	15.46	23.17

N, Number of rabbits; *n*, number of implants evaluated.

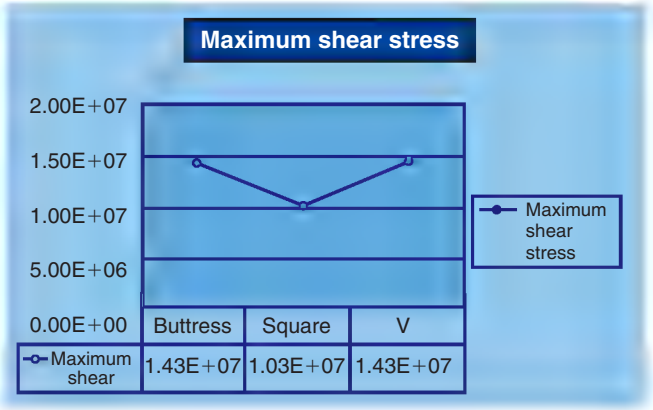


FIGURE 15-48. Evaluation of three thread type implants of similar diameter and length, thread number, and depth with a three-dimensional finite element analysis. The overall stresses and shear stresses are compared. The square-thread implant has less overall stress and less shear stress. The V-shaped thread and reverse buttress thread shape are similar. (From Kim WT, Cha YF, Oh SJ, et al: The three dimensional finite element analysis of stress according to implant thread design under the axial load, *Korean J Oral Surg* 27:3–8, 2001.)

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loads and weakest to shear loads. This is true for porcelain, dental cements, implant materials, fixation screws, and bone.[38] Therefore, a reduced risk is present when a compressive force is applied to all these components, and shear force should be eliminated or reduced wherever possible.

The face angle of the thread or plateau in an implant body can modify the direction of the occlusal load imposed on the prosthesis and abutment connection to a different direction at the bone interface. The face angle of a V-shaped thread is 30 degrees off the long axis, but a square thread may be perpendicular to the long axis. As a result, occlusal loads in the axial direction of an implant body may be compressive at the bone interface when the implant body incorporates square or plateau designs but can be converted to higher shear loads at the bone interface when the implant body incorporates V-shaped threads[37] (see Figure 15-35).

The shear force on a V-thread face that is 30 degrees (typical of Nobel BioCare, Zimmer Screw-Vent, and Biomet 3i) is approximately 10 times greater than the shear force on a square thread.[15] The shear component per unit length of a reverse buttress thread design is similar to a V-thread when subjected to an occlusal load. The shear component of a 15-degree face angle (Straumann ITI implant) is five times greater than the shear force on a square thread. The reduction in shear loading at the thread–bone interface provides for more compressive load transfer, which is particularly important in compromised bone density, short implant lengths, or higher force magnitudes.

A 30-degree load to an implant increases the force to the bone–implant interface by 50% compared with a long-axis load, and the shear component of force is increased.[53] A 30-degree load to the implant–bone interface loads the bone interface at a 30-degree angle and decreases the compression and tensile strength of the interface. The 30-degree load to bone decreases the bone strength in compression by 11% and decreases the tensile strength of bone by 26%.[53] Therefore, when a long-axis load is delivered to the implant crown, the face angle of the implant body thread can modify the occlusal axial load to an angle bone–implant load. A power thread (square) may load the bone interface in compression when an axial load is delivered to the implant crown.

A finite element, three-dimensional study of a thread shape was evaluated by Kim et al.[85] An implant with the same number and depth of threads with different thread shapes (V shaped, buttress, and square) were evaluated (Figure 15-48). The V-shape and reverse buttress threads had similar values. The square thread had less stress in both compressive and, more important, shear forces. Chun et al. also used finite element analysis to evaluate design parameters of osseointegrated dental implants.[27] They also concluded the square-thread design has a beneficial shape for occlusal loading compared with other thread designs. Therefore, thread shape may alter the functional load conditions and influence the type of force transmitted to bone. A review of the literature suggests that the square-thread implant design may provide similar success rates in the maxilla and mandible in a wide range of differences in bone density.[14,86–88]

Implant Design and Bone Response

Studies have shown that when implants act as functional units for a prosthesis, an elevated BRR is an ongoing response adjacent to many dental implants.[89] A BRR higher than 500% per year in the bone immediately adjacent (within 5 mm) to a V-shape threaded implant, but approximately 50% in the regions distant from the interface, has been observed. These findings suggest that the bone at the interface of the implants in their report is likely in the mild overload zone (Figure 15-49). Cooper presented a histologic report of Roberts et al., which evaluated the turnover rate of bone next to a macrosphere surface design (Endopore Sybron Corp) implant retrieved from a human maxilla in the premolar region.[90] This implant had a BRR that ranged between 400% and 908% per year. It is interesting to note that the developers of this implant design believe that bone loss is often a consequence of stress shielding as in orthopedic hip prostheses rather than occlusal overload conditions. Therefore, they believe more stress should be applied to the

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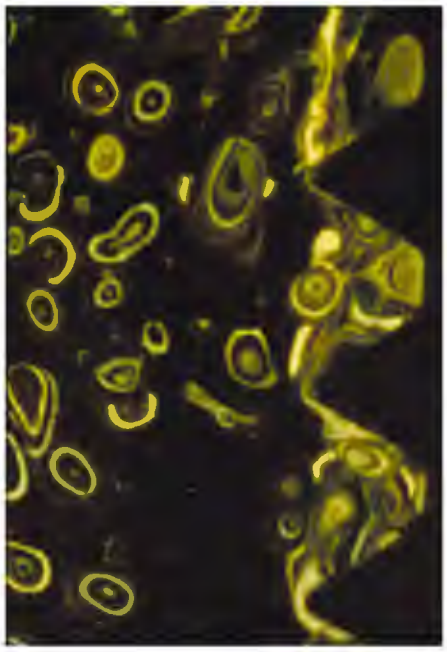


FIGURE 15-49. In an animal model (dog), the remodeling rate of bone away from the implant was 40% per year (physiologic or adapted window). The bone remodeling rate next to the Brånemark implant (Nobel Biocare) was 500% per year (mild overload zone).

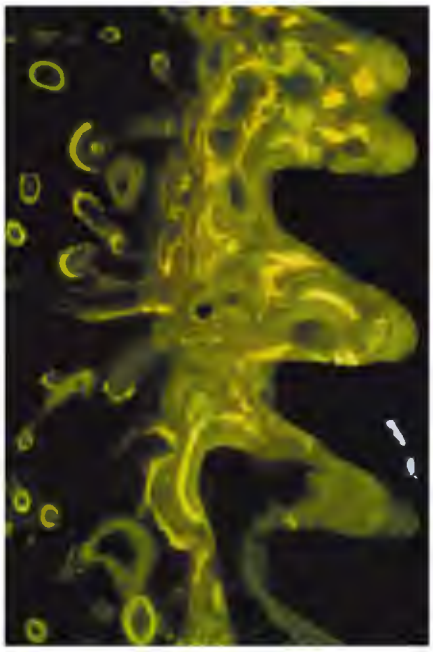


FIGURE 15-50. Garetto et al. evaluated in an animal model (dog) the bone remodeling rate (BRR) next to a Steri-Oss dental implant (Nobel Biocare).[89] The bone several millimeters away from the implant had a BRR of 40% per year. The region around the implant had a BRR of 680% per year (mild to pathologic overload). As a result, the Steri-Oss dental implant had a smaller percentage of bone–implant contact compared with the Brånemark implant design.

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implant interface. The BRR, at least in this one reported patient, appears to indicate a greater strain condition does exist with this design compared with other implant designs or conditions that have been reported.

Roberts et al. observed a difference in interface contact percentage between an asymmetrical implant thread design (Nobel Biocare, Steri-Oss, Yorba Linda, CA) and a symmetrical threaded surface (Nobel BioCare, Brånemark, Gothenburg, Sweden).[91] The V-shaped thread of Brånemark had a higher bone contact and reduced bone turnover rate (500%) compared with the reverse buttress thread shape with a reduced thread number implant (Steri-Oss) with 680% BRR (Figure 15-50). The higher the BRR, the greater the woven bone formation and the risk that the interface is in the pathologic overload zone in the next zone (which results with fibrous tissues at the interface). The BRR reported in these three reports is different for each implant design and is directly correlated with the surface area of the implant evaluated. The more surface area of the implant body, the lower the BRR.

The magnitude of load may also affect the BRR at the implant interface. Roberts et al. evaluated successful implants in humans, used for orthodontic anchorage for 3 years or more.[92] The duration of an orthodontic force is constant, and the forces used for tooth movement (<5 N) are much less than the typical forces of function or parafunction (100–1000 N). The bone–implant interface of these implants only remodeled at a rate in the range of 30% per year. As a result of a decrease in force magnitude or type of force applied (constant vs. dynamic), the lower bone turnover rate may signify the decrease in force magnitude tensile loads at the implant interface during orthodontic anchorage may allow the bone to remain in a physiologic loading zone.

Several studies and reports demonstrate that prosthetic loading conditions on the implants can cause implant failure, crestal bone loss, or implant fracture.[93] It is therefore hypothesized by Misch et al. that the phenomenon of the elevated BRR at the implant interface, compared with that found several millimeters away, may be used as an indication of increased biomechanical risk for the supporting implant–bone interface, as related to or created by specific clinical conditions.[72]

Brunski et al. used a dog model in which loads were applied to a titanium V-shaped thread screw dental implant.[94] Implants in the mandibles and radii were allowed to heal for 4 to 7 months and then loaded with cyclic axial compression in the mandibles and axial tension on the radii sites. There were no significant differences between the controls and loaded interfaces. Brunski et al. believe this was most likely a result of insufficient levels of loading to observe a difference. The similar result may also be related to the implant body V-shaped thread shape, which gives similar stress profiles in compression and tension. A follow-up study by Hoshaw et al. using dog tibiae and larger axial tensile loads with a longer healing time before loading found more crestal bone loss around the loaded implants, an elevated BRR in the cortex, and resorptive modeling on the periosteal surface.[75] Hence, the magnitude and type of force is also related to the cellular reactions of bone.

If an implant design and force application are bioengineered so that loading will produce a microstrain within the adapted window zone, it should maintain lamellar bone at the interface during loading, as represented by a similar BRR adjacent to and distal from the implant interface. Therefore, a prospective goal by Misch et al. of an implant design project involved modifying the parameters of an implant design that affect the response of the surrounding bone tissue next to the implant at the cellular level.[95]

To reduce shear loading to bone, a square-thread design to axial loading may be used on the body of the dental

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FIGURE 15-51. A square-threaded implant (BioHorizons, Birmingham, AL) was loaded in an animal model. A bone remodeling rate of 40% to 50% per year was observed, which was similar to the remodeling rate several millimeters from the implant interface.

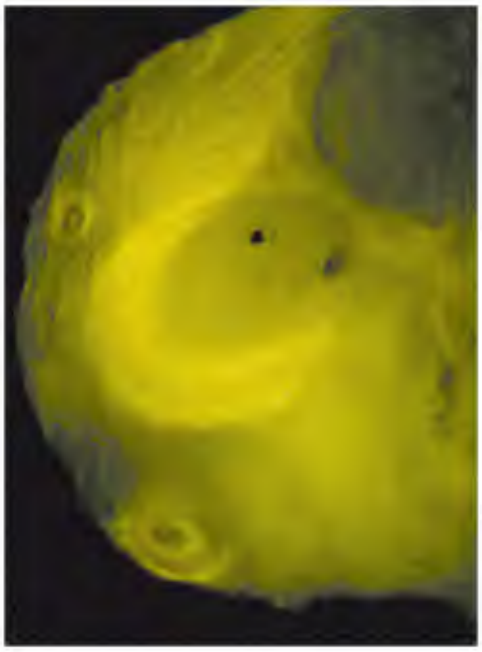


FIGURE 15-52. The bone remodeling rate of bilateral maxillary first premolar implants with a square-thread design (BioHorizons, Birmingham, AL) was evaluated after 1 year of occlusal loading in a human. The bone remodeling rate was 40% to 50% per year and similar to the bone away from the implant interface.

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implant.[75,84,85] The turnover rate of bone within the square threads of the implant (BioHorizons Maestro D2 and D3 implants) in both a dog study and human case report has been reported to be 40% to 50% and was the same as observed in the bone away from the implant interface (Figures 15-51 and 15-52).[50,72] This rate corresponds to the rate of lamellar bone remodeling in the adapted window zone. This condition may place the interface at less biomechanical risk because lamellar bone is more mineralized, more rigid, and stronger than the reactive woven bone found in the mild overload zone.

The concept presented in this chapter is not meant to suggest that adequate strain levels may only be obtained with one implant design or even that ideal strain levels are necessary for long-term maintenance of osseointegration. The strain environment around an endosteal implant is very complex, and variables such as bone density, bone volume, and bone shape are most likely influential but not yet fully understood. Future experimental models should evaluate how the influence of implant design, surface condition, intensity of load, frequency of load, direction of force, and bone density interrelate to the long-term success of dental implants. It is suggested the bone turnover rate may be a method to evaluate these conditions.

Apical Implant Design Considerations

The apical portion of a root form implant is most often tapered to permit the implant to seat within the osteotomy before the implant body engages the lateral aspects of the bone region (Figure 15-53). As a result, the patient does not need to open the mouth as wide, which is especially of benefit in the posterior regions of dentate patients. This apical feature also favors the initial threading step of implant insertion. The tapered apex also is a benefit in an implant positioned next to convergent or dilacerated roots or bone undercuts.

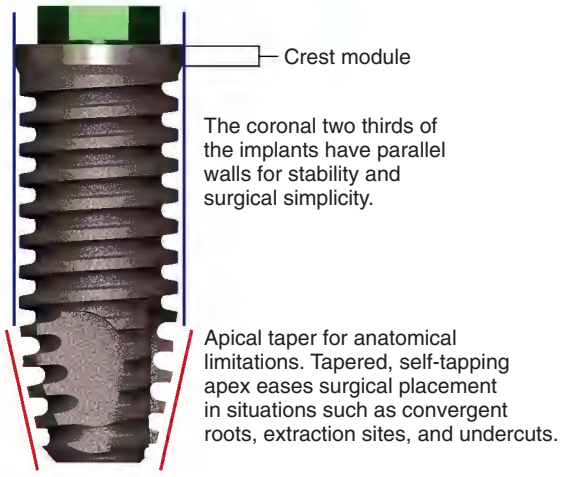


FIGURE 15-53. A 0.5-mm smooth metal collar may provide for a closer abutment–crest module connection compared with a rough-surface connection. The apical end of an implant is often tapered to ease surgical placement because it fits within the osteotomy before engaging the walls of the bone. It is also of benefit when the implant is positioned next to a tooth with a convergent or dilacerated root or available bone with an undercut region. (BioHorizons, Birmingham, AL.)

Most root form implants are circular in cross-section. This permits a round drill to prepare a round hole, precisely corresponding to the implant body. Round cross-sections, however, do not resist torsion or shear forces when abutment screws are tightened or when freestanding, single-tooth implants receive a rotational (torsional) force. As a result, an antirotational feature is incorporated into the implant body, usually in the apical region. The most common design is a hole or vent. In theory,

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FIGURE 15-54. The apical hole or open cylinder may fill with mucus when placed within a sinus and result in a retrograde infection around the implant.

bone can grow through the apical hole and resist torsional loads applied to the implant. The apical hole region may also increase the surface area available to transmit compressive loads to the bone.

A disadvantage of the apical hole occurs when the implant is placed through the sinus floor or becomes exposed through a cortical plate. The apical hole may fill with mucus and become a source of retrograde contamination or will likely fill with fibrous tissue (Figure 15-54). If the apical hole is several millimeters in height, the region filled with fibrous tissue decreases bony contact in the apical region of the implant. This concern is greatest with an open basket body design, less with a vertical hole of 4 mm, and even less with a round 1-mm-diameter hole. The apical aspect of a solid implant (without apical hole) may slightly perforate any opposing cortical plate and act as a wedge to seal the opening.

Another antirotational feature of an implant body may be flat sides or grooves along the body or apical region of the implant. Bone grows against the flat or grooved regions and helps resist torsional loading. In addition, the grooves or recessed areas of the apical portion of the implant help to enhance the "self-tapping" aspect of an implant design. This occurs in several ways. First, the recess areas of the apical portion allow bone fillings from the cutting threads to fill the area. Otherwise, these bone chips may fall to the apical floor of the osteotomy and prevent the implant from completely seating or compress into the trabecular bone and contribute to a pressure or resistance to rotational insertion of the implant. Second, the recess area may be designed to decrease the angle of the cutting thread along the apical portion of the implant. As a result, less torque is required to thread the implant into the bone.

The apical end of each implant should be flat rather than pointed. Pointed geometry has less surface area, thereby raising the stress level in that region of bone. Additionally, if an opposing cortical plate is perforated, a sharp, V-shaped apex may irritate or inflame the soft tissues if any movement occurs (e.g., the inferior border of the mandible).

Implant Body Related to Fracture

Implant bodies and components have a risk of fracture, most often during the intermediate- to long-term loading condition. According to Goodacre et al., the risk of implant body fracture in the early to intermediate period for implants 3.75 mm in diameter is 1%, the abutment screw fracture risk is 2%, and the prosthetic screw risk is 4%.[33] However, the incidence of fracture dramatically increases when force conditions are greater or the cyclic loads are increased in number. Cantilevers, angled loads, and parafunction increase the risk of fracture. The risk of fracture also increases over time because the number of cycles of load is increased. Rangert et al. reported that in the long-term loading condition, 80% of all failures may be related to implant body fracture.[96] The elements of the implant body that influence the fracture risk include the biomaterial, the implant size, and the implant design.

Force Magnitude and Implant Body Design

Normal physiology imposes constraints on the magnitude of forces that must be withstood by engineering designs in the oral environment. The magnitude of bite force varies as a function of anatomical region and state of the dentition. Average bite forces can range from 10 to 350 lb.[97] The magnitude of force is greater in the molar region (200 lb), less in the canine area (100 lb), and least in the anterior incisor region (25–35 lb). These average bite forces increase with parafunction to magnitudes that may approach 1000 lb in the posterior regions.[98]

Implant body designs used in the posterior areas of the mouth with higher forces should incorporate specific design features that make them less susceptible to the higher load profiles, therefore further decreasing the risk of fracture. The ability of implants and components (e.g., abutment screws) to resist fracture from bending loads is directly related to the component's moment of inertia (or bending fracture resistance factor). This parameter is a function of the size of the cross-sectional geometry of the component. A solid cylinder fracture resistance is equal to the radius to the fourth power.

$$I\,(\text{Moment of inertia})_{\text{Solid cylinder}} = \tfrac{1}{4} \times \pi \times \text{Radius}^4$$

Therefore, an implant or component two times as wide is 16 times more resistant to fracture. As a result, wider-diameter implants may be used when offset loads (cantilevers) or greater stress conditions (i.e., parafunction, molar regions) exist.

Considering the same equations, it can be shown that an abutment screw, which has a smaller cross-sectional area than an implant (typically ≈2 mm), is more susceptible to fracture. This is particularly true when the abutment screw comes loose and bears a large, disproportionate component of a transverse load.

Some investigators have suggested the phenomenon of screw breakage to be a long-term advantage for the implant. Restated, it is better for the screw to break than the implant because the screw is easily retrievable but the implant body is not. Although this concept has some value, it is also a faulty safety factor. Most implant prostheses have more than one implant abutment. As soon as one screw loosens or breaks, the stresses are increased to the remaining implants, components, and bone interfaces. The additional off-axis loads resulting from the screw fracture increase the stresses in the overall system and may contribute to bone loss or implant component fracture of the remaining fixated units. Therefore, rather than depending on a safety factor as a broken screw when the stresses are too great, transverse load contacts should be identified and corrected by designing reduced cantilevers or occlusal adjustments before screw breakage is imminent.

Where s represents the stress, M is the moment load caused by eccentric loading and cantilevers, y is a point in the center of

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the part, and *I* is the moment of inertia. Therefore, it can be shown that by increasing *I*, which is dependent on the part geometry, stress is decreased. Restated, by optimizing the implant body geometry within the anatomical dimensional limitation, it is possible to reduce the overall stress in the implant.

The relationship of moment of inertia to overall fracture resistance can be demonstrated by this engineering mechanics equation:

$$s = My/I$$

Implant body design may also increase the risk of long-term fatigue fracture. The abutment screw length is shorter than the receptor site within the implant. This permits the receptor site within the implant to be machined and allows the abutment screw to tighten the abutment without the risk of "bottoming out" before the screw is completely tightened. The cross-section of this portion of the implant body can be modeled as an annulus or hollow cylinder, similar to the cross-section of a pipe. The wall thickness of the implant body in the region below the abutment screw controls the resistance to fatigue fracture. Therefore, the annulus of an implant should be as apical as reasonable within the implant body, which requires a longer abutment screw (Figure 15-55).

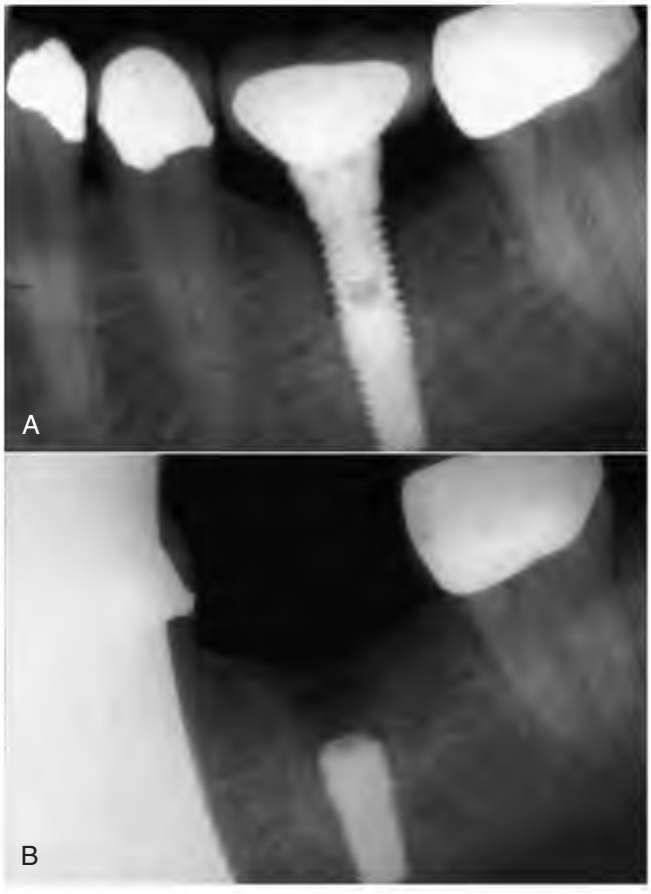


FIGURE 15-55. The annulus is the space within the implant body below the abutment screw. In this implant design, the annulus is only a few millimeters below the crest module. When bone loss occurs to the annulus, the hollow cylinder implant design is susceptible to fracture.

Morgan et al. reported on fatigue failures of Brånemark implants subjected to bending loads.[99] Scanning electron micrographs of the fracture surfaces, coupled with the known position of the implants within the oral environment, enabled the authors to determine the load direction was buccolingual bending. Implant fracture occurred, as predicted, in the region of the implant that was characterized by a reduced annular cross-section. When the abutment screw is only 6 mm long and crestal bone loss of 6 mm occurs, the annulus (and weakest portion of the implant body) is positioned in the highest stress locations from the increased bending moment at that location. As a result, implant body fracture is imminent. Therefore, the abutment screw length is an important implant design issue and should be as long as possible.

The formula for the bending fracture resistance in an annulus condition is related to the outer diameter radius to the fourth power minus the inner diameter radius to the fourth power. For example, if a 3.75-mm-diameter implant has a 0.4-mm thread depth, the outer diameter related to body fracture is actually 2.95 mm (3.75–0.4 mm on each side or 2.95 mm with a radius of 1.475 mm). If this implant has a 2.5-mm abutment screw hole (inner radius of 1.25 mm), its moment of inertia or bending fracture resistance at the end of the screw can be shown as: $\frac{1}{4} \times \pi$ (R outer diameter^4 – R inner diameter^4)

$$I_{\text{Hollow cylinder}} = \tfrac{1}{4} \times \pi \left(1.475^4 - 1.25^4\right)$$

Therefore, even a small dimensional change in wall thickness can result in a significant change in bending fracture resistance because the dimension is multiplied to a power of four (Figure 15-56).

When the outer diameter increases 0.1 mm and the inner diameter remains unchanged, the moment of inertia increases to 2.329 mm^4 or a 30% increase in strength. When the outer diameter remains unchanged and the inner diameter decreases 0.1 mm, the increase is 2.087 mm^4, or a 16% increase. Therefore, an increase in outer diameter has a more significant effect on body wall strength even though the metal thickness is similar in both scenarios. Therefore, a 4-mm-diameter implant body has a significant increase in strength compared with a 3.75-mm implant body, especially at the annulus position. The overall bending stress (and likelihood of fracture) decreases exponentially as the moment of inertia (bending fracture resistance factor) increases (Figure 15-57).

An interesting analysis compares a solid, one-piece implant with a two-piece, traditional root form implant. A solid implant with a 1.23-mm diameter has the same resistance to bending fracture as the annulus region of a 3.75-mm traditional design at the annulus position. Moreover, a solid 3-mm implant has an approximately 340% increase in moment of inertia over the 3.75-mm traditional two-piece root form at the annulus position.

The crest module of an implant body may be designed to have a space around the abutment screw. This space increases the risk of fracture at this location. An external hex implant has the space above the implant body, but an internal hex system has the space within the implant body. Therefore, the external hex has a slightly higher risk of fracture within the abutment, and an internal hex implant body has an increased risk of fracture at the crest module of the implant. The reduced strength of the implant body is not as great as the annulus at the end of the abutment screw. However, the lack of metal continuity is at the crest of the ridge, where the greatest forces occur. As a result, conditions such as a decrease in implant diameter or angled

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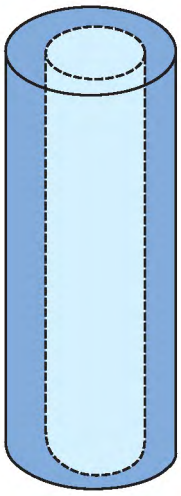


FIGURE 15-56. The equation for determining resistance to fatigue fracture is largely controlled by wall thickness in a dental implant.

$$I_{hollow\ cylinder} = \frac{1}{4} \times \pi \times (r_{outer\ diameter}^{4} - r_{inner\ diameter}^{4})$$

$$I_{hollow\ cylinder} = \frac{1}{4} \times \pi \times (1.475^4 - 1.25^4)$$

$$\text{or } I = 1.799\ \text{mm}^4$$

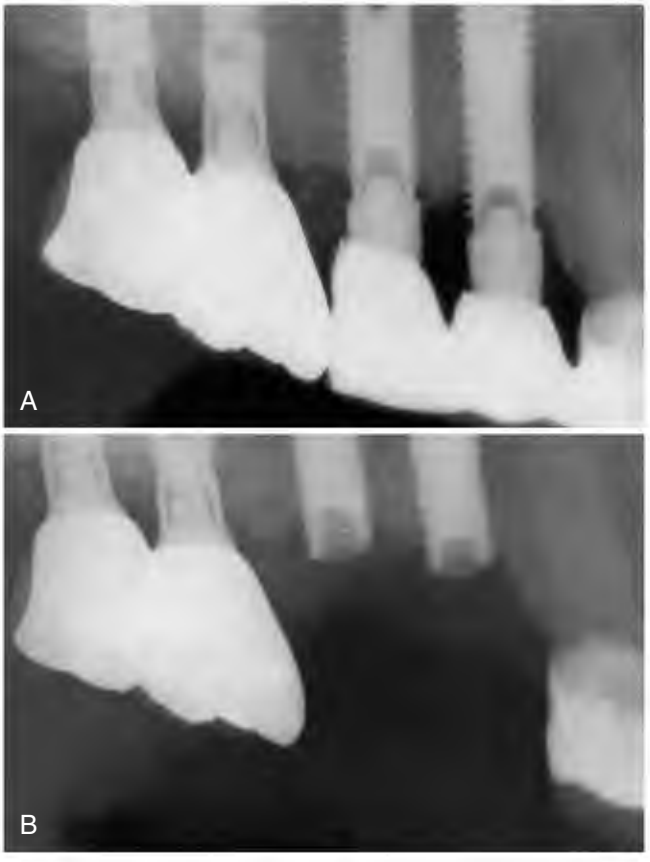


FIGURE 15-57. **A,** The implant in the first molar position is 4 mm with bone loss to the seventh thread and at the level of the implant annulus. **B,** The implant body becomes dramatically weaker at the annulus position and fractured.



FIGURE 15-58. The internal hexagonal implant shown (Screw-Vent, Zimmer, Encino, CA) has fractured at the crest module as a result of fatigue and implant design.

forces increase the risk of fracture to the crest module at this site (Figure 15-58).

The outer body wall thickness is reduced for an internal hex implant because the antirotational feature is wider than an abutment screw. As a result, a smaller diameter implant with an internal hex or trilobe design may even fracture as the implant is seated into position. This is especially noteworthy when a tapered implant is used in dense bone because the torque forces are greater (Figure 15-59).

Implant Body Biomaterial Related to Fracture

Many biocompatible materials are unable to withstand the type and magnitude of parafunctional loads that may be imposed on dental implants. As an example, ceramic, which has excellent biocompatibility, is very susceptible to tension and bending loads. Such loads are commonly applied to dental implants and render this material unsuitable in many implant body applications. In addition, materials such as hydroxyapatite are quite biocompatible with biological tissues but lack the mechanical material properties to withstand the loads imparted on implants. In contemporary applications, many of these materials are considered for use as a coating when applied to a stronger substrate material.

Titanium and titanium alloys have a long history of successful use in dental and orthopedic applications. The excellent biocompatibility of titanium and its alloy has been well

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documented.[100] There are four grades of commercially pure (CP) titanium used in dentistry (grades 1–4) and one grade of titanium alloy (grade 5). Regardless of the grade of titanium or alloy, the surface condition to the bone is similar (i.e., titanium oxide). With its highly active titanium oxide layer, these materials are extremely well tolerated by local tissues.

Titanium–aluminum–vanadium alloy (Ti-6Al-4V) has been shown to exhibit the most attractive combination of mechanical and physical properties, corrosion resistance, and general biocompatibility of all metallic biomaterials.[96] The primary advantage of titanium alloy compared with other grades of titanium is its strength. As shown in Table 15-7, the mechanical properties of titanium alloy are superior to those of commercially pure titanium.[101–103] Titanium alloy is four times stronger than grade 1 CP–titanium and almost twice as strong as grade 4. Ultimate strength and fatigue strength is a primary consideration given the ramifications of the loading profiles to which dental implant bodies are subjected and the possible component fractures incurred because of weaker materials or designs.

The modulus of elasticity (stiffness or rigidity) of the four different grades of titanium is similar (103 GPa), and titanium alloy is only slightly higher (113 GPa). Although there is a significant difference in strength between grades of CP titanium and its alloy, the elastic modulus is similar for all of these materials. Titanium and its alloy represent the closest approximation to the stiffness of bone of any surgical-grade metal used as an artificial replacement for skeletal tissue even though it is almost six times stiffer than dense cortical bone. However, because of the geometry and functional requirements of dental implants, the elastic modulus is not nearly as important as the biocompatibility and strength offered by titanium alloy. Thus, titanium alloy represents the best compromise (given current biomaterials technology) among biomechanical strength, biocompatibility, and the potential for relative motion (from elastic modulus mismatch) at the bone–implant interface.

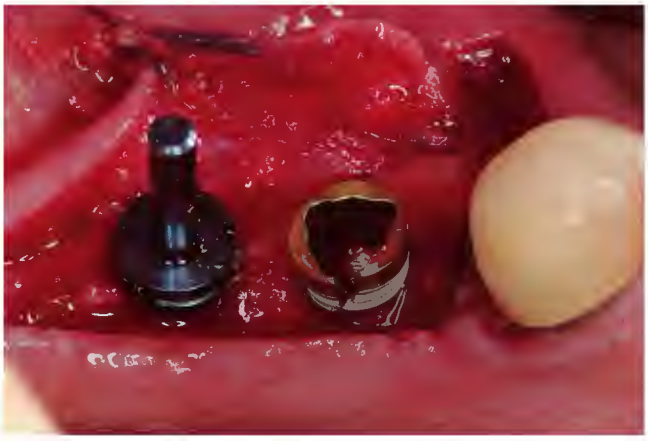


FIGURE 15-59. A tapered implant with a trilobe internal hex has a thin outer wall at the crest module and increased insertion torque may result in outer body wall fracture. (Nobel BioCare, CA.)

Implant Design Failures Related to Biomaterial and Force Magnitude

Two examples of implant body failures related to biomaterial choice have appeared in the historical implant literature. The vitreous carbon implants optimized the modulus of elasticity (stiffness) of the biomaterial (carbon) without appropriate attention to ultimate strength considerations. Conversely, Al_2O_3 ceramic implants optimized ultimate strength without adequate attention to modulus of elasticity or type of loading conditions placed on implants in parafunction.

The vitreous carbon implant design was composed of a smooth, tapered-step carbon body with an internal 316-L stainless steel post. The stiffness of the carbon was compatible with the surrounding bone; however, the carbon body was incapable of withstanding the physiologic loads within the oral environment.[102,104] The geometric design of the implant is equally, if not more important, to resist occlusal loads. Microcracks in the body developed, and a pathway of biological fluids was thus introduced to the internal stainless steel post. The post was then subjected to dramatic corrosion with the subsequent release of metallic ions into the interfacial tissues. Gross tissue inflammation with ultimate implant failure and removal resulted. A close match of biomaterial and bone material stiffness alone cannot, in isolation, provide clinical success.

The ceramic implants, as a class, were antithetical to the carbon implants. Ultimate compressive strength was optimized at the sacrifice of matching biomaterial and bone stiffness. In addition, the brittle nature of ceramic and susceptibility of failure in tension and shear require geometric designs of the implant that may not be compatible with the anatomical dimensional limitations (i.e., available bone width and height) of the jaw. The modulus of elasticity for ceramics is approximately 33 times stiffer than cortical bone.[105] The result was apparent stress shielding of the interfacial bone. Bone must receive greater than 50 microstrains to function in a physiologic load window.[106] The very stiff ceramic implants carried a disproportionate amount of the load, and the interfacial bone was moved into disuse atrophy.

More recently, zirconium implants have been introduced into the market because of zirconium's white color and biocompatible surface. However, the modulus of elasticity of this material is similar to alumina and other ceramics. Hence, stress shielding may occur coupled with bone loss and failure (Figure 15-60).

Force Duration and Implant Body Design

The duration of bite forces on the dentition has a wide range. Under ideal conditions, the teeth come together during

TABLE 15-7
Mechanical Properties for Different Grades of Titanium

Property	Grade 1	Grade 2	Grade 3	Grade 4	Ti-6A1-4V
Tensile strength, min (MPa)	240	345	450	550	930
Yield strength, 0.2% offset, min (MPa)	170	275	380	483	860
Modulus of elasticity (GPa)	103	103	103	103	113

Grades 1 to 4, commercial pure titanium; *Ti-6Al-4V,* titanium–aluminum–vanadium alloy.

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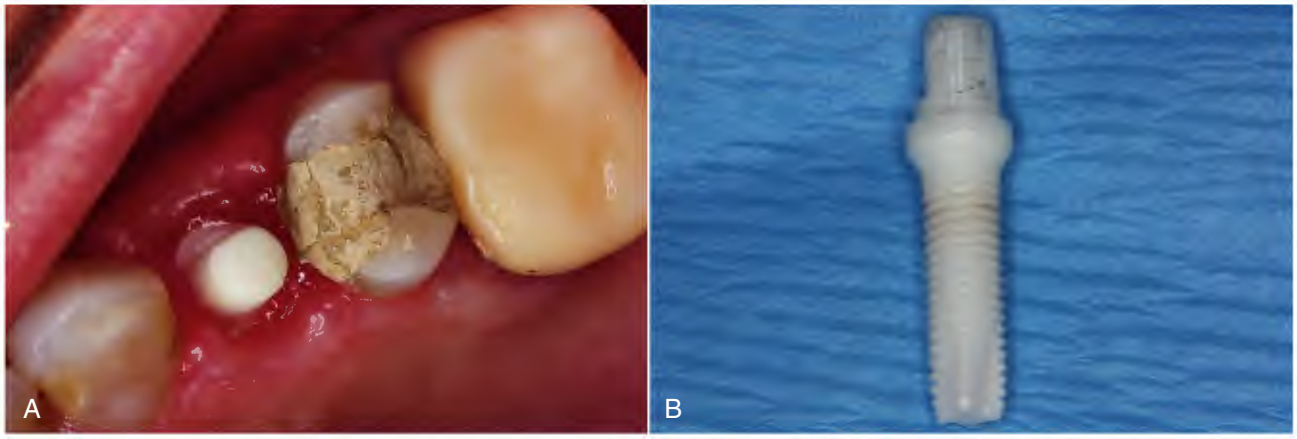


FIGURE 15-60. **A,** A zirconium implant has a modulus of elasticity similar to alumina (which is more than 30 times stiffer than bone). Hence, stress shielding and bone loss may be a consequence. **B,** This implant lost bone and became mobile after loading.

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swallowing and eating for only brief contacts. The total time of those brief episodes is less than 30 minutes per day.[107] Patients who exhibit bruxism, clenching, or other parafunctional habits, however, may have their teeth in contact several hours each day. This force duration essentially is able to create a fatigue load on the implant.

Influence on Implant Body Design

Implant bodies and components are prone to fatigue fractures, with incidence reported between 1% to 4% after 5 to 10 years of loading.[33] The most common cause of long-term failure occurred when a grade 1 titanium implant body was used, coupled with a less than ideal treatment plan that has higher stresses, as was demonstrated with 80% of failures from fracture of the Brånemark implant body over 15 years.[97] An increase in fracture risk was also observed with parafunctional forces when a cantilever load was applied to the implant body.[99] Several factors influence the risk of fracture because of fatigue, including the material, force type, the direction of the applied load, and the overall geometric design.

Typical mechanical failures are caused by either static loads or fatigue loads. Static load (i.e., one load cycle of long duration) failures cause the stress in the material to exceed its ultimate strength after one load application applied over time. Fatigue load failures happen if the material is subjected to lower loads but repeated cycles of that load. The endurance limit or fatigue strength is the level of highest stress a material may be repetitively cycled without failure. The endurance limit of a material is often less than half its ultimate tensile strength. Therefore, fatigue and ultimate strength values are related, but fatigue is a more critical factor, especially for patients with parafunction because they impose higher stress magnitude and greater cycles of load. Different materials have varying degrees of resistance to repeated loading and subsequent fatigue-related failures. The fatigue strength of titanium alloy (Ti-6Al-4V) is four times greater (and safer) than grade 1 titanium and almost two times greater than grade 4 titanium[101] (see Figure 15-60). Therefore, long-term fracture of implant bodies and components may be dramatically reduced with the use of titanium alloy rather than any grade of commercially pure titanium. Therefore, grades 1 to 4 titanium are at greater risk of implant body or component fracture under any condition compared with titanium alloy (grade 5).

Summary

The implant body design is responsible for transmitting the occlusal stress of the prosthesis to the supporting bone. The product used by the implant team may increase or decrease the risk of screw loosening, crestal bone loss, implant body bone loss, periimplantitis, esthetics of the soft tissue drape, implant failure, and implant body fracture. Therefore, it is prudent to make a selection based on a scientific approach rather than on advertising or marketing opinion. This decision is even more important when force factors are greater than usual, bone density is poorer than usual, or implant body size is reduced.

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CHAPTER **16**

Preimplant Prosthodontics: Overall Evaluation, Specific Criteria, and Pretreatment Prostheses

Carl E. Misch and Francine Misch-Dietsh

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Implants serve as a foundation for the prosthetic support of missing teeth. However, in a partially edentulous patient, the existing teeth may often require restorations or other types of treatment. Hopeless teeth should be extracted and teeth with advanced periodontal or endodontic conditions treated before determining the final implant restoration and the implant position and number (Figure 16-1). Too often, a detailed treatment plan (complete with study models and computed tomography [CT] scans) is attempted before the extraction of hopeless teeth. After the extractions, more (or less) bone grafting and implant treatment is a usual consequence. As such, the time and effort to prepare the treatment plan are wasted. In addition, it causes confusion for the patient and often results in the delay of critical decisions for predictable treatment.

Extraction of Teeth with a Poor Prognosis

Maintaining natural teeth in health, function, and esthetics is a primary goal of all dentists. In the past, the maintenance of natural teeth was paramount because tooth replacement techniques were costly and not as predictable as repairing natural teeth. However, today dental implants are very predictable when available bone volume and density are present in the edentulous site. As such, under some conditions, the advanced repair procedures of a natural tooth, such as retreatment of endodontic failures or furcation treatment, may have a lower success rate than an implant to replace the tooth. Therefore, on occasion, when the natural tooth is significantly compromised, the extraction and replacement with an implant is the treatment of choice. In addition, multiple advanced procedures on the same tooth may be more expensive (and less predictable) than extraction of the tooth and replacement with an implant.

A tooth may be considered for extraction because of prosthetic, endodontic, periodontal, or surgical considerations. On rare occasions, extraction is considered rather than orthodontics to restore the teeth in a more esthetic or functional position.

Prosthetic Considerations

Caries on a natural tooth is most often able to be removed and the tooth restored. However, on occasion, the tooth is unrestorable after the decay is removed. A prosthetic axiom is to have at least 1.5 to 2 mm of tooth structure for a crown with a cervical ferule effect. In addition, adequate retention and resistance from the tooth preparation should exist.[1–2] As a result of the caries, additional treatment as endodontic therapy, post and core, and functional crown lengthening may be required (Figure 16-2). Thus, procedures to save the tooth are costly and on occasion less predictable than an implant. In addition, the end result may not be esthetically pleasing. For example, when a central incisor requires considerable functional crown lengthening, the gingival margin may be compromised and have a poor esthetic result.

A patient with a history of high decay rate, a high caries index, and recurrent caries under crowns requiring endodontics with a post and core before restoration and may be better served with an extraction and implant insertion (Figure 16-3). The repeated recurrent decay can be eliminated, at least for that tooth, with an implant. In addition, when caries extends within the root canal, the outer structural walls of the natural root may be too thin for a predictable post or restoration. As a result, extraction and implant insertion has a better prognosis.

When the dentate arch opposing an edentulous posterior region exfoliates or extrudes beyond the occlusal plane many millimeters, the tooth may require several procedures to restore the correct occlusal plane. Endodontics and functional crown lengthening beyond the furca of the roots may be necessary. After these procedures, the lateral wall thickness of the root may



FIGURE 16-1. Before developing a definitive treatment plan, it is beneficial to extract hopeless teeth and treat teeth with advanced oral conditions of the hard and soft tissues.

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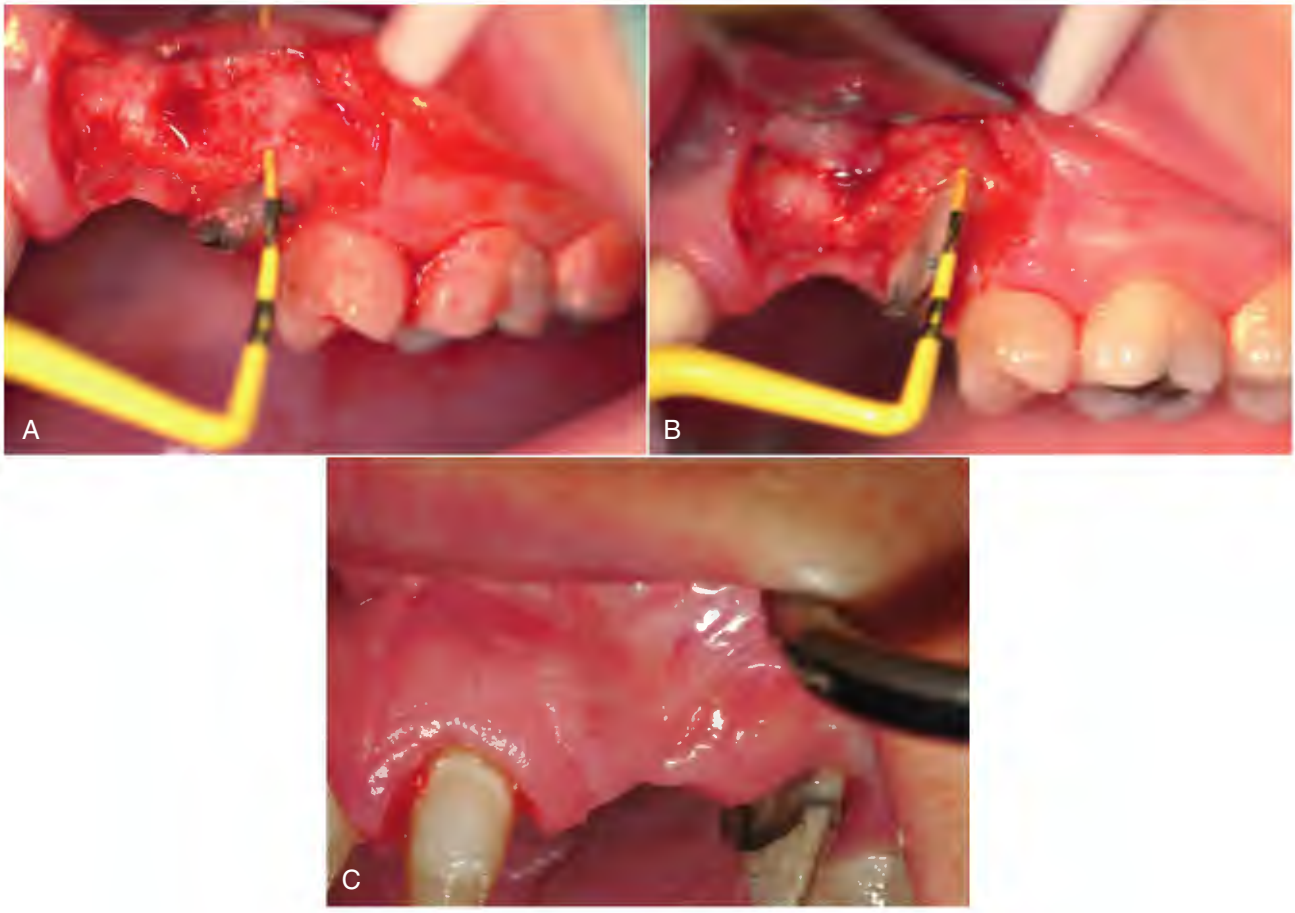


FIGURE 16-2. **A,** An endodontic-treated maxillary canine with inadequate exposed tooth structure to predictably restore. **B,** After functional crown lengthening, there is adequate tooth structure for a ferule effect from the crown to help prevent tooth fracture and improve crown retention and resistance. **C,** After soft tissue healing, a post and core improves retention and resistance for the canine crown.

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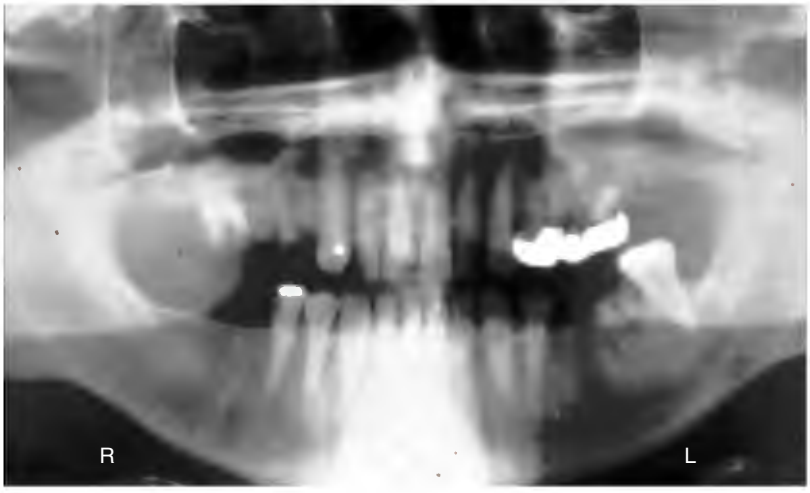


FIGURE 16-3. A panoramic radiograph of a patient with recurrent decay and many hopeless teeth.

be minimal for the post and core. A structural failure is most likely under these conditions. An extraction and implant may be appropriate, especially in cases of moderate to severe parafunction. Another option for extruded or exfoliated teeth may be orthodontic intrusion, often with an implant as a transitional anchorage device (TAD). This is more often the treatment of choice when orthodontic therapy is required to improve the position of the rest of the teeth in both arches.

Endodontic Considerations

Endodontic conditions may cause the dentist to consider tooth extraction rather than traditional treatment. For example, when the root canal cannot be accessed because of abnormal root anatomy or previous restoration, an extraction and implant insertion may be considered rather than an apicoectomy (Figure 16-4). On occasion, the endodontic procedure in the posterior

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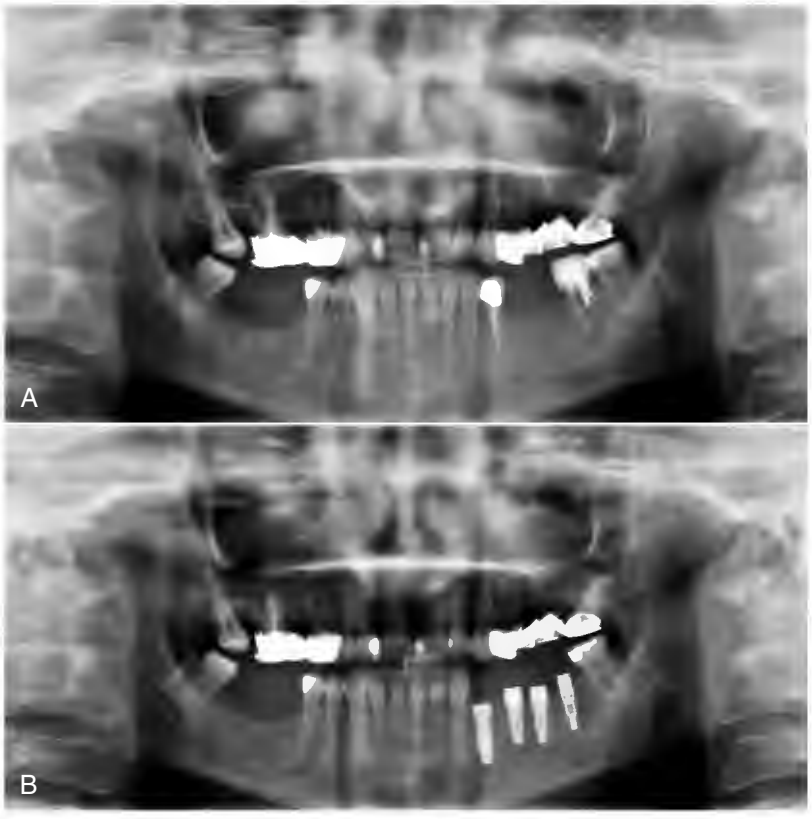


FIGURE 16-4. **A,** A panoramic radiograph of a patient with mandibular second molar with a lesion of endodontic origin and the canal access is compromised with a post (and perforation of the distal root and furca is present). **B,** A panoramic radiograph of the patient after extraction and implant insertion.

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mandible requires an apicoectomy and has a moderate to high risk of paresthesia. An implant after extraction may be less invasive and have less risk of paresthesia.

A tooth with a "split root" syndrome may have root canal therapy, with pain still present during function, and may be treated with extraction and implant insertion. If the endodontic procedure appears satisfactory but pain persists during function, retreatment of the tooth is often not predictable. Rather than waiting for an observable symptom, the subjective finding of pain during function may be enough cause to extract the tooth. An extraction and implant insertion is usually a definitive treatment that eliminates more predictably pain during function than endodontic retreatment of the tooth.

A meta-analysis of endodontic success concludes the success rate of endodontic therapy is 90% at 8 years. However, it must be noted that the rates of success for endodontics are different than the "success" rates reported with implants.[3,4] Success rates reported with dental implants are most often survival rates.[5] If the implant is in the mouth, it is considered a "success" regardless of the quality of health. However, success in many endodontic studies is often related to resolution of all peirapical pathology. Hence, when tooth survival after endodontic therapy is considered, endodontic treatment is similar to implant therapy. As such, traditional endodontics is the treatment of choice for most teeth that are able to be restored.

Whereas a vital tooth has endodontic success rates above 93%, a nonvital tooth has an 89% rate.[6,7] A large periapical lesion (larger than 5 mm) compromises the success rate of traditional endodontics. A nonvital tooth with large periapical pathology has a success rate of 78%. As a result of a lower "success" rate, endodontic therapy should still be performed, but the tooth should be evaluated over several months before post, core, and crown treatment (Figure 16-5).

If endodontic retreatment is necessary, consideration for extraction may be more justified. A retreatment of an endodontic tooth (that appears radiographically to be within normal limits) with a periapical lesion has a reported "success" rate of 65%. As a result, the additional retreatment cost may lead to consideration for extraction and implant replacement. Therefore, for devital teeth with more than 5-mm apical radiolucencies that do not resolve after initial endodontic treatment and periapical lesions remain or reappear with clinical consequences, an extraction should be considered. This may be even more justified when an apicoectomy is the treatment of choice to treat the failure.[8]

Periodontal Considerations

The existing teeth in a partially edentulous patient should be evaluated for periodontal disease. Advanced periodontal disease may be addressed with extraction of questionable abutments more frequently than in the past, provided the resulting edentulous area offers sufficient bone for predictable endosteal implant placement and a predictable prognosis[9] (Figure 16-6).

Herodontics are discouraged when the prognosis is poor or failure of treatment may result in inadequate bone for implant placement. This is especially noted when the existing available bone around the tooth roots is compromised in height, especially in the posterior mandible. Unsuccessful periodontal treatment and continual bone loss may render the remaining bone inadequate for placement of implants after extraction of the teeth. Bone grafting to improve available bone height in the posterior mandible is more unpredictable than any other region of the jaws. As a result, when 10 mm of bone is all that remains from the mandibular canal to the remaining bone around the periodontally involved teeth, consideration is given to the

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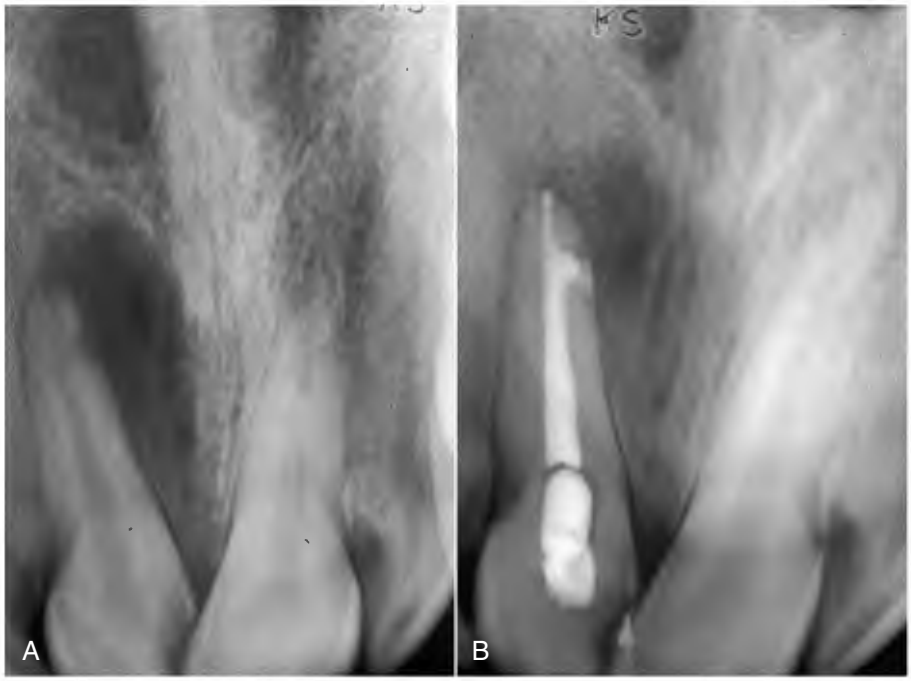


FIGURE 16-5. **A,** A periapical radiograph of a maxillary central incisor with a lesion of endodontic origin greater than 5 mm in diameter. A devital tooth with an endodontic lesion of more than 5 mm has less than an 88% treatment success rate. **B,** A postoperative periapical radiograph of the central incisor after endodontic therapy. The large endodontic lesion has started to resolve. As a result, the tooth may be restored with confidence. If not successful, extraction rather than retreatment is considered because the retreatment success rate is 65%.

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predictable aspects of periodontal therapy. When in doubt, the teeth should often be extracted (Figure 16-7).

The etiology of furcation involvements includes bacteria as well as plaque in the furca with extension of inflammation in the region with loss of interradicular bone. This leads to a progressive and site-specific loss of attachment in most individuals. A first molar furcation entrance cannot be accessed with traditional periodontal hand instruments almost 60% of the time.[10] In addition, pulpal pathoses with accessory canals in the furca may cause a combination of endodontic and periodontal problems. Vertical root fracture after endodontic therapy may also occur with greater incidence. Hence, patients with moderate periodontal disease that includes the molars are at greater risk of the continuation of the disease.

Furcation treatment of molars may include root amputation. The lowest success rate for root resection was found on mandibular distal root resections (75%).[11,12] Even when successful, the remaining root indicates endodontics, core and crown of the remaining root, and the prosthetic replacement of the distal root with an implant or fixed partial denture (FPD) (Figure 16-8). An extraction, socket graft, and implant is more predictable to treat this condition. An implant may also replace the whole tooth with a lower cost. As a consequence, mandibular molar root resection should be replaced by extraction and implant therapy.

A distal furca in a maxillary molar is the most common furca involvement because it is directly below the interproximal contact and has difficult access for hygiene.[13,14] A maxillary molar that has lost bone to the furcation has lost almost 30% of the root surface area of support. However, when a distal buccal root is resected in the maxilla, often the crown may be restored to fill the mesiodistal space, and an additional procedure is not required. Hence, a distal–palatal furca treated with a root resection is often indicated in the maxilla rather than extraction and an implant.

When a maxillary molar has more than one furca condition or short roots, a root resection, or even a considerable functional crown lengthening may compromise the remaining support or result in another furcation involvement. The endodontics, post and core, and functional crown lengthening may not be as predictable as extraction and implant insertion. In addition, the cost of this conventional treatment may be twice the cost of an implant.

On occasion, successful periodontal therapy is accompanied with a poor esthetic result. It may be more prudent to extract the unesthetic teeth even though the periodontal therapy was "successful." Under these conditions, implant prosthesis may restore the dentition with a more esthetic restoration (Figure 16-9).

Traditional methods to save a tooth have increased in cost over the years. The cost of questionable periodontal treatment may result in the patient's inability to afford the subsequent more predictable implant therapy. Multirooted endodontic therapy now approaches the cost of an implant surgery. When functional crown lengthening and endodontic posttreatment are also required, the fees are usually greater than those for extraction and implant insertion. Therefore, part of the equation of whether to extract or treat a tooth may also relate to the cost of the service provided. The natural molar tooth that requires endodontics, root amputation, post and core placement, and nevertheless a compromised root with a poor root surface area may be cost prohibitive for the service provided. In these cases, an implant in the site after tooth extraction is often less expensive and more predictable in the long term.

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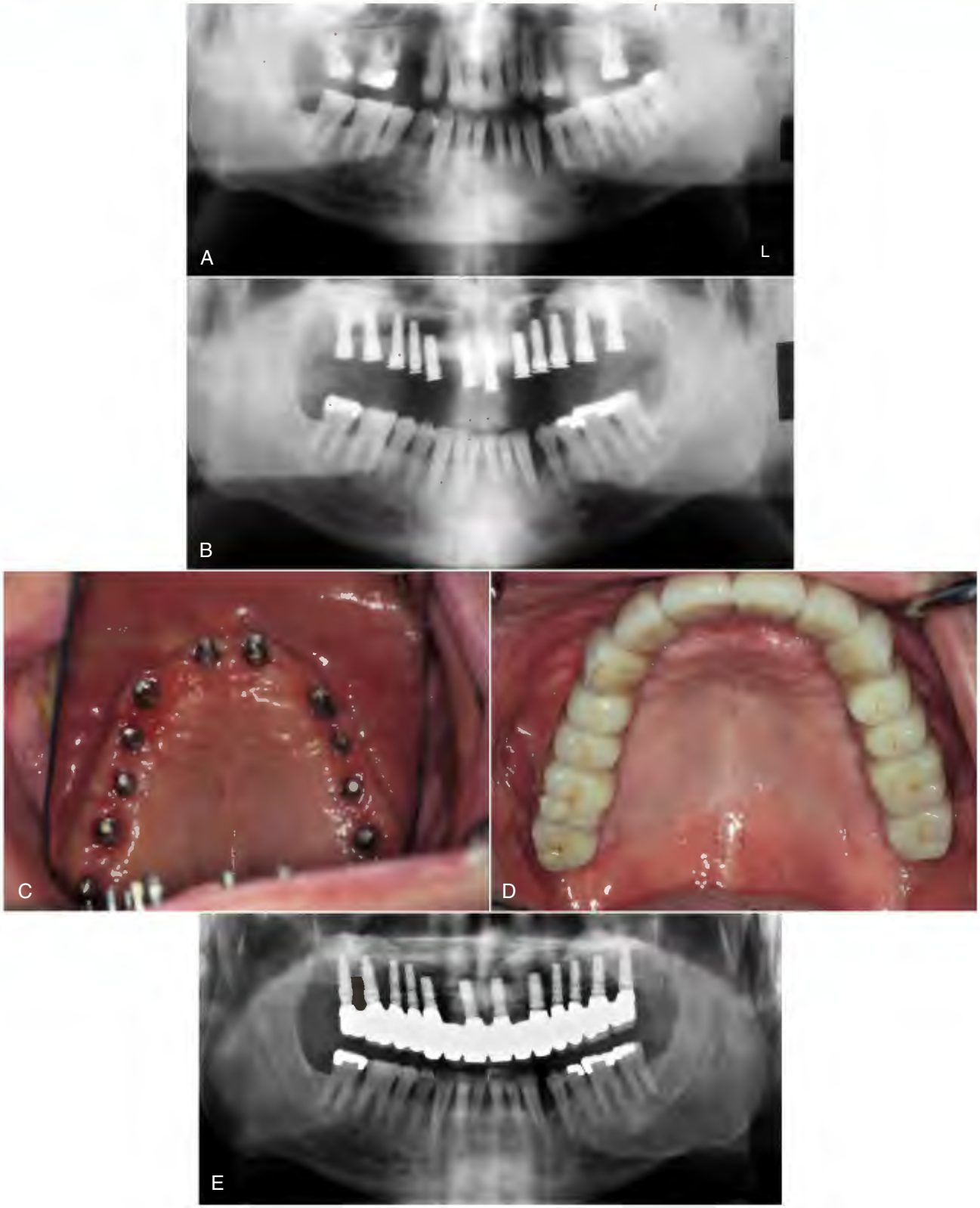


FIGURE 16-6. **A,** A panoramic radiograph of a patient with advanced periodontal disease in the maxillary arch and moderate disease in the mandibular arch. **B,** The maxillary teeth were extracted, and after initial healing, dental implants were inserted. **C,** An intraoral view of the implant abutments after initial healing. **D,** A full arch maxillary implant prosthesis from an intraoral view. **E,** A 10-year panoramic radiograph of the maxillary implants and prosthesis.

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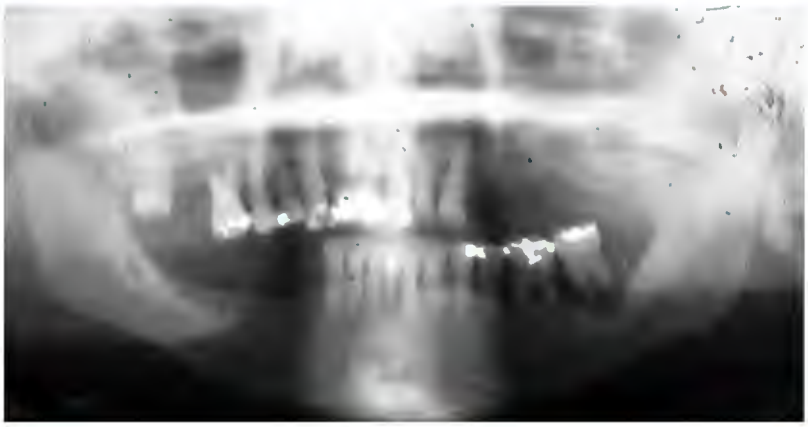


FIGURE 16-7. A panoramic radiograph of a patient with advanced periodontal disease in the maxilla and mandibular second molar. The mandibular second premolar and molar should also be considered for extraction because the remaining bone above the canal is still adequate for implants, and the periodontal prognosis is questionable.

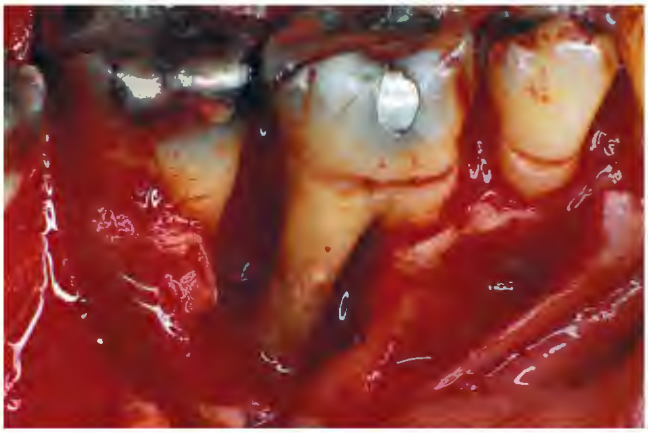


FIGURE 16-8. A mandibular first molar with a distal root resection generally has a success rate of 75%. Even when successful, the mesial root requires endodontic treatment, core, and crown, and the distal root needs replacement. Therefore, an implant or three-unit fixed partial denture is indicated. It is more cost effective to extract, implant, and fabricate one crown even when bone grafting is indicated.

BOX 16-1 Extract or Maintain Natural Tooth: 0-, 5-, and 10-Year Rule[12]

PROGNOSIS	PROTOCOL
>10 years	Keep the tooth and restore as indicated.
5–10 years	Independent implant restoration. If the natural tooth must be included with implants in the restoration, make it a "living pontic" by adding implants on each side and splint together.
<5 years	Extract the tooth and graft the site or consider an implant.

It should be noted that the recent trend to extract teeth with a good prognosis (with or without the need for endodontic or periodontal treatment) is discouraged.[15] Implants are not yet 100% predictable, and implants should not be substituted for natural teeth presenting a good or even a fair prognosis.

0-, 5-, or 10-Year Rule

The dentist evaluates the natural teeth for their quality of health with widely used prosthetic, periodontal, and endodontic indexes. After this is accomplished, the dentist may obtain an estimate of longevity and decide whether to extract or to treat and maintain the tooth following a 0-, 5-, or 10-year rule.[16] Box 16-1 summarizes the decision-making protocol involving a natural tooth. If the natural tooth has a favorable prognosis for more than 10 years, it is included in the treatment plan. The decision to use it or not as an abutment if it is adjacent to an edentulous space requires additional information, but few reasons support removal of the tooth to restore the partially edentulous patient.

If the natural tooth prognosis (after periodontal, endodontic, or restorative therapy when necessary) is in the 5- to 10-year range, the tooth should be maintained. If the tooth is adjacent to a missing tooth site, an independent implant-supported prosthesis is indicated. If the edentulous region does not provide sufficient implant support for an independent restoration, then placement of as many implants as possible around the tooth, with treatment alternatives that will permit removal of the tooth without sacrificing the restoration is indicated. For example, a coping may be placed on the tooth with a 5- to 10-year prognosis, and the tooth may act as "living pontic" in the final restoration, splinted to the adjacent implants on each side. Whether the tooth is missing or present does not modify the prosthesis. In this way, the prosthesis may be removed in the future, and the tooth may be extracted (if indicated). In this way, the prosthesis essentially is maintained without compromise.[17]

When teeth with copings are joined to implants, the copings on the teeth should be designed with a different path of insertion than the FPDs, and the coping should be cemented with permanent cement. The fixed implant prosthesis usually is cemented with a weaker (soft access) or temporary cement. Thus, the FPD path of removal differs from that of the natural tooth coping and, along with the weaker cement, allows the prosthesis to be removed while the coping remains permanently cemented on the tooth. The preparation of copings on natural teeth often requires additional removal of tooth structure to prevent overcontoured restorations and as a consequence may mandate endodontic therapy.[19]

When the estimate of survival of the natural tooth is in the 0- to 5-year survival (even after treatment), strong consideration is given to extraction of the tooth and implant replacement. As a consequence, the definitive treatment plan is delayed until after the extraction(s). For example, CT scans, mounted study casts, treatment prostheses, bone grafts (other than socket grafts), and so on are delayed until after the extraction sites

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FIGURE 16-9. **A,** A preoperative view of a patient with moderate bone loss from periodontal disease. **B,** The periodontal surgery and orthodontics successfully treated the patient, but a poor esthetic result was obtained. **C,** The anterior four teeth were extracted, bone grafted, and implanted. **D,** The final implant prosthesis is more esthetic than the original condition.

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initially heal because some intraoral conditions may be modified during this process. This treatment scenario may also often be faster and less costly over a 5- to 10-year period compared with maintaining a questionable tooth, especially when it is adjacent to an edentulous site.

Clinical Examples

If hygiene is poor in patients with a grade II or III furca involvement in molars, the tooth most often is considered in the 0- to 5-year category and is considered for extraction. This is especially considered when other teeth in the same quadrant are missing or hopeless or only 8 to 10 mm of bone remains between the crest of bone and the opposing landmark.[12,13,18]

Molars with grade I furcation involvement often are placed in the 5- to 10-year prognosis category. However, it should be noted that maxillary molars are at higher risk of furca complications, and even grade I furcations are lost 33% of the time within 5 years without treatment.[14] Mandibular molars have a 20% failure at this same reference time. Therefore, even when grade 1 furcas are diagnosed, aggressive treatment and good oral hygiene are necessary, especially if the tooth needs extensive restoration.

Patients with a potential structural failure after restoration (as a result of caries or trauma) and who require endodontics, functional crown lengthening, posts and cores are considered in the 0- to 5-year category. When the caries index is high, especially with poor hygiene, and multiple restorations have failed, extraction of those teeth may be indicated.

When the patient has an endodontic lesion of greater than 5 mm on a previously treated endodontic tooth (which appears within an acceptable technique), the tooth is considered for extraction. A tooth that has pain during function, despite radiographically successful endodontic therapy, may have a split root and is considered to be in the 0- to 5-year category.

The dentist should evaluate teeth especially next to an edentulous site. A natural tooth distant from the future implant restoration site is less likely to affect the implant reconstruction and alter the treatment sequences in this site. However, failure of a natural tooth adjacent to an implant site may cause failure of the adjacent implant and almost always (whether failure occurs or not) causes the restoration to be delayed and compromised. Therefore, if the practitioner is not sure whether the tooth is in the 0- to 5-year or 5- to 10-year category, the tooth adjacent to the future implant site more often should be considered to have the poorer prognosis.

Overall Evaluation

The evaluation of the remaining teeth should precede the definitive treatment plan to replace missing teeth. The existing conditions of the stomatognathic system outside the range of normal

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BOX 16-2 Overall Evaluation: Sequence of Treatment

Maxillary anterior tooth position
Occlusal vertical dimension
Mandibular incisal edge
Maxillary posterior plane
Mandibular posterior plane

should be evaluated and treated when necessary. This treatment may be performed before or in conjunction with implant therapy. As such, preimplant prosthodontic considerations are a vital phase of the overall treatment.

The existing teeth and arch relationships do not need to be perfect before implant surgery. However, because implant dentistry always concerns the replacement of teeth, at least a diagnosis and treatment plan should occur before implant placement. The goal is to identify and restore the prosthetic parameters of the remaining teeth within normal limits. The correct tooth positions should be first determined, so even if the total treatment time is extended over several years, at least each segment will aim toward a consistent goal. Too often the restoring dentist assumes the patient wants the cheapest or fastest treatment related to each treatment or to remain within the dental insurance limits of reimbursement. As a consequence, the mouth is restored one or two teeth at a time, fitting the restoration into the patient's present occlusal condition, which usually worsens over time and never improves on its own. As a result, after the patient has been in the same practice for several decades, the overall dentition is in poorer condition than when the patient started. Although it is easier to restore an entire mouth to the correct occlusal relationships at one time, it is also possible to obtain a similar result one tooth at a time as long as each step proceeds along the predetermined course of the overall treatment.

The preimplant prosthodontic evaluation of the patient's overall condition closely resembles traditional dentistry. When a restoring dentist first evaluates the prosthetic needs of a patient, an orderly process is required regardless of the current state of the dentition. In other words, regardless of whether the patient has all of his or her teeth or is missing all of the teeth, after the dentist accepts the responsibility of long-term professional guidance and treatment as necessary, a consistent approach to care is beneficial.

There are five initial elements of the existing teeth that should be assessed in sequence and treated when indicated. These elements are the maxillary anterior tooth position, existing occlusal vertical dimension (OVD), mandibular incisor edge position, maxillary occlusal plane, and mandibular occlusal plane[16] (Box 16-2). These elements are evaluated in a partially edentulous patient during the initial clinical examination and may also be assessed on mounted diagnostic casts (which may also serve for diagnostic wax-up procedures).

Maxillary Anterior Tooth Position

The position of the existing maxillary anterior teeth is first assessed. Most often these natural teeth are adequate in location and incisal edge position. However, if their position is undesirable for any reason, orthodontics or restoration may be indicated. At this point, the evaluation is not for the cosmetic aspects of tooth color or shape, but tooth position is scrutinized. If the maxillary incisor edge is modified in either the horizontal or vertical plane, all other four elements of the stomatognathic system may also need to be changed.

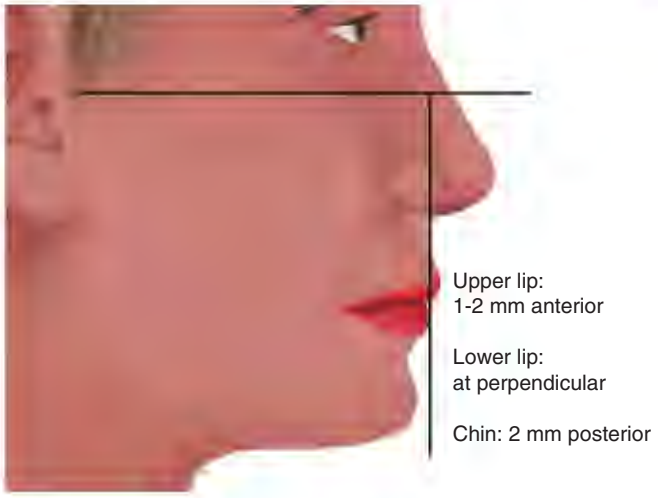


FIGURE 16-10. The labial position of the teeth is first evaluated relative to the support of the maxillary lip. A vertical line is drawn through the subnasal point and perpendicular to the Frankfort plane. The maxillary lip should be 1 to 2 mm anterior to this line, the lower lip even with the line, and the chin 2 mm behind the line.

The labial position of the maxillary anterior teeth is first determined with the lip in repose. This is primarily evaluated by overall support of the maxillary lip and its relationship to the balance of the face, especially in relation to the nose and presence or absence of a philtrum in the midline.[19–21] A perpendicular line from the Frankfort plane (plane passing through the lowest point in the floor of the left orbit and the highest point of each external auditory meatus of the skull) that touches the lower lip should most often find the maxillary lip 1 to 2 mm in front of this line and the chin 1 to 2 mm behind this line (at the correct OVD) (Figure 16-10).

When the teeth are positioned more labially, the vertical position of the lip is elevated. Likewise, a more palatal position of the maxillary anterior teeth results in a more inferior or extended position of the lip. If the labial or horizontal position of the lip is going to be altered, orthodontic therapy is the treatment of choice in a dentate premaxilla. On occasion, a prosthetic or surgical approach may be indicated with or without orthodontic treatment.

An alternative to increasing the length of the anterior teeth so more teeth are visible with the lip in repose may be to increase the thickness of the premaxillary alveolar ridge. This extra alveolar ridge thickness brings out the lip and raises the vermilion border. As a result, the teeth are not longer, but the border of the lip is higher. In addition, if the added width to the ridge is with autologous bone, replacing teeth with implants rather than pontics further helps to maintain the situation. The fuller maxillary lip may also look younger because vertical age lines may also be reduced.

In a completely edentulous patient, the labial flange of the patient's existing denture may be removed and the lip position evaluated before the completed treatment plan for a fixed restoration. When the lip needs the support of the labial flange for esthetics yet a fixed restoration is planned, onlay grafts with hydroxyapatite (HA), connective tissue, autograft, or allograft

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may be indicated to increase labial tissue thickness for proper lip support.

The next step in the evaluation process (when the labial position is acceptable) is the vertical position of the maxillary anterior teeth related to the lip in repose.[22] The maxillary canine is the key for this position.[23] Misch has suggested the canine tip be located ± 1 mm with the lip in repose regardless of the age or sex of the patient (Figure 16-11). A horizontal line drawn from one canine tip to the other should be level to the horizon. The central incisors are 1 to 2 mm longer than the horizontal plane to the canines.

The position of the maxillary central incisor, in relation to the maxillary lip and the age of the patient (a range of 8 mm) is much more variable than the position of the canine (a range of 3 mm).[23] The lip bow in the center of the upper lip rises several millimeters on some women and is barely obvious on others. The higher the lip bow, the more central incisor surface is seen on the patient regardless of age. Men rarely exhibit an exaggerated lip bow and therefore have a more consistent incisor edge to lip position. The canine position is closer to the corner of the lip and is not affected by the lip bow effect in the midline. As such, it is a more consistent position and usually corresponds to the length of the resting lip position from 30 to 60 years of age in both men and women.

No other region of the mouth should be restored until this position is corrected because it negatively influences the proper position of every other segment (e.g., OVD, mandibular anterior tooth position, and posterior planes of occlusion). If the patient is wearing a maxillary complete denture, the maxillary anterior tooth position is often incorrect. As a result of resorption of the premaxilla, the denture shifts apically and posteriorly following the bone loss pattern.



FIGURE 16-11. **A,** The vertical position of the maxillary anterior teeth is assessed. The ideal position is determined by the canine to lip in repose position: a horizontal line is drawn from canine tip to canine tip, and the central incisors are 1 to 2 mm longer. **B,** This position is consistent (within 1 mm) regardless of the age or sex of the patient.

Arch relationships are often affected by resorption patterns in edentulous ridges. The anterior and posterior edentulous maxilla resorbs toward the palate after tooth loss.[24] The width of the alveolar ridge decreases 40% within a few years, primarily at the expense of the labial plate. Consequently, implants are often placed lingual to the original incisal tooth position. The final restoration is then overcontoured facially to restore the incisal two thirds in the ideal tooth position for esthetics. This results in a cantilevered force on the implant body. The maxilla is affected more often than the mandible because the incisal edge position in the esthetic zones cannot be modified and is dictated by esthetics, speech, lip position, and occlusion. Anterior cantilevered crowns from maxillary anterior implants often require additional implants splinted together and an increase in the anteroposterior (A-P) distance between the most distal to most anterior implant positions to compensate for the increased lateral loads and moment forces to the premaxillary implants, especially during mandibular excursions.

The maxillary anterior horizontal and vertical tooth positions are evaluated before any other segment of the arches, including the OVD. If the maxillary anterior teeth are significantly malpositioned, the clinician should obtain further diagnostic studies, such as a cephalometric radiograph, to determine the relationship of the maxilla to the cranial base. The patient may have unfavorable skeletal relationships (vertical maxillary excess or deficiency). If the position of the natural maxillary anterior teeth is undesirable for any reason, orthodontics, orthognathic surgery, or restoration may be indicated. After the position of the maxillary anterior teeth is acceptable, the next prosthetic step is either the evaluation of the OVD or maxillary occlusal plane.

Existing Occlusal Vertical Dimension

To determine the anterior position of the mandible and the crown height space (CHS) of the maxilla, mandible, or both, the overall issue of OVD must be addressed. The patient's existing OVD should be evaluated early in an implant prosthetic treatment plan because any modification will significantly modify the overall treatment. Not only will a change in OVD require at least one full arch to be reconstructed, but it will also affect the CHS and therefore the potential number, size, position, and angulation requirements of the implants.

The OVD is defined as the distance between two points (one in the maxilla and the other directly below in the mandible) when the occluding members are in contact.[25] This dimension requires clinical evaluation of the patient and cannot be evaluated solely on the diagnostic casts.

The determination of the OVD is not a precise process because a range of dimensions is possible without clinical symptoms.[26,27] At one time, it was believed OVD was very specific and remained stable throughout a patient's life. However, this position is not necessarily stable when the teeth are present or after the teeth are lost. Long-term studies have shown that this is not a constant dimension and often decreases over time without clinical consequence in dentate, partially edentulous, and completely edentulous patients. A completely edentulous patient often wears the same denture for more than 10 years,

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during which time the OVD is reduced 10 mm or more without symptoms or even patient awareness.

The OVD may be altered without the symptoms of pain or dysfunction, especially when the condylar disc assembly is healthy. However, this is not to say that altering the OVD has no consequence. Rather, a change in OVD affects the esthetics of the chin to face position and the CHS. As such, it may affect the biomechanics of the support system of a prosthesis. Any change in the OVD will modify the horizontal dimensional relationship of the maxilla to the mandible. Therefore, a change in OVD will modify the anterior guidance, range of function, and facial esthetics.[28]

The most important effect of OVD on tooth (implant) loading may be the effect on the biomechanics of anterior guidance. The more closed the OVD, the farther forward the mandible rotates and the more skeletal class III the chin appears (Figure 16-12). A bruxing patient who had a skeletal class I tooth position may develop an end-to-end incisal position along with a closed OVD (Figure 16-13). Because this type of patient has lost incisal guidance, the continued bruxism will more rapidly wear the anterior and posterior teeth. Hence, restoring OVD and incisal guidance is paramount to any oral reconstruction.

In a skeletal class II, division 2 patient, the more closed the OVD, the steeper the anterior guidance and the greater the vertical overbite of the anterior teeth. When the OVD is opened, there may be no anterior contact in occlusion. Hence, orthodontics or repositioning the lower anterior teeth may be necessary to restore incisal guidance. Anterior guidance is necessary to maintain incisal guidance during mandibular excursions to decrease the risk of posterior interferences.

The conditions of an increased vertical overbite will increase the forces to the anterior teeth (or implants). Hence, the OVD should be increased in a skeletal class II division II patient. Increasing the OVD has the opposite effect on the incisal guidance. In general, for a dentate patient, it may be more precarious to close an OVD than to open it because the resulting anterior rotation of the mandible will position mandibular incisor teeth facially in a closer relationship to the maxillary teeth in centric occlusion.

In completely edentulous patients restored with fixed implant prosthodontics, a change in OVD in either direction affects biomechanics. Opening the OVD and decreasing the incisal guidance with a resulting bilaterally balanced occlusion may increase forces placed on posterior implants during mandibular excursion. Closing the OVD may increase the forces to anterior implants during any excursion. On occasion, a change in the OVD may also affect the sibilant sounds by altering the horizontal position of the mandible.

The OVD is almost never naturally too large and, unless some manufactured interference has been created, it is within clinical guidelines or collapsed. Therefore, the restoring dentist most often should determine whether the OVD needs to be increased. In other words, the existing OVD in a patient without symptoms of the temporomandibular joint (TMJ) is a position to start the evaluation, not one that necessarily must be maintained.

According to Kois and Phillips, three situations primarily mandate the modification of the OVD: (1) esthetics, (2) function, and (3) structural needs of the dentition.[28] Esthetics is related to OVD for incisal edge positions, facial balance, and position of the chin and the occlusal plane. Function is related

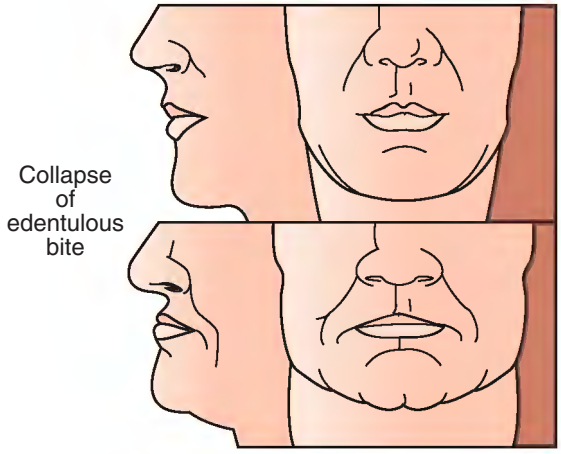


FIGURE 16-12. The closed *(bottom)* occlusal vertical dimension (OVD) rotates the chin farther forward than the original position *(top)*.





FIGURE 16-13. **A,** A bruxing patient may wear the anterior teeth and end up with an edge to edge occlusion and a closed occlusal vertical dimension (OVD). The more closed the occlusal vertical dimension, the farther forward the mandibular teeth occlude. **B,** This same patient has a closed OVD, and the chin is anterior to the lips.

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to the canine positions, incisal guidance, and angle of load to teeth or implants. Structural requirements are related to dimensions of teeth for restoration while maintaining a biological width, or the CHS, which may modify biomechanical force.

Methods to Evaluate Occlusal Vertical Dimension

In traditional prosthodontics, a range of techniques has been described to establish the OVD. Whereas objective methods use facial dimension measurements, subjective methods rely on esthetics, resting arch position, and closest speaking space. There is no consensus on the ideal method to obtain the OVD. Therefore, this dimension is part art form and part science. And yet it is critical enough that a final treatment plan should not be rendered until a determination has been made relative to this dimension.

The subjective methods to determine OVD include the use of resting interocclusal distance and speech-based techniques using sibilant sounds.[29,30] Niswonger proposed the use of the interocclusal distance ("freeway space"), which assumes that the patient relaxes the mandible into the same constant physiologic rest position.[27] The practitioner then subtracts 3 mm from the measurement to determine the OVD. Two observations conflict with this approach. First, the amount of freeway space is highly variable in the same patient, depending on factors such as head posture, emotional state, presence or absence of teeth, parafunction, and time of recording (greater in the morning). Second, interocclusal distance at rest varies 3 to 10 mm from one patient to another. As a result, the distance to subtract from the freeway space is unknown for a specific patient. Therefore, the physiologic rest position should not be the primary method to evaluate OVD. However, it should be evaluated after the OVD is established to ensure a freeway space exists when the mandible is at rest.

Silverman stated that approximately 1 mm should exist between the teeth when making an *S* sound.[31] Pound further developed this concept for the establishment of centric and vertical jaw relationship records for complete dentures.[32,33] Although this concept is acceptable, it does not correlate to the original OVD of the patient. Denture patients often wear the same prosthesis for more than 14 years and during this time lose 10 mm or more of their original OVD. Yet all of these patients are able to say "Mississippi" with their existing prosthesis. If speech were related to the original OVD, these patients would not be able to pronounce the *S* sound because their teeth would be more than 11 mm apart. But to say the letter "S" with the correct sound, the teeth must be approximately 1 mm apart. Therefore, the speaking space should not be used as the only method to establish OVD. After the OVD has been determined, the speaking space should be observed, and the teeth should not touch during sibilant sounds. On occasion, a short adjustment period of a few weeks may be required to establish this criterion. Therefore, on occasion, a transitional prosthesis should be used to evaluate this position in case it must be modified before the final restoration.

Kois and Phillips have noted that the subjective method of esthetics to establish an OVD is the most difficult to teach inexperienced dental students and therefore is least likely to be initially addressed when teaching the concepts of determining OVD.[28] However, experienced clinicians often value this method more than any other to assess OVD.

After the position of the maxillary incisor edge is determined, the OVD influences esthetics of the face in general. Facial dimensions are objective (because they are measured) and directly related to the ideal facial esthetics of an individual. They can be easily assessed regardless of the clinician's experience.[34–42] This objective evaluation is usually the method of choice to initially evaluate the existing OVD or establish a different OVD during prosthetic reconstruction. In addition, it may be performed without the need of additional diagnostic tests.

Facial measurements can be traced back to antiquity, when sculptors and mathematicians followed the *golden ratio* for body and facial proportions as described by Plato and Pythagoras. The golden ratio relates to the length and widths of objects in nature as 1 to 0.618. It was observed that biologic features follow this ratio. Architectural proportions often follow the golden ratio because it is considered the most esthetically appealing to the human eye.[35–37] Leonardo da Vinci later contributed several observations and drawings on facial proportions, which he called *divine proportions*.[39] He observed the distance between the chin and the bottom of the nose (i.e., OVD) was a similar dimension as (1) the hairline to the eyebrows, (2) the height of the ear, and (3) the eyebrows to the bottom of the nose—and each of these dimensions equaled one third of the face.

Many professionals, including plastic surgeons, oral surgeons, artists, orthodontists, and morticians, use facial measurements to determine OVD. Misch reviewed the literature and found that many different sources reveal many correlations of features that correspond to the OVD[40,41]:

1. The horizontal distance between the pupils
2. The horizontal distance from the outer canthus of one eye to the inner canthus of the other eye
3. Twice the horizontal length of one eye
4. Twice the horizontal distance from the inner canthus of one eye to the inner canthus of the other eye
5. The horizontal distance from the outer canthus of the eye to the ear
6. The horizontal distance from one corner of the lip to the other following the curvature of the mouth (cheilion to cheilion)
7. The vertical distance from the external corner of the eye (outer canthus) to the corner of the mouth
8. The vertical height of the eyebrow to the ala of the nose
9. The vertical length of the nose at the midline (from the nasal spine [subnasion] to the glabella point)
10. The vertical distance from the hairline to the eyebrow line
11. The vertical height of the ear
12. The distance between the tip of the thumb and the tip of the index finger when the hand lays flat with the fingers next to each other (Figure 16-14).

All of these measurements do not correspond exactly to each other, but they usually do not vary by more than a few millimeters (with the exception of the vertical height of the ear) when facial features appear in balance. An average of several of these measurements may be used to assess the existing OVD. In a clinical study by Misch, the OVD was often slightly larger than the facial measurements listed (more in men than women) but was rarely a smaller dimension.[41] The subjective criteria of pleasing esthetics may then be considered after the facial dimensions are within balance to each other.

Esthetics are influenced by OVD because of the relationship to the maxillomandibular positions. The smaller the OVD, the more skeletal class III the jaw relationship becomes; the greater the OVD, the more skeletal class II the relationship becomes. The maxillary anterior tooth position is determined first and is

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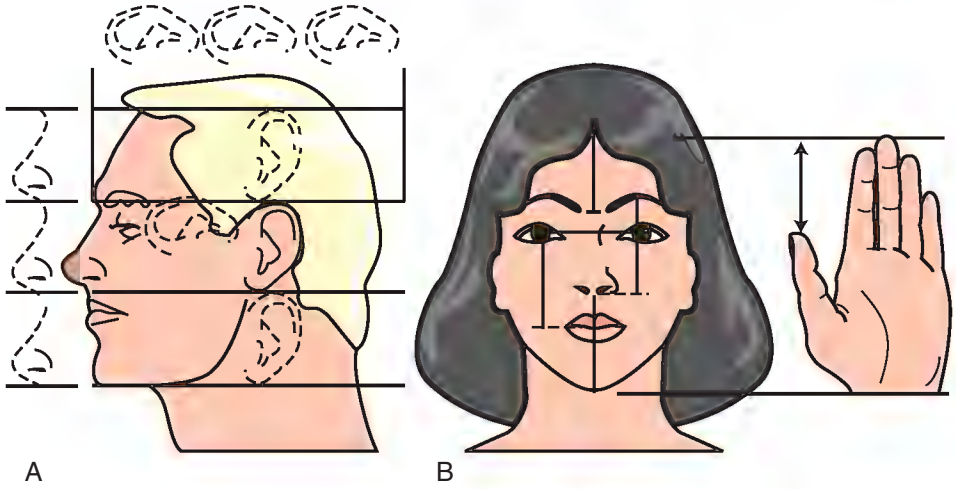


FIGURE 16-14. **A,** The occlusal vertical dimension (OVD) may initially be evaluated by objective measurements, comparing facial dimensions with the existing OVD. Leonardo da Vinci described divine proportions in the following way: "The distance between the chin and the nose and the hairline and the eyebrows are equal to the height of the ear and a third of the face. From the outer canthus of the eye to the ear, the distance is equal to the height of the ear and to one-third of the face height." **B,** In addition, facial height (from chin to hairline) is equal to the height of the hand, and the nose to chin is the same length as the distance between the tip of the thumb and the tip of the index finger.

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most important for the esthetic criteria of the reconstruction. Alteration of the OVD for esthetics rarely includes the maxillary tooth position. For example, the OVD position may be influenced by the need to soften the chin for a patient with a large mental protuberance by increasing the OVD.

Radiographic methods to determine an objective OVD are also documented in the literature. Tracings on a cephalometric radiograph are suggested when gross jaw excess or deficiency is noted. Such conditions may stem from vertical maxillary excess; vertical maxillary deficiency; vertical mandibular excess (long chin); vertical mandibular deficiency (short chin); or apertognathia or skeletal class II, division 2 (deep bite) situations. Orthodontic treatment planning of a dentate patient often includes a lateral cephalogram and may be used to evaluate OVD (glabella–subnasale, subnasale–menton). The same measurements may be performed on an edentulous patient.[43,44]

After the OVD satisfies the esthetic requirement of the prosthetic reconstruction, it may still be slightly refined. For example, the OVD may be modified to improve the direction of force on the anterior implants. In addition, on occasion, anterior mandibular implants are too facial to the incisal edge position, and increasing the OVD makes them much easier to restore. Therefore, because the OVD is not an exact measurement, the ability to alter this dimension within limits may often be beneficial.

Combination Syndrome

The evaluation of the pretreatment OVD is also very important for a patient wearing a complete maxillary denture opposing a partially edentulous mandible, especially in the case of edentulous posterior segments that are not compensated by a removable partial denture (Kennedy-Applegate class I). Under these conditions, a combination (Kelly) syndrome may be present and is especially noteworthy if the OVD is within normal limits.[45] The clinical symptoms include (1) maxillary incisors of the denture positioned up and rotated back from ideal, (2) lower natural anterior teeth overerupted and beyond the mandibular occlusal plane, (3) maxillary horizontal occlusal plane tilted apically in the anterior and occlusally in the posterior regions, (4) enlarged tuberosities encroaching on the mandibular interarch space, (5) maxillary palatal hyperplasia, and (6) highly mobile tissue in the premaxilla. In addition, because the mandibular posterior teeth have been missing for many years to develop these clinical conditions of this syndrome, there is a lack of posterior bone in the mandible to place endosteal implants (Figure 16-15).

The proper maxillary incisal edge position and OVD are especially critical for these patients because of the incidence of mandibular incisor extrusion beyond the maxillary occlusal plane. The extrusion is usually accompanied by the alveolar process. To position the maxillary incisors properly, the mandibular anterior teeth must be repositioned at the proper incisal plane. Orthodontic intrusion (often with implants that are TADs) or enamel plasty and endodontic therapy and crown lengthening procedures are necessary to precede the restorations on the lower arch to obtain a retentive and esthetic restoration. On occasion, the remaining roots of the mandibular anterior teeth are too short to consider for long-term prognosis after orthodontics or the crown lengthening is performed. Under these conditions, extraction of the mandibular anterior teeth, alveoloplasty, and implant placement may be indicated.

When the residual arch shape after extraction is ovoid to tapered, five anterior implants may be adequate to serve as support for a full-arch implant–supported restoration. Therefore, the implants replace the teeth extracted from overeruption, and they can also replace the posterior missing teeth. This is usually very helpful because long-term edentulous posterior segments are usually deficient in bone volume. Thus, this approach eliminates the need for posterior bone grafts to restore the lower arch with a fixed implant–supported restoration.

Mandibular Incisor Edge Position

After the maxillary incisal edge and the OVD are deemed clinically acceptable, the position of the lower anterior teeth

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FIGURE 16-15. **A,** A combination syndrome describes the clinical conditions occurring when a maxillary denture opposes mandibular anterior teeth and no partial denture. The mandibular teeth overerupt as the maxillary denture seats up in the anterior and down in the posterior. **B,** The premaxillary bone is lost and the tuberosities enlarged.

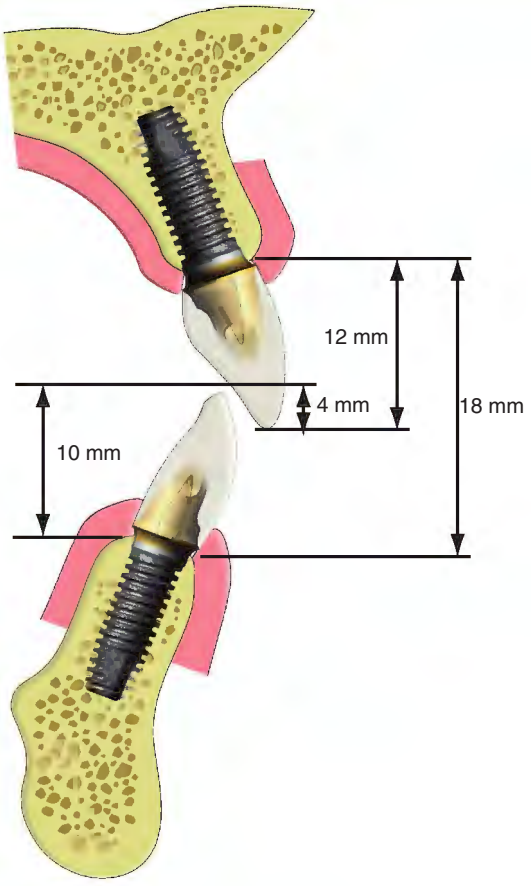


FIGURE 16-16. A full-arch maxilla and mandibular implant prosthesis or maxillary denture or overdenture does not have anterior centric contacts in centric occlusion. In addition, the vertical overbite is reduced to 3 to 4 mm. The crown height space in the anterior region is measured from the crest of the bony ridge to the incisal edge.

is evaluated. When natural teeth are present or when a fixed prosthesis supported by natural teeth is planned in the anterior region, the mandibular teeth incisal edge should contact the lingual aspect of the maxillary anterior natural teeth at the desired OVD position.[46] In a full-arch maxillary and mandibular overdenture, implant prosthesis, or maxillary denture, no anterior contact in centric relation (CR) occlusion is designed.[47] A vertical overbite with natural maxillary anterior teeth is usually in the range of 5 mm. When an implant prosthesis is planned in both anterior jaw regions, a reduced 3- to 4-mm vertical overbite is beneficial (Figure 16-16).

The incisal guidance is defined as the influence of contacting surfaces of the mandibular and maxillary anterior teeth on mandibular movements.[25] The incisal guide angle is formed by the intersection of the plane of occlusion and a line within the sagittal plane determined by the incisal edge of the maxillary and mandibular central incisors in maximal intercuspation (MI). It is responsible for the amount of posterior tooth separation during mandibular excursions; to do so, it should be steeper than the condylar disc assembly (Christensen's phenomenon). Therefore, any planned prosthesis and associated compensating curves should be developed within these confines. If not, the maxillomandibular arch position may be improper (i.e., in a skeletal class II, division I patient), and the posterior teeth may exhibit lateral contacts during mandibular excursions. Under these conditions, the masseter and temporalis muscles do not reduce their contraction force during these jaw movements (as they do when only anterior teeth occlude in excursions), and the strong muscles of mastication continue to contract and place an increased force on the entire stomatognathic system.

An anterior cantilever on implants in the edentulous mandibular arch may correct an Angle's skeletal class II, division I jaw relationship. The maxillary anterior teeth support the lower lip at rest in both Angle's skeletal class I and class II relationships. A traditional complete mandibular denture cannot extend beyond the anatomical support or neutral zone of the lips without decreasing stability of the prosthesis. However, with implants, the denture teeth may be set in a more ideal esthetic and functional position.[16]

The anterior cantilever in the class II mandible depends on adequate implant number and A-P distance between the splinted implants. To counteract the anterior cantilever effect, the treatment plan should provide increased implant support by increasing the surface area by number, size, design, or A-P implant position. In these cases, a RP-4 prosthesis, designed to prevent food impaction, may facilitate daily care compared with a FP-3 prosthesis.

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The palatal resorption pattern of the maxilla, paired with the anterior rotation of the mandible from decreased OVD found in long-term, complete denture patients may mimic an Angle's skeletal class III relationship on a lateral cephalometric radiograph. However, in this condition, class III mandibular mechanics do not apply (primarily vertical chewers with little to no anterior excursions during mastication or parafunction). On the contrary, these patients exhibit a full range of mandibular excursions and can contribute significant lateral forces on the maxillary restoration, which is cantilevered off the implant base to obtain a skeletal class I esthetic restoration. Therefore, additional splinted implants are suggested in the maxilla with the widest A-P distance available. This usually requires sinus grafts and posterior implants in the first or second molar position splinted to the anterior implant support.

The incisal guidance is often evaluated on mounted diagnostic models. A steep incisal guidance helps in avoiding posterior interferences in protrusive or lateral movement. However, the steeper the incisal guide angle, the greater force applied to anterior teeth and crowns. This may present a significant problem for an anterior single tooth implant replacement. On occasion, this occurs because the natural tooth is lost as a result of severe parafunction on a tooth with a steep incisal guidance (usually from fracture after endodontic therapy).

On the other hand, if the existing incisal guidance is too shallow and posterior contracts exist in excursions, it may be necessary to plan recontouring or prosthetic restoration of posterior teeth that exhibit contact during excursions. For example, a mesially tipped mandibular third molar is often in this situation and may greatly compromise the implant placed in a maxillary second molar region.

Existing Occlusal Planes (Posterior Maxillary and Mandibular Planes of Occlusion)

After the maxillary anterior teeth position, OVD, and mandibular anterior teeth position are deemed acceptable, the horizontal occlusal planes are evaluated in the posterior regions of the mouth. The maxillary occlusal plane may also be determined immediately after the maxillary incisal edge position is correct. One side of the arch should be parallel to the other. When it is not, one ramus may be longer than the other or one side may have extruded (exfoliated) from the lack of opposing dentition.[46] Their position related to the curves of Wilson (mediolateral) and Spee (A-P) and to each other should allow harmonious occlusion with maximum occlusal interdigitation and canine or mutually protected occlusion in excursions.

In complete denture fabrication, the posterior occlusal plane is often established by a horizontal line drawn from the tip of the mandibular canine to a position half the height of the retromolar pad.[29] The posterior position of the plane (half up the retromolar pad) is often parallel to line from the ala of the nose to the bottom of the ear. In other words, it is well below Camper's plane.[16] Ideally, the maxillary posterior occlusal plane should be parallel to the Camper's plane (i.e., to the midtragus to ala position) (Figure 16-17).

The maxillomandibular relationships are assessed in the vertical, horizontal, and lateral planes. An improper skeletal position may be modified by orthodontics, surgery, or prosthetics. It is far better to discuss these options with the patient before implant surgery because the implant placement may compromise the final prosthetic result if the arch positions are altered after implant insertion. Compromises of the final result should be discussed with patients when orthognathic surgery or orthodontic therapy is declined by patients with skeletal discrepancies.

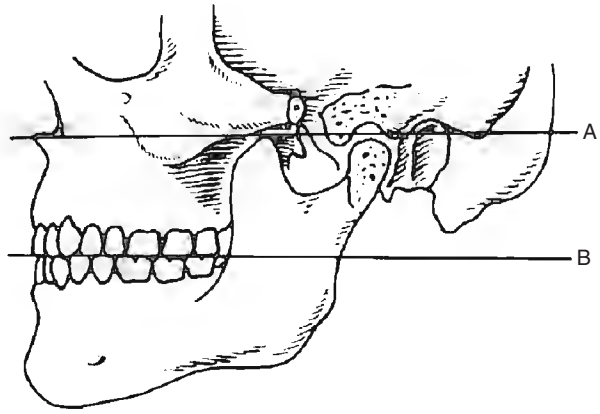


FIGURE 16-17. The ala–tragus line (Camper's plane) (line A) is parallel to the occlusal plane of the maxillary teeth (line B).

The CHS in the edentulous site may be significantly reduced as a result of posterior extrusion or exfoliation. The implant drills and implant body insertion often require a posterior CHS of more than 8 mm from the ideal plane of occlusion, so the handpiece, drill, or implant may be inserted at the correct position and angulation.

The natural dentition of a partially edentulous ridge also must be carefully examined and often needs modification before surgical placement of the implants, especially in the posterior regions of the mouth. The remaining posterior teeth have often drifted or tipped into the edentulous site as a result of improper or missing opposing occlusal contacts.

Odontoplasty, endodontic therapy, functional crown lengthening, and crowns are indicated to remedy tipping or extrusions (exfoliation) of adjacent or opposing natural teeth. A pretreatment diagnostic wax-up is suggested to evaluate the needed changes before implant placement when these conditions exist. A proper curve of Spee and curve of Wilson are also indicated for proper esthetics and are reproduced in the compensating curves for complete denture fabrication (Figure 16-18).

The occlusal plane correction seems like an obvious step in the patient dental evaluation. However, an evaluation of three-unit fixed prostheses in several large dental laboratories revealed most restoring dentists prepare crowns or three-unit fixed prostheses without correcting the opposing occlusal plane. Apparently, the existing occlusal plane is not routinely evaluated before the fabrication of the prosthesis, or the patient and doctor have decided to compromise the final result and restore the missing teeth to the preexisting poor position. Instead, the restoring dentist should highlight to the patient the extrusion or exfoliation of the surrounding teeth, which is often obvious on a panoramic radiograph or diagnostic casts, after it is noted. The need to restore the missing tooth sooner rather than later is apparent to the patient because the teeth are already shifting as a result of the arch collapse. If the patient cannot afford the complete treatment plan related to the missing teeth, the opposing arch with the poor occlusal plane should be treated first, not the arch with the missing tooth. In this way, opposing quadrants will ultimately be restored to a proper relationship. Of course, the missing tooth should be replaced before the occlusal plane is compromised again.

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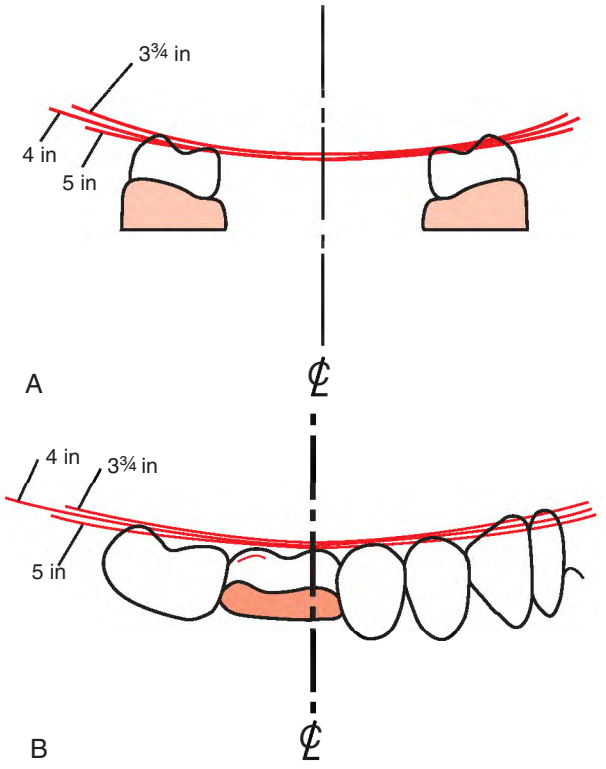


FIGURE 16-18. **A,** The curve of Spee is similar to the radius of a 4-inch sphere and is related to skull size. **B,** The curve of Wilson is evaluated before reconstruction in the region. The radius of the average curve also corresponds to the radius of a 4-inch sphere.

An occlusal plane analyzer may be used on diagnostic casts to evaluate pretreatment conditions and assist in intraoral occlusal plane correction. Occlusal analyzers may be fabricated in several sizes. The average size corresponds to a 4-inch sphere and provides a starting point for ideal curves of Wilson and Spee. Any discrepancy observed on the cast may be corrected in the mouth. Misch has designed a laboratory-assisted template with this intent.[48] In the laboratory, a vacuum or press fit of an acrylic shell is prepared over the cast. The occlusal plane analyzer is then used to evaluate and correct an improper occlusal plane. A handpiece is used to grind the acrylic shell and protruding occlusal cusps on the duplicate diagnostic cast. The clear acrylic shell is then taken intraorally and inserted over the teeth. Any cusp extending through the acrylic shell is recontoured to the level of the surrounding acrylic. As such, the occlusal plane is rapidly corrected to an ideal condition (Figure 16-19).

The partially edentulous posterior ridge with facial resorption and outside the range of esthetics during smiling or speech may require implant insertion more medial in relation to the original central fossa of the natural dentition. Enameloplasty of the stamp cusps of the opposing teeth is often indicated to redirect occlusal forces over the long axis of the implant body and may be determined with the diagnostic casts and modified in the mouth before the opposing arch impression and bite registration at the final impression appointment.[47] Then, at the metal try-in or final prosthesis delivery, the final modifications of the opposing dentition may be made.

Transversal arch relationships include the existence of posterior crossbites, which occur frequently in implant dentistry, especially when they are out of the high lip line esthetic zone. Edentulous maxillary posterior arches resorb palatally and medially after tooth loss. Sinus grafts can restore available bone height, but the ridge still remains medial to the opposing mandibular tooth central fossa. This is especially pronounced when opposing a Misch-Judy division C–h or moderately atrophic mandible because the mandible widens after the residual alveolar ridge resorbs. For example, when mandibular implants are used in division C–h bone volume for implant support opposing a complete denture, the posterior teeth may be set in crossbite (especially when out of an esthetic zone) to decrease the moment forces developing on the maxillary posterior teeth, causing denture instability.

Specific Criteria

After the five elements of the existing teeth (restorations) have been evaluated and modified when necessary, several other conditions may modify and hinder the course of implant treatment if overlooked. These conditions should be considered before the final treatment plan is presented to the patient and include the following:

1. Active lip lines
2. Existing occlusion
3. CHS
4. TMJ status
5. Existing prostheses
6. Arch form (ovoid, tapering, square)
7. Soft tissue evaluation of edentulous sites

A large number of these items may be evaluated on the mounted diagnostic casts. Others require the direct observation of the patient. A checklist is helpful to methodically gather the data, which may directly influence the treatment plan.

Active Lip Lines

Teeth Number

Active lip positions are evaluated, not only the lip in repose. Maxillary high lip line during smiling, and mandibular low lip line during speech are observed in relation to the teeth and the surrounding soft tissue (the soft tissue drape). The lip line positions are especially noted when teeth within the "esthetic zone" are replaced or restored.

The number of teeth displayed in the horizontal dimension in a broad smile is first assessed and is variable[49] (Figure 16-20). Approximately 7% of patients only show the anterior six teeth in the maxilla or mandible when smiling or during speech. The first premolar is more often seen in the maxilla during smiling and represents 48.6% of the population and is the largest group of patients. The second premolar can be seen in 40.6% of the population. The first molar can be seen in 3% of the patients and is the smallest group (Figure 16-21). When the teeth are in the esthetic zone, the facial contours of the teeth should not be compromised. Bone augmentation may be necessary to insert the implants in a more ideal position, so facial ridge laps or cantilevers are not necessary.

The active lip positions in the vertical position are also highly variable but in general are related to the patient's age and sex. In general, older patients show less maxillary teeth during smiling but demonstrate more mandibular teeth during sibilant sounds.[49] Women show more maxillary teeth during smiling, and younger patients show more teeth than older patients. Men show more mandibular teeth during speech.[50] A man shows fewer teeth than a woman of the same age.

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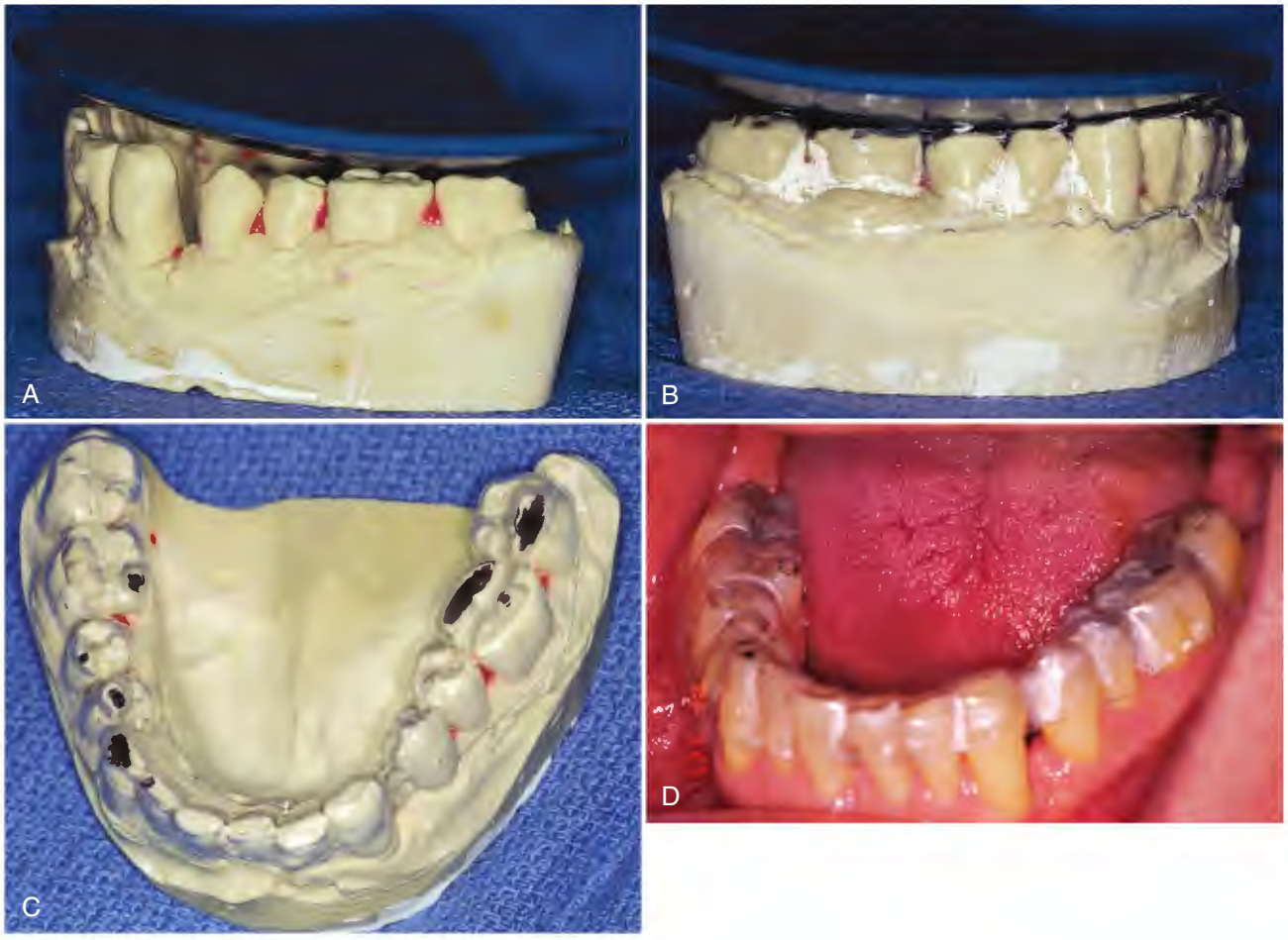


FIGURE 16-19. **A,** A Misch Occlusal Analyzer is fabricated in three sizes as follows: ¾-inch, 4-inch, and 5-inch sphere. The occlusal plane of the patient is evaluated before the restoration of the opposing arch. **B,** A press-form (vacuum) shell is placed over a duplicate study cast of the patient. The template and teeth are adjusted so the casts follow the Misch Occlusal Analyzer more accurately. **C,** The areas on the cast are marked to indicate the areas to modify intraorally. The modified template is inserted in the mouth, and the dental regions above the template are recontoured. **D,** Intraorally, the correction is performed using the template.



FIGURE 16-20. The horizontal depth of a smile is highly variable and should be evaluated relative to the teeth and the soft tissue drape before developing a treatment plan.

Maxillary High Lip Line

The vertical translation of the maxillary lip during smiling is variable. The maxillary high lip line is determined while the patient displays a natural, broad smile. There are three vertical categories of maxillary high lip lines: low, average (ideal), and high ("gummy") (Figure 16-22). The low active lip line displays no soft tissue around the teeth (interdental papilla or gingiva above the teeth) during smiling (Figure 16-23). The active high lip line demonstrates all of the interdental papillae and any of the soft tissue above the cervices of the teeth. This is slightly different than the high lip position described in "esthetic dentistry," which most often used a 2-mm cervical soft tissue guideline.[49] This modification is necessary with implant prostheses

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because the cervical soft tissue will need to be replaced or the teeth will often appear too long (Figure 16-24). The clinical characteristics of the average or ideal esthetic smile include crown exposure, any of the interdental papilla, and no gingival exposure over the cervicals of the teeth (maxillary lip at the free gingival margin of the centrals and canines during smiling) (Figure 16-25).

Approximately 70% of the adult population has a high smile line within a few millimeters of the free gingival margin, and approximately 60% of the population shows interdental papillae but no cervical tissue[49] (Figure 16-26). In implant restorations, if any of the soft tissue (e.g., interdental papilla or cervical tissue) is displayed, the implant surgery, bone graft, or restoration must also replace soft tissue. The FP-1 prosthesis in implant dentistry attempts to reproduce a normal crown contour. However, with a high lip position during smiling, this goal must also make sure the soft tissue drape is ideal around the crown. As a consequence, the esthetic requirements are much more demanding and often mandate additional surgical steps to enhance the soft and hard tissues before the crown restoration. The selection of a FP-2 and a FP-3 fixed prosthesis is often based solely on the evaluation of the high lip line. A FP-2 prosthesis is easier to fabricate because it does not require gingiva-colored restorative materials in the prosthesis, but it can only be used when no soft tissue is exposed during smiling or speech.

Approximately 30% of men and 12% of women older than the age of 35 years have a low lip line and do not show the interdental papilla when smiling (average of 20%)[49] (see Figure

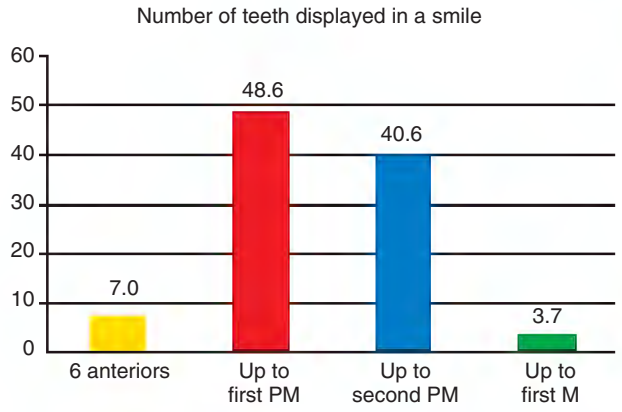


FIGURE 16-21. The number of teeth displayed in a smile most often includes the first and second premolar (PM) region.



FIGURE 16-22. The vertical translation of the maxillary lip is variable and classified as low **(A),** average **(B),** and high **(C).**



FIGURE 16-23. **A,** A full-arch maxillary FP-2 implant prosthesis. **B,** The low lip line during smiling does not show any of the soft tissue drape.

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FIGURE 16-24. **A,** A high smile line exposes all of the clinical crown, the interdental papillae, and the full gingival margin above the teeth. **B,** This patient has a full-arch implant–supported FP-3 porcelain–metal prosthesis.



FIGURE 16-25. **A,** An ideal high smile line exposes the clinical crown and the interdental papillae. **B,** The patient in **A** has a full-arch implant–supported FP-3 pink and white porcelain–metal prosthesis (shown here in a retracted position).

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16-26). This percentage increases to 40% behind the maxillary canine and 70% behind the first premolar. In these patients, the soft tissue drape does not require a primary focus and can often be compromised with a FP-2 restoration when the patient is notified before treatment. However, an average to high lip position during smiling contraindicates this restoration type because of poor cervical esthetics.

A gummy or high smile line occurs in 14% of the young female patients and 7% of young male patients and in fewer of older patients[48] (see Figure 16-26). The normal clinical crown height is 10 mm for the central incisor, 9 mm for the lateral incisor, and 10 mm for the canine. If the patient demonstrates a band of gingiva over the cervical areas of the teeth, the height of the clinical crowns are evaluated, relative to their width. The height/width ratio is 0.86 for the central incisor, 0.76 to 0.79 for the lateral incisor, and 0.77 to 0.81 for the canine.[51] Esthetic crown lengthening is often a good option when the height of the central clinical crown is less than 10 mm (and the width is greater than 8 mm). Often the effect of crown lengthening is a dramatic improvement and may be accomplished at the same time as the implant surgery.

In patients with a high lip line during smiling who are missing all their anterior teeth, the prosthetic teeth can be made longer (up to 12 mm) instead of the average 10 mm height to reduce the gingival display and result in a more esthetic restoration. Therefore, the height of the maxillary anterior teeth is determined by first establishing the incisal edge of the canine

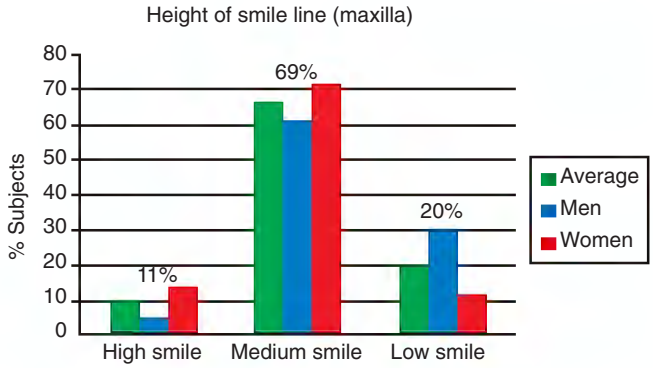


FIGURE 16-26. The height of the maxillary lip during smiling is variable and is usually more in women than men.

by the lip in repose. Second, the high smile line determines the height of the tooth (from 9 to 12 mm).[16] Third, the width of the anterior teeth is determined by the height–width ratios.

The cervical third of the maxillary premolars is also observed during a high smile line. It is not unusual to reveal the cervical third and gingiva of the interdental papilla of the premolar with a high lip line (Figure 16-27). These teeth should not appear too short (or long) and unnatural in height. Resorption may also cause the implants to be inserted more palatally in this

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FIGURE 16-27. The high smile line is evaluated for all the exposed teeth in the maxilla. The anterior region may be ideal, yet the posterior region may have a "gummy" smile.



FIGURE 16-28. The high smile line of this patient shows the soft tissue drape around her natural teeth. The anterior FP-3 prosthesis is more noticeable because the pink porcelain is difficult to match to the soft tissues.

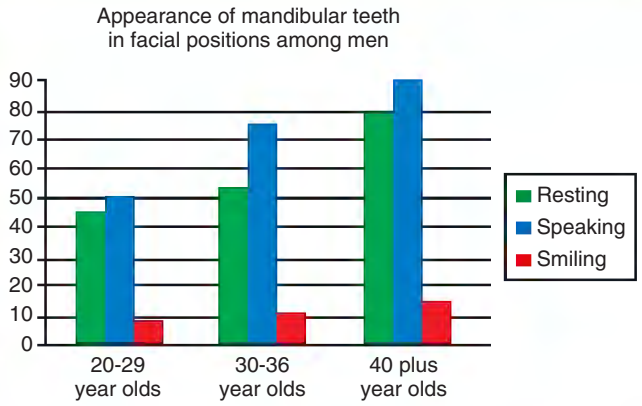


FIGURE 16-29. The mandibular anterior teeth often are displayed during speech, especially in older men.



FIGURE 16-30. A FP-3 implant prosthesis for the mandibular arch.

area. The position of these crowns may then be too palatal and therefore affect the esthetic result. Bone and soft tissue grafts are the primary method to eliminate the need for ridge laps or the addition of pink porcelain at the gingiva. They are also indicated to reduce crown height.

For a multiple tooth replacement in the posterior regions, when the high lip line exposes the interdental papilla region but not the cervical gingival region, the interimplant space may use pink restorative materials to replace the papillae. When the high lip line exposes the cervical areas, the interdental and cervical aspects of the region should be addressed with surgery (e.g., grafting) or prosthetics (e.g., FP-3 restorations).

A high lip position of the edentulous maxilla restored with a FP-3 prosthesis that displays the patient's soft tissue in the edentulous site is more difficult to restore than when the CHS is greater than usual but no soft tissues are shown in the edentulous site. When the patient's soft tissue is seen, the prosthetic gingival replacement must match the color and texture of the patient's tissue (Figure 16-28). When the patient's soft tissue is not visible, the restoration materials do not need to match the existing color, and it is easier to obtain an esthetic result.

The pink porcelain restoration (FP-3) to replace the soft tissue may be esthetic but is rarely the treatment of choice for single tooth replacement. The lack or deficiency of an interdental papilla is difficult to blend into the existing soft tissue. On the other hand, in multiple missing adjacent anterior teeth, the pink porcelain is often the treatment of choice because the soft tissue drape is usually unable to be ideal, even with bone and tissue grafts.

Mandibular Low Lip Line

The mandibular low lip position during speech is often neglected, with disastrous esthetic results. The mandibular incisors are more visible in middle-aged and older patients during speaking than maxillary teeth, especially in men (Figure 16-29). In addition, lower central incisors are often visible in their incisal two thirds during exaggerated smiles.[50] Although the maxillary high lip line is evaluated during smiling, the mandibular low lip position should be assessed during speech. In pronunciation of the *S* sound, or sibilants, some patients may expose the entire anterior mandibular teeth and gingival contour.

Patients are often unaware of the preexisting lower lip position during speech and blame the final restoration for the display of the mandibular gingiva or complain that the teeth look too long. Therefore, it is recommended to make the patient aware of the active existing lip lines in both the maxilla and mandible before treatment and emphasize that these lip positions will be similar after treatment. A FP-3 mandibular restoration may be indicated to restore the patient with a low mandibular lip position. Rarely is the FP-3 restoration required distal to the mandibular canine position (Figure 16-30).

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Existing Occlusion

Maximal intercuspation is defined as the complete intercuspation of the opposing teeth independent of condylar position, sometimes described as the best fit of teeth regardless of the condylar position.[25] *Centric occlusion* is defined as the occlusion of opposing teeth when the mandible is in CR.[25] This may or may not coincide with the tooth position of MI. Its relationship to CR—a neuromuscular position independent of tooth contact with the condyles in an anterior, superior position—is noteworthy to the restoring dentist.[46] The potential need for occlusal adjustments to eliminate deflective tooth contacts as the mandible closes in CR and the evaluation of their potential noxious effects on the existing dentition and the planned restoration is important to evaluate.

Correction of the deflective contacts before treatment presents many advantages and may follow a variety of approaches depending on the severity of the incorrect tooth position: selective odontoplasty (a subtractive technique), restoration with a crown (with or without endodontic therapy), or extraction of the offending tooth. The existing occlusion is best evaluated with facebow-mounted diagnostic casts and open-mouth bite registration in CR.

Controversy exists as to the necessity to have MI harmonious with CR (CR occlusion). A vast majority of patients around the world do not have such a relationship, yet they do not exhibit clinical pathology or accelerated tooth loss. Therefore, it is difficult to state that these two positions must be similar. What is important is to evaluate the existing occlusion and the mandibular excursions to consciously decide whether the existing situation should be modified or be maintained. In other words, dentists should determine whether they are going to ignore or control the occlusion of the patient (Figure 16-31).

As a general rule, the more teeth replaced or restored, the more likely the patient is restored to CR occlusion. For example, if a completely edentulous mandible is to be restored with an implant-supported fixed prosthesis, the CR occlusion position provides consistency and reproducibility between the articulator and the intraoral condition, and slight changes in OVD to position anterior implant abutments in a more favorable restoration position may be studied and implemented on the articulator without the need to record the new occlusal vertical position on the patient.

On the other hand, when one anterior tooth is being replaced, the existing MI position is often satisfactory to restore the patient even though a posterior interference and anterior slide into full interdigitation may be present. The underlying question that helps determine the need for occlusal correction before restoration of the implant patient is the observation of negative symptoms related to the existing condition. This may include TMJ conditions, tooth sensitivity, mobility, wear, tooth fractures or abfraction, or porcelain fracture. The fewer and less significant the findings, the less likely an overall occlusal modification is required before restoration of the patient. However, to properly assess these conditions, the dentist must not ignore them before treatment.

Crown Height Space

The *interarch distance* is defined as the vertical distance between the maxillary and mandibular dentate or edentate arches under specific conditions (e.g., the mandible is at rest or in occlusion).[25] A dimension of only one arch does not have a defined term in prosthetics; therefore, the author proposed the term *crown height space*.[52,53] The CHS for implant dentistry is measured from the crest of the bone to the plane of occlusion in the posterior region and the incisal edge of the arch in question in the anterior region (see Figure 16-16). The ideal CHS for a FP-1 fixed implant prosthesis should range between 8 and 12 mm. This space accounts for the "biological width," abutment height for cement retention or prosthesis screw fixation, occlusal material strength, esthetics, and hygiene considerations around the abutment crowns (Figure 16-32). Removable prostheses often require more than 12 mm of CHS for denture teeth and acrylic resin base strength, attachments, bars, and oral hygiene considerations.

Biomechanic Consequences of Excessive Crown Height Space

Mechanical complication rates for implant prostheses are often the highest of all complications reported in the literature



FIGURE 16-31. The existing occlusion is evaluated to decide whether the maximal intercuspation (MI) is similar to centric occlusion (the mandible is in centric relation). The mandibular excursions are also evaluated. The lack of canine contact and premature first premolar contact in the excursion and the uneven occlusal plane indicated correction of the occlusion before final reconstruction.

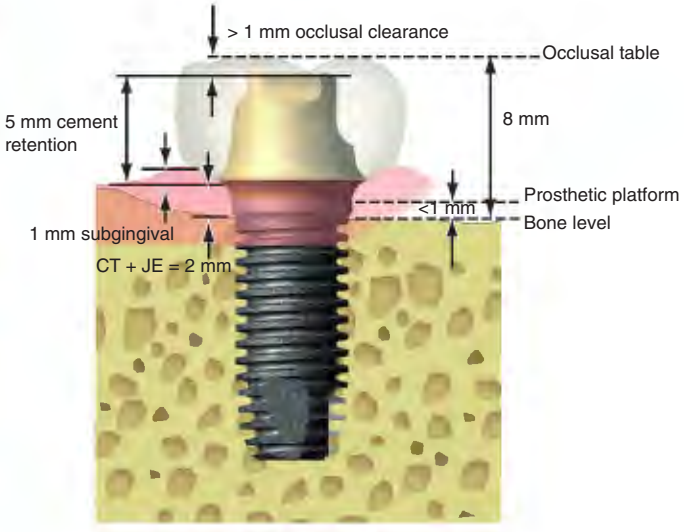


FIGURE 16-32. The crown height space is measured from the occlusal plane to the level of the bone. *CT*, Connective tissue attachment; *JE*, junctional epithelial attachment.

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and are often caused by excessive stress applied to the implant–prosthetic system.[54] Implant body or component failure may occur from overload and result in prosthesis failure and bone loss around the failed implants.[47] Crestal bone loss may also be related to excessive forces and often occurs before implant body fracture. The biomechanics of CHS are related to lever mechanics. The issues of cantilevers and implants were demonstrated in the edentulous mandible where the length of the posterior cantilever directly related to complications or failure of the prosthesis.[55] Rather than being a posterior cantilever, the CHS is a vertical cantilever and therefore is also a force magnifier.

When the direction of a force is in the long axis of the implant, the stresses to the bone are not magnified in relation to the CHS (Figure 16-33). However, when the forces to the implant are on a cantilever or a lateral force is applied to the crown, the forces are magnified in direct relationship to the crown height. Bidez and Misch evaluated the effect of a cantilever on an implant and its relation to crown height.[47,55] A horizontal cantilever may have three different directions of applied load (occlusal–gingival, buccolingual, and mesiodistal). These force directions result with six different rotational forces applied to the implant (moment forces). When the crown height is increased from 10 to 20 mm, two of six of these moments are increased 200%. As a consequence, when the available bone height is decreased, the CHS is increased, and the resultant forces on the shorter implants are increased.

An angled load to a crown also magnifies the force to the implant. A 12-degree force to the implant increases the force by 20%. This increase in force is further magnified by the crown height.[47] For example, a 12-degree angle with a 100-N force will result in a force of 315 N-mm on a crown height of 15 mm. Maxillary anterior teeth are usually at an angle of 12 degrees or more to the occlusal planes. Therefore, even implants placed in an ideal position in the premaxilla are usually loaded at an angle to the occlusal load. In addition, maxillary anterior crowns are often longer than any other teeth in the arch, and the effects of an increased crown height cause greater risk. The angled force to the implant may also occur during protrusive or lateral excursions because the incisal guide angle usually is greater than 20 degrees.[46] Anterior implant crowns will therefore be loaded at a considerable angle during excursions compared with the long axis of the implant. As a result, an increase in the force to maxillary anterior implants should be compensated for in the treatment plan.

Most forces applied to the osseointegrated implant body are concentrated in the crestal 7 to 9 mm bone regardless of implant design and for most bone densities. Therefore, unlike a natural tooth root, implant body height is not an effective method to counter the effect of crown height. Moderate bone loss before implant placement may result in a crown height–bone height ratio greater than 15 mm, with greater lateral forces applied to the crestal bone than in abundant bone (in which the crown height is less). A linear relationship exists between the applied load and internal stresses.[55] Therefore, the greater the load applied, the greater the tensile and compressive stresses transmitted at the bone interface and to the prosthetic components.

The greater the CHS, the greater number of implants usually required for the prosthesis, especially in the presence of other force factors. This is a complete paradigm shift to the concepts advocated originally with many implants in greater available bone and small crown heights and fewer implants with greater crown heights in atrophied bone[56] (Figure 16-34). Because an increase in the biomechanical forces is in direct relationship to the increase in CHS, the treatment plan of the implant restoration should consider stress-reducing options whenever the CHS is increased (Box 16-3).

Excessive Crown Height Space

Crown height space is excessive when greater than 15 mm. Treatment of excessive CHS as a result of vertical resorption of bone before implant placement includes surgical methods to increase bone height or stress reduction methods to the support system and prosthesis. Several surgical techniques may be considered to increase bone height, including block onlay bone grafts, particulate bone grafts with titanium mesh or barrier

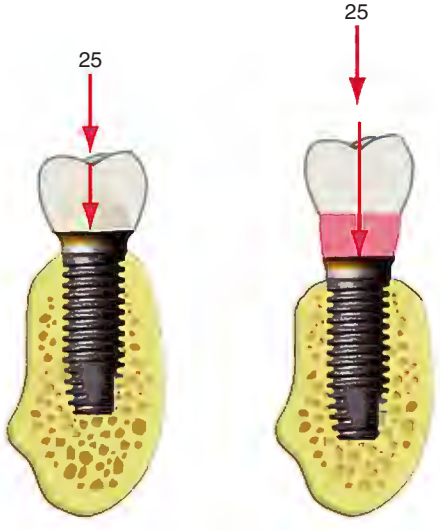


FIGURE 16-33. The crown height is not a multiplier of force when the load is in the long axis of the implant. However, any angled force or cantilever increases the force, and the crown height magnifies the effect.



FIGURE 16-34. The greater the crown height space (CHS), the more implants are required to restore the patient *(right side)*. The less the CHS *(left side)*, the fewer the implants to restore the patient.

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BOX 16-3 Excessive Crown Height Space: Treatment Planning Options to Decrease Stress

- Shorten cantilever length.
- Minimize buccal and lingual offset loads.
- Increase the number of implants.
- Increase the diameters of implants.
- Design implants to maximize the surface area.
- Fabricate removable restorations (less retentive) and incorporate soft tissue support.
- Remove the removable restoration during sleeping hours to reduce the noxious effects of nocturnal parafunction.
- Splint implants together regardless of whether they support a fixed or removable prosthesis.

membranes, interpositional bone grafts, and distraction osteogenesis.[52,53]

Bone augmentation may be preferred to prosthetic replacement. Surgical augmentation of the residual ridge height will reduce the CHS, improve implant biomechanics, and often permit the placement of wider-body implants with the associated benefit of increased surface area. Although prosthetics is the most commonly used option to address excess CHS, it should be the last option used. Gingiva-colored prosthetic materials (pink porcelain or acrylic resin) on fixed restorations or changing the prosthetic design to a removable restoration should often be considered when restoring excessive CHS with the prosthesis.

In the maxilla, a vertical loss of bone results with a more palatal ridge position. As a result, implants are often inserted more palatally than the natural tooth position. A RP-4 removable restoration (removable but completely implant supported, retained, and stabilized) has several advantages under these clinical circumstances. The removable prosthesis does not require embrasures for hygiene and may be removed during sleep to decrease the effects of an increase in CHS on nocturnal parafunction. It may also improve the deficient lip facial support. The overdenture may have sufficient bulk of acrylic resin to permit denture tooth placement without infringement of the substructure and to decrease the risk of prosthesis fracture. The RP-4 restoration may also improve oral hygiene of the implant interface because it may be removed before daily hygiene procedures. However, it has identical requirements for the implant support system (e.g., implant position, number, and size) as a fixed prosthesis because it is rigid during function (hidden cantilever situation).

In the case of removable prostheses with mobility and soft tissue support (a RP-5 prosthesis), two prosthetic levers of height should be considered. The first is the height of the attachment system to the crest of the bone. The greater the height distance, the greater the forces applied to the bar, screws, and implants. The second CHS to consider is the distance from the attachment to the occlusal plane. This distance represents the increase in prosthetic forces applied to the attachment. Therefore, in a CHS of 15 mm, an O-ring may be 7 mm from the crest of bone, resulting in a lever action of 7 mm applied to the implants. The distance from the rotation point of the O-ring to the occlusal plane may be an additional 8 mm or more. Under these conditions, a greater lever action is applied from the prosthesis occlusal plane to the attachment system. This results in increased instability of the restoration under lateral forces.[53]



FIGURE 16-35. A large crown height space with a traditional porcelain–metal prosthesis requires a large amount of metal in the substructure with increased risk of complications such as porosities and fracture during cooling.

Crown height space greater than 15 mm means a large amount of metal must be used in the substructure of a traditional fixed restoration to keep porcelain to its ideal 2-mm thickness (Figure 16-35). Control of surface porosities of metal substructures after casting becomes increasingly difficult because their different metal components cool at different rates.[57,58] If not controlled properly, both of these factors increase the risk of porcelain fracture after loading.[59] Noble metals are often used to control alloy's heat expansion or corrosion in these large castings, and the cost of such implant restorations is dramatically increased. For excessive CHS, considerable weight of the prosthesis (approaching 3 oz of alloy) may affect maxillary trial placement appointments because the restoration does not remain in place during the try-in appointment without the use of adhesive. Proposed methods to produce hollow frames to alleviate these problems include using special custom trays to achieve a passive fit, which can double or triple the labor costs.[56] An alternative method to fabricate fixed prostheses in situations of CHS 15 mm or greater is the fixed complete denture or hybrid prosthesis, which has a smaller metal framework, denture teeth, and acrylic resin to join these elements together (Figure 16-36). This type of fixed prosthesis is often indicated for implant restorations with a large CHS.

On occasion, undercontoured interproximal areas are designed by the laboratory in restorations of large CHS to assist oral hygiene and have been referred to as *high-water restorations*. This is an excellent method in the mandible; however, it results in food entrapment, affects air flow patterns, and may contribute to speech problems in the anterior maxilla.

Because crown height is a considerable force magnifier, the greater the crown height, the shorter the prosthetic cantilever should extend from the implant support system. In crown heights of more than 15 mm, no cantilever should be considered unless all other force factors are minimal and bone is of good quality (more often in the mandible opposing a maxillary denture in an elderly female). The occlusal contact intensity should be reduced on any offset load from the implant support system. Occlusal contacts in CR occlusion may even be eliminated on the most posterior aspect of a cantilever.[47] In this way, a parafunction load may be reduced because the most cantilevered portion of the prosthesis is only loaded during functional activity while eating food.

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FIGURE 16-36. A hybrid prosthesis (maxillary arch) uses a cast metal substructure (smaller in size than porcelain to metal), acrylic, and denture teeth to restore the patient.

BOX 16-4 Reduced Crown Height Space

1. Structural integrity problems of a restoration increase with a reduced CHS.
2. Surgical procedures during implant placement may increase a CHS.
3. Complications of an insufficient CHS may be increased by the surgical position of the implant (e.g., poor angulation, implant platform several millimeters above the bone).
4. Different implant systems have a different minimum CHS related to the height of the prosthetic components.

CHS, Crown height space.

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Reduced Crown Height Space

Issues related to CHS are accentuated by an excessive CHS that places more forces on the implant and prosthetic system, but reduced CHS makes the prosthetic components weaker. An ideal CHS is 8 to 12 mm. The 8-mm requirement for CHS consists of 2 mm of occlusal material space, 4-mm minimum abutment height for retention, and 2 mm above the bone for the biological width dimension (which does not include the sulcus, as a crown margin may be 1 mm subgingivally for retention or esthetics) (see Figure 16-32).

A reduced CHS has biomechanical issues related to a reduced strength of implant material or prosthetic components, an increased flexibility of the material, and a reduction of retention requirement of the restoration.[52] The fatigue strength and flexure of a material is related to its radius to the power of 4.[55] In fixed restorations, the flexure of the reduced diameter material may cause porcelain fracture, screw loosening, or uncemented restorations. Therefore, in the situation of reduced CHS, material failures are more common (Box 16-4).

Skeletal discrepancies (e.g., deep bite), reduced OVD from attrition or abrasion, minimal bone atrophy after tooth loss, and supraeruption of unopposed teeth may all result in less than ideal space for prosthetic replacement of the dentition. Traditional prosthetic and restorative procedures are indicated to restore the proper OVD and plane of occlusion. However, on occasion, even when the opposing arch and OVD is corrected, the CHS may still be less than ideal (<8 mm).

When the reduced OVD is in partially edentulous patients, the OVD may be restored by orthodontics, which is the preferred method. TAD may be necessary to extrude the teeth. This correction may also require a surgical orthognathic surgery, such as a LeFort I osteotomy and superior repositioning. However, use of prosthetics is a common approach and may involve an entire arch.

When the opposing teeth are in the correct OVD and centric occlusion position and the CHS is insufficient, additional space may be gained surgically with osteoplasty and soft tissue reduction of one arch, provided adequate bone height remains after the procedure for predictable implant placement and prosthetic support (Figure 16-37). If a removable implant-supported prosthesis is planned, an aggressive alveoloplasty should often be performed after tooth extraction to provide adequate prosthetic space.

Additional prosthetic space can also be obtained in many completely edentulous situations by soft tissue reduction, especially in the maxilla. Soft tissue reduction should be performed in conjunction with second-stage surgery if the implants heal in a submerged location. This allows the thicker tissue to protect the implants from uncontrolled loading by a soft tissue–supported prosthesis during healing. If the implants heal permucosally (one-stage surgery), the soft tissue reduction procedures should be done during implant placement. Soft tissue reduction procedures may include gingivectomy, removal of connective tissue, or apical repositioning of flaps. Efforts should be made to maintain adequate keratinized tissue around the implants. Soft tissue reduction also has the benefit of decreased probing depths around the implants. However, the definition of CHS is from the bone to the occlusal plane; therefore, although the prosthetic space is improved, the CHS remains similar when only soft tissue reduction is performed.

When the CHS is less than ideal, the following prosthetic parameters should be identified[53]:

1. Available space
2. Abutment taper
3. Surface area of abutment
4. Cement type
5. Surface finish
6. Occlusal topography and material
7. Load on final restoration
8. Fit of restoration to abutment
9. Retention of prosthesis
10. Implant manufacturer
11. Implant platform to occlusal plane dimension

The consequences of insufficient CHS include a decrease in abutment height (which may lead to inadequate retention of the restoration), inadequate bulk of restorative material for strength or esthetics, and poor hygiene conditions compromising long-term maintenance. In addition, the final restoration flexes inversely to the cube of the thickness of material. A fixed prosthesis half as thick will flex eight times as much and will further result in loss of cement retention, loosening or fracture of fixation screws, or porcelain fracture.[60] Inadequate thickness of occlusal porcelain or acrylic or unsupported occlusal material caused by inadequate metal substructure design may also result in complications such as component fracture.

Minimum restorative requirements vary in function of the implant system. The minimum restoration space may be determined by limiting the occlusal material to 1 mm (metal occlusals) and reducing the abutment height to the top of the retaining screw. The smallest minimum restoration spaces

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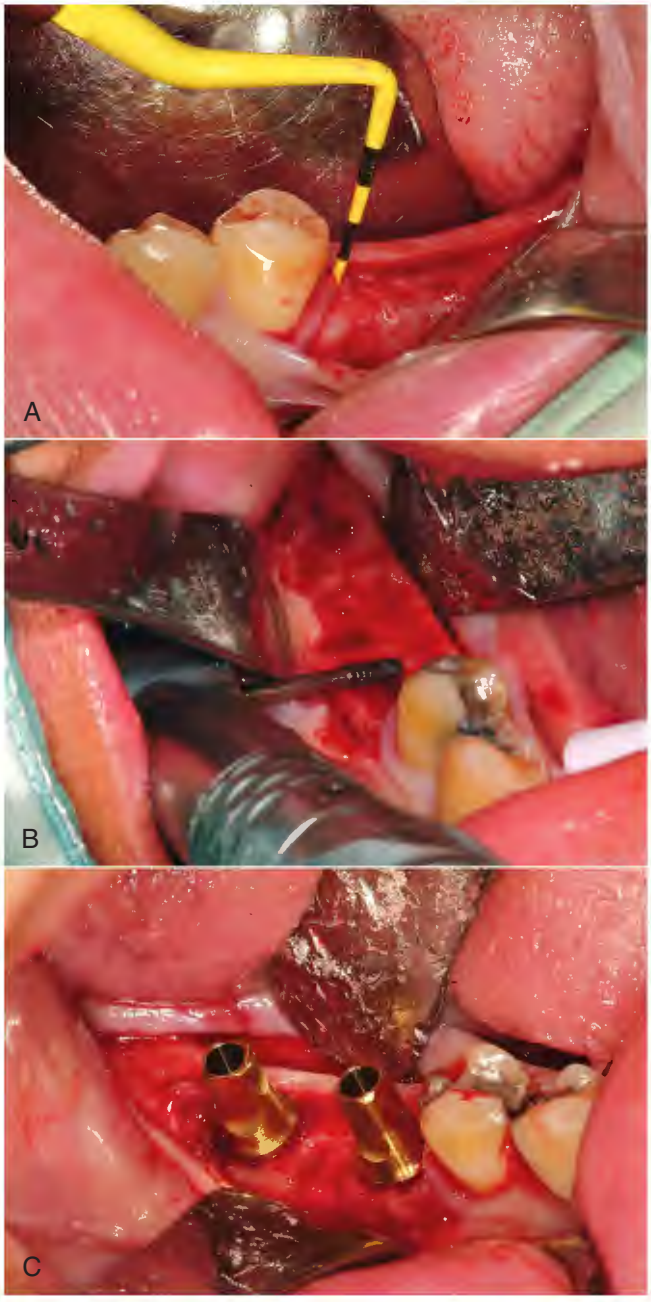


FIGURE 16-37. **A**, A reduced crown height space (CHS) results in short abutments, less cement retention, and increase of flexibility of the metal in the prosthesis. **B,** An osteoplasty increases the CHS before implant insertion. **C,** The implants may be positioned with an increase in CHS and fewer prosthetic complications.

correspond to 4.21 mm for 3I Osseotite, 4.35 mm for Replace Select (Nobel BioCare), 4.5 mm for BioHorizons, and 4.56 mm for Frialit 2 systems. The greatest restoration space requirements are found in Astra (6.6-mm), Lifecore (6.84-mm), and Straumann (7.0-mm) systems.[61]

When fabricating a cemented restoration, the restoration technique (indirect vs. direct) may be influenced by the CHS. Because additional abutment height for retention may be gained by a subgingival margin, the indirect technique (making an implant body level impression) may have an advantage over a direct intraoral impression. An implant body level impression and implant analog used to fabricate the prosthesis permits the subgingivally restoration to be placed more than 1 mm subgingival with greater accuracy because a subgingival margin and impression technique is more difficult when the margin extends more than 1 mm below the tissue. The indirect technique is also used for custom abutments, which can be designed with increased diameter to increase the overall surface area for retention. A custom abutment may also be fabricated to decrease the total occlusal convergence angle to increase retention for cemented prostheses. Therefore, the indirect laboratory analog technique represents benefit in a reduced CHS situation, especially when the soft tissue is several millimeters thick.

The retention and resistance difference between a 3-mm-high and a 5-mm-high implant abutment may be as great as 40% for a 4.5-mm-diameter abutment. Less than 3 mm of abutment height indicates a screw-retained crown, 3 to 4 mm requires a screw-retained or resin-cemented restoration, and greater than 4 mm of abutment height allows the operator's preference, although the ideal abutment height is 6 mm for ideal CHS and greater for larger CHS situations. Splinting implants together, regardless of whether they are screw retained or cement retained, can also increase retention.

Conditions such as cement hardness, surface condition of the abutment, and occlusal material (porcelain vs. metal) are also to be considered in limited CHS situations. The occlusal material is important to consider in reduced CHS for two primary reasons. When metal is used as the occluding surface, it is possible to provide greater retention for the prosthesis as a result of an increase in abutment height. The abutment height may be greater because the occlusal space required above the abutment is only 1 mm, but porcelain requires 2 mm of occlusal space and acrylic resin requires 3 mm or more. Another factor is the strength of the material. Metal occlusal surfaces provide the greatest resistance to fracture and should be considered when there is limited CHS. When a screw is used to retain the crown, the strength of occlusal porcelain is reduced by as much as 40% because an access hole penetrates the surface. Therefore, cemented restorations are a benefit unless the abutment is less than 4 mm high and the prosthesis screw is required to retain the restoration. Acrylic resin requires the most dimension for strength and is much more likely to fracture when the CHS is limited. This is one reason why acrylic resin overdentures require more CHS than a porcelain–metal fixed prosthesis.

Too little CHS can be further complicated when the surgeon places the implant above the bone. The surgeon may also magnify the prosthetic problem of limited CHS by placing the implant at an angle to the ideal position. Angled abutments lose surface area of retention from the abutment screw hole and further compromise the limited space conditions. In addition, a 30-degree taper on an abutment to correct parallelism loses more than 30% of the abutment surface area and dramatically decreases the retention for the abutment.

Overdentures also exhibit greater complications in situations of reduced CHS. Removable prostheses have space requirements for elements such as a connecting bar, type, and position of attachments and restorative material (metal vs. resin). According to English, the minimum CHS for individual attachments is 10 mm of CHS for Locator-type attachments and between 12 and 15 mm for a bar and O-rings.[62] The ideal CHS for removable prostheses is greater than 14 mm, and the minimum height is 10.5 mm.[53] The lowest possible profile attachment should be used in situations of reduced CHS to fit within the contours of the restoration, provide greater bulk of acrylic resin to decrease fracture, and allow proper denture tooth position

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without the need to weaken the retention and strength of the resin base.[63]

Overdenture bars may be screw retained or cement retained.[64] The most common method of retention for a fixed prosthesis is cement retention. The most common method of bar retention by almost the same percentage for overdentures is screw retention. Yet the advantages of cement retention for a fixed prosthesis also apply to an overdenture bar. Therefore, in minimum CHS situations, the screw-retained bar has a clear advantage, but in ideal to excessive CHS situations, the cemented bar should be considered. A combination of screw retention on some abutments and cement retention on others offers an advantage for many RP-4 prostheses.

Temporomandibular Joint

The TMJ may exhibit signs and symptoms of dysfunction. Symptoms include pain and muscular tenderness experienced by the patient. Noises or clicking in the joint during opening, deviation of the mandible during jaw opening, and limited jaw movements are signs of potential dysfunction observed during the patient examination. Patient complaints or signs gathered during the initial evaluation should be carefully evaluated before further reconstructive treatment.[46]

Palpation of the temporalis, masseter, and internal and external pterygoid muscles is part of the TMJ examination. The muscles should not be tender during this process. Parafunction may contribute to TMJ disorders and is a direct source of muscle tenderness. Under these conditions, the muscles are usually hypertrophied as a result of the excess occlusal forces. The masseter and temporalis muscles are easily palpated. The lateral pterygoid muscle is often overused in this patient profile yet is difficult to palpate. The ipsilateral medial pterygoid muscles can be as diagnostic and are easier to evaluate in the hamular notch region. They act as the antagonist to the lateral pterygoid muscle in hyperfunction and, when tender, it is a good indicator of overuse of either muscle.[46]

Deviation to one side during opening indicates muscle imbalance on the same side as the deviation and possible degenerative joint disease.[46] The patient should also be able to perform unrestricted mandibular excursions. Maximal opening is noted during this examination and is normally greater than 40 mm from the maxillary incisal edge to the mandibular incisal edge in an Angle's skeletal class I patient. If any horizontal overjet or vertical overbite exists, it is subtracted from the 40-mm minimum opening measurement.[65] The range of opening without regard to overlap or overbite ranges from 38 to 65 mm in men and 36 to 60 mm in women, from one incisal edge to the other.

The practitioner is encouraged to carefully evaluate the TMJ status. It is beyond the scope of this text to address the methods of treatment of TMJ dysfunction. However, many patients with soft tissue–borne prostheses and TMJ dysfunction benefit from the stability and exacting occlusal aspects that implant therapy provides. As such, these patients may benefit from implant support to improve their condition. However, a transitional prosthesis is often a benefit to evaluate the TMJ function and symptoms before the fabrication of the final restoration.

Existing Prostheses

When present, existing prostheses are evaluated for proper design and function. A removable partial soft tissue–supported restoration opposing the proposed implant-supported prosthesis is of particular interest. The occlusal forces vary widely as the underlying bone remodels. The patient may not even wear the opposing removable partial denture in the future, which will dramatically modify the occlusal conditions. Therefore, continued maintenance and follow-up evaluations are indicated, including relines and occlusal evaluation.

The patient should be asked whether esthetic desires are met with the current restorations. It is not unusual that the prosthesis is completely acceptable yet the patient wishes a different shade or contour for the teeth. If unacceptable to the patient, the reasons for dissatisfaction are noted. In addition, the existing restorations are evaluated throughout the mouth for clinical harmony. It is better to leave a poor esthetic restoration that is in occlusal harmony than to provide one that is esthetic but improper in position because the latter may influence all future restorations. Pontic regions of existing prostheses may often be improved with the addition of connective tissue grafts.

An acceptable preexisting maxillary removable prosthesis, which will be replaced with a fixed implant prosthesis, may be used as a template for implant reconstruction when fabricating an implant-supported fixed or removable implant prosthesis.[64] The thickness of the labial flange of the existing denture is evaluated and is often removed to evaluate the difference in lip position and support. If implants may be correctly inserted yet additional lip support is needed after the labial flange is eliminated, an HA, connective tissue, or acellular dermal onlay graft is usually indicated. This graft is not intended for implant support or placement but to enhance the support of the labial alveolar mucosa to improve maxillary lip support.

Arch Form

Two different arch forms are to be considered for implant prostheses.[16] The first arch form is of the residual edentulous bone and determines the A-P distance for implant support. The second arch form is of the replacement teeth position. The edentulous arch form and the dentate arch form in the horizontal plane are described as ovoid, tapering, or square. In the edentulous arch form, the ovoid arch form is the most common followed by the square and then the tapered form. The square arch form may result from the residual formation of the basal skeletal bone. However, the presence of a square arch form is more common in maxillary implant patients as a result of labial bone resorption of the premaxilla region when anterior teeth are lost earlier than the canine. The tapering arch form is often found in skeletal class II patients as a result of parafunctional habits during growth and development. It is not uncommon to find different arch forms in the upper and the lower arches.

The dentate and edentulous arch form are not necessarily related, and the worst situation in the maxilla corresponds to a square residual arch form that supports a tapered dental restoration. The prosthesis cantilever off the anterior available bone is greatest in this combination (Figure 16-38).

The most ideal biomechanical arch form depends on the restorative situation. The tapering residual ridge arch form is favorable for anterior implants supporting posterior cantilevers. The square dental arch form is preferred when canine and posterior implants are used to support anterior teeth in either arch. The ovoid arch form has qualities of both tapered and square arches.

The arch form is a critical element when anterior implants are splinted together and support a posterior cantilever

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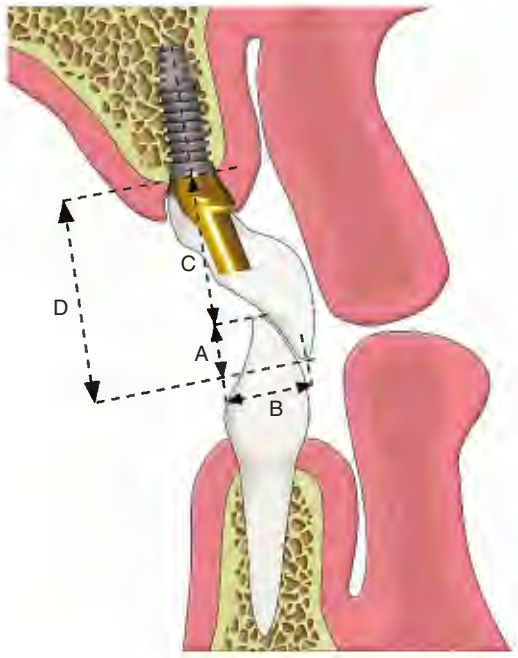


FIGURE 16-38. The dental arch form may be different than the arch form of the residual arch. A tapered dentate arch form on a square residual bone form is the worst combination because the anterior teeth are cantilevered from the implant abutments.

restoration. For these conditions, a square arch form provides a poorer prognosis than a tapered arch form. The A-P distance or A-P spread is the distance from the center of the most anterior implant to a line joining the distal aspect of the two most distal implants.[66] It provides an indication as to the amount of cantilever that can be reasonably planned. When five anterior implants in the mandible are used for prosthesis support, the cantilevered posterior section of the restoration should not exceed two times the A-P spread when all patient force and stress factors are low and bone density is favorable. The actual length of the cantilever depends not only on implant position but also on other stress factors, including parafunction, crown height, implant width, and number.

The predominant factors to determine the cantilever length are related to stress, not only the A-P distance.[16,67] For example, the distance between two implants supporting a cantilever (C) forms a class I lever. For implants 10 mm apart and a 10-mm posterior cantilever, the following forces are applied: a 25-lb force on cantilever C results in a 25-lb force on the most anterior implant from the cantilever (A) and 50 lb for the nearest implant to the cantilever (B), which acts as a fulcrum. An interimplant distance of 5 mm with the same 10-mm cantilever and a 25-lb force applied on C results in a 50-lb force on A and a 75-lb force on B. The diminution in the distance between implants significantly increases the forces to both implants. But in the first example, if a patient with parafunction bites with a 250-lb force on C, the force on implant A is 250 lb, and the force on implant B is 500 lb. In other words, parafunction is much more meaningful in terms of force than the interimplant distance (A-P distance) when designing a cantilever.[16] Therefore, A-P distance is only one stress factor to evaluate for cantilever length. Parafunction, crown height, masticatory dynamics, arch position, opposing arch, direction of force, bone density, implant number, implant width, implant design, and A-P distance are all factors to be considered. When the force factors are low and the area factors (implant number, width, and design) are high, the cantilever length may be as much as two times the A-P distance in good-quality bone.

As mentioned previously, anterior endosteal implants often may not be inserted in their ideal location in the maxilla as a result of labial plate resorption and inadequate bone width at the implant site. This not only requires implant placement more palatally compared with the original natural teeth, but it may also negate the lateral and central positions and require the use of the canine regions in more advanced atrophic arches. The resulting restoration is a fixed, anteriorly cantilevered prosthesis to restore the original arch form. Under these conditions, greater stresses are placed on the dentate tapered arch forms compared with dentate square arch forms, all other factors being identical.[67]

The maxillary anterior cantilever to replace teeth in a dentate-tapered arch form requires the support of additional implants of greater width and number to counteract the increase in lateral load and moment force. For example, not only are the canine implants necessary, but two more additional anterior implants are also suggested even if bone grafting is required before their placement. In addition, additional posterior implants in the first to second molar region splinted to the most anterior implants are highly suggested. Therefore, if a maxillary tapered arch form requires this treatment approach, at least eight implants (four on each side) and an increased A-P distance from molar implants splinted to incisor implants is suggested. In addition, second molar implants should be splinted to the anterior implants to increase the A-P distance.[67] In the maxilla, the recommended anterior cantilever dimension is less than for the posterior cantilever in the mandible because of poor bone density and forces directed outside the arch during excursions.

Soft Tissue Support

The evaluation of the soft tissue support is primarily concerned with the treatment planning of RP-5 prostheses (overdentures which gain dual support from implants and edentulous ridges). RP-5 restorations should have implant retention and some stability from the anterior region. The posterior soft tissue regions provide the region for soft tissue support. The following factors should be evaluated: ridge shape, size, parallelism, and palate shape.

Large jaws with little resorption provide a better support base than smaller-sized ridges with greater atrophy in either the maxilla or mandible. The size of the soft tissue support cannot be solely evaluated on a radiograph because it is highly dependent on the position of the muscle attachments. High muscle attachments on abundant to moderate bone (division A or B) may be improved by vestibuloplasty procedures in conjunction with implant surgery.

Prosthesis support depends on the shape of the residual ridge and, in the maxilla, the palatal vault. A square ridge form yields optimal resistance and stability. A relatively flat one represents a compromised factor for retention and stability, although support is still adequate. Tapering ridges in the maxilla with the palatal vault usually equate with poor stability.[56]

Ridge parallelism to the opposing arch is also evaluated. The edentulous ridge parallel to the occlusal plane is most favorable for soft tissue support. If the ridges are divergent, the stability of the denture will be greatly affected.

The lateral throat form in a maxillary denture or RP-5 restoration is evaluated. A soft palate slope is favorable when it has a long, gradual slope from the junction of the hard and soft

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palate, which allows a greater extension of the posterior palatal seal and enhances retention.[68] On the other hand, a soft palate that drops abruptly may lead to soreness, loss of valve seal, and gagging.[69]

Soft tissue support elements are of great diagnostic value in the evaluation of the maxillary fully edentulous patient who may consider an implant-supported overdenture. A greater number of unfavorable anatomical structures may direct the treatment plan toward a RP-4 prosthesis with greater implant support and no soft tissue support to address all the anatomic needs of the patient.[70,71]

It should be emphasized to the patient that a partial or total soft tissue–borne prosthesis will not stabilize bone loss. As a result, all soft tissue–borne devices should be considered transitional dentures. They all require repeated relines, rebasing, and refabrication to replace the missing bone. A totally implant-supported restoration (fixed or removable) does not require soft tissue support and may be considered a definitive restoration.

Many soft tissue–supported restorations are fabricated because the patient cannot afford a totally implant-supported restoration, especially in a completely edentulous patient. However, the doctor often forgets that if a patient cannot afford the ideal treatment today, it does not mean the patient cannot afford any further treatment later. For example, if a patient needs four first molars replaced but cannot afford all restorations at this time, the doctor most often can still replace one of the molars. Then a few years later, the next tooth may be replaced. Eventually, the four molar sites are treated and the arch form and occlusion restored. In similar fashion, a patient who can afford only two implants to retain a mandibular denture could possibly afford further treatment later. Therefore, a lifetime strategy for health should be established, which may include the addition of more implants in the future to reduce and eventually halt the continued bone loss and consequences on esthetics and function.

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Treatment Prostheses

Fixed Restorations

Pretreatment prostheses in restorative dentistry are often indicated to obtain a diagnosis, improve soft tissue health before fabricating soft tissue–borne restorations, reestablish or evaluate the OVD, evaluate esthetic considerations, or treat TMJ dysfunction (Figure 16-39). Restoration of implant patients may also require treatment prostheses for similar reasons. In addition, the pretreatment prosthesis may be used to select a prosthetic option, to progressively load bone to improve its strength, and as a transitional restoration to protect a healing bone graft or implant. Immediate restoration after insertion of an implant system often uses a transitional prosthesis out of occlusion in a partial edentulous situation. In a completely edentulous patient, the transitional immediate load restoration has no cantilevers in nonesthetic areas. Treatment prostheses may also help evaluate the psychologic attitude of a patient before irreversible implant procedures are begun (Box 16-5).

Diagnosis in medicine is the first step to establishing a treatment for a disease or disorder. Likewise, to establish a treatment plan for a partially or completely edentulous patient, a proper diagnosis should be established. A treatment prosthesis may be required to help in this process. For example, questionable teeth may require initial restoration to assess their prognosis related



FIGURE 16-39. **A,** The patient has a collapsed occlusal vertical dimension (OVD) and a poor occlusal plane. When the final result is not clear to the restoring dentist, a treatment prosthesis is often a benefit to assess and reestablish prosthetic parameters. **B,** An acrylic removable partial denture in place is used as a treatment prosthesis to reestablish the proper OVD, jaw position, plane of occlusion, temporomandibular joint status, speech, and potential prosthetic result.

BOX 16-5 Implant Treatment Prostheses

1. Help with diagnosis
   a. Crown lengthening
   b. Occlusal plane
   c. Hopeless teeth
2. Evaluate the psychologic profile of the patient.
   a. Denture before implant surgery
3. Improve soft tissues before final impression for implant overdentures.
4. Postoperative to implant surgery
5. Evaluate occlusal vertical dimension.
6. Evaluate temporomandibular joint dysfunction.
7. Improve implant position related to final tooth position.
8. Evaluate esthetics before surgery.
9. Evaluate hygienic contours of fixed restorations.
10. Determine whether removable restoration is required for maxillary lip support (RP vs. FP).
11. Protect bone graft or implants during healing.
12. Patient's financial and compliance management.
13. Progressive bone loading
14. Phonetics and esthetics for full-arch implant–fixed prostheses on complete edentulous patients

RP, Removable prosthesis; *FP,* fixed prosthesis.

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to whether or not the extraction of the tooth and implant replacement therapy is required.

A treatment prosthesis may correct the existing occlusal plane; identify extruded teeth; and indicate whether endodontic therapy, crown lengthening, or extraction is required to complete the final treatment plan. Remember, after prosthetic crown lengthening is performed, at least 4 mm of tooth structure should be supracrestal (2 mm for connective tissue and junctional epithelial attachment and 2 mm to create a ferrule effect with the crown to reduce the risk of root fracture). As a consequence, the crown–root ratio is increased, and the mobility of the tooth should be evaluated after treatment. Excessive mobility may require additional implants, splinting teeth, or even extraction and additional implant insertion.

A partially edentulous patient with three or more adjacent teeth missing often wears a fixed-treatment prosthesis, which also acts as an interim prosthesis. Metal-reinforced transitional prostheses may be used when three to five pontics are present. These fixed, transitional treatment restorations may be used during bone grafts or healing of implants to decrease forces on the soft tissues that transmit forces the graft or healing implants.

Progressive Load

A pretreatment prosthesis to improve the quality of bone is most always used in D3 or D4 bone-supporting implants before the fabrication of the final restoration. Interim (provisional) acrylic restorations that gradually load bone for progressive loading may be considered pretreatment prostheses. A decrease in crestal bone loss and decrease in implant failure, especially in soft bone types, are particular advantages with progressively loaded treatment prostheses. Pretreatment prostheses also assist in the determination of the final form and function of the final prosthesis, especially for completely edentulous patients, for whom the "pretreatment" prosthesis may be the first full-arch–fixed restoration they have worn after several years of wearing a complete denture.

Financial Barriers

An additional benefit of pretreatment prostheses is that patient financial management may be facilitated and compliance issues resolved before more irreversible phases of treatment are rendered. However, it is beneficial to clearly establish the cost and emphasize the need to progress forward with treatment in an orderly fashion. Very few pretreatment or transitional restorations may be worn for years without risk of fracture, uncementation, or compromises in the bone graft or implants.

Removable Prostheses

Treatment prostheses may be used to improve the soft tissues used for support, stability, or retention before RP-5 overdentures or complete denture restorative procedures. The first evidence of residual ridge destruction by an ill-fitting denture is often deformed and traumatized overlying soft tissue.[69] The soft tissue bed may exhibit different degrees of redundant hyperplasia, epulis, hypertrophy, or abrasions.[70] A tissue conditioning treatment is usually indicated to restore soft tissue health before making the final impression for the soft tissue bone prosthesis.[71] Additional treatment such as surgical removal of excessive hypermobile tissues is often warranted before soft tissue conditioning. The soft tissue conditioner may need to be replaced every 2 to 3 days (although 10 to 14 days is usually sufficient) to return the soft tissue to normal condition. The existing denture can often be used as the treatment prosthesis. Modification for tissue conditioning or to wear over healing implants is usual.

It should be noted that soft tissue conditioners are different from soft liners used in soft tissue support areas of removable prostheses. Tissue conditioners change dimensions during the first 18 to 24 hours. As such, as the tissues return to a more normal condition, the material changes dimension to allow and encourage these changes. However, the modifiers required for this reaction leach out of the material, halt the process within a day, and result in a stiff material. Soft liners, on the other hand, stay soft longer than tissue conditioners, especially when coated with a sealer. However, the material does not change dimension during the first day and therefore will not accommodate a changing tissue condition.

Most often, tissue conditioners are used to improve abused tissues before a final soft tissue impression for a removable prosthesis. In addition, these materials are used after implant surgery in regions under a removable prosthesis while the implant–bone interface heals. The tissue conditioner may respond to the swelling and tissue changes immediately after soft tissue reflection. In addition, it is relieved over the implant site. At the suture removal appointment, the tissue conditioner is removed and replaced with a sealed soft liner. This material stays soft during extended periods and is less likely to load the implant through the soft tissue.

Occlusal Vertical Dimension

Long-term edentulous patients who have been wearing the same denture may require a treatment prosthesis to restore the OVD and ridge relationship before implant treatment.[72] The OVD may gradually collapse, especially in a completely edentulous patient, as a result of continued bone loss and prosthesis occlusal wear. TMJ and myofacial dysfunction may be the further consequence of this condition. A treatment prosthesis to reestablish the proper OVD or assess a symptomatic joint helps determine the patient's specific needs regarding the dysfunction.

As the OVD decreases, the mandibular jaw rotates forward and closes in a more prognathic pseudo skeletal class III relationship. To place the implants in the correct angulation, the OVD should be reestablished before implant surgery so the correct position of the teeth relative to the arch is established.

A pretreatment prosthesis for a completely edentulous patient before the delivery of a fixed- or removable-implant prosthesis is most often a complete denture. It is fabricated with acrylic teeth to facilitate recontouring and the addition of cold-cured acrylic for repairs or to change the OVD or lip support.

In the case of immediate implant loading for a completely edentulous patient, a treatment prosthesis is delivered at or soon after the implant surgery. The design of the prosthetic superstructure concomitant with the implant substructure is necessary for immediate loading in implant overdentures. Therefore, a treatment prosthesis is indicated to establish the proper OVD and tooth position before the placement of the implants and fabrication of the superstructure bar.

As the OVD increases in the skeletal class III patient, the maxillomandibular relationship evolves toward a class I relationship. This influences the position or angulation of the implant. In addition, the location of an overdenture bar may be equally influenced by variations of the OVD. The treatment

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prosthesis may be used to establish the prosthetic position of the teeth.

Esthetic Assessment

On occasion, a patient's desire for esthetic improvement may be very demanding or unrealistic. In a completely edentulous patient, a treatment denture may be used to evaluate if the esthetic concerns can be satisfied before implant surgery. Tooth shape, surface quality, size and position, tooth color, lip and soft tissue contour, tooth position, gingival color, soft tissue contour, and papilla support may all be evaluated.[73] If the patient cannot be satisfied with the pretreatment prosthesis, it is far better to realize this before implant placement. Although demanding patients may not be satisfied with the pretreatment prosthesis, they can decide to lower expectations and continue with treatment or be referred to another dentist. If the latter is chosen, it is prudent to contact the next practitioner and inform him or her that another pretreatment prosthesis is indicated before implant placement.

A high lip line in the maxilla or low lip line position in the mandible may influence the need for a specific gingival contour and color in the restoration, yet the maintenance needs of the restoration may compromise the final esthetic result. A fixed restoration must be designed to allow access for proper hygiene procedures around the teeth and implants. A pretreatment prosthesis may help determine whether an implant-supported removable prosthesis rather than a fixed restoration is required to satisfy the patient's esthetic goals and desires for the restoration yet may be removed to allow proper daily maintenance.

The maxillary vermillion border of this lip is usually altered by the loss of the maxillary anterior teeth. After bone is also lost, the natural support of the entire lip is often deficient and depends on the labial flange of the prosthesis. A FPD may require an anterior cantilever away from the soft tissue in a horizontal and vertical dimension to provide this support. A pretreatment prosthesis can provide the information required to determine whether a fixed prosthesis will compromise esthetics, support, or hygiene in this region above the teeth.

Psychologic Attitude

The finalized treatment plan and patient's physical and mental evaluation should be assessed before implant surgery. If the restoring dentist is not sure the planned final prosthesis is compatible with the desires of the patient or the patient's attitude and demand do not seem reasonable, further evaluation is required. A pretreatment prosthesis provides additional appointments and time for these evaluations.[73,74]

Summary

Preimplant prosthodontics for partially edentulous patients includes overall evaluation of five intraoral segments: (1) the maxillary incisal edge, (2) the OVD, (3) the mandibular incisor edge, (4) the maxillary occlusal plane, and (5) the mandibular occlusal plane. In addition, 10 specific criteria affect a treatment plan: (1) lip lines, (2) maxillomandibular relationships, (3) existing occlusion, (4) CHS, (5) TMJ status, (6) extraction of hopeless or guarded-prognosis teeth, (7) existing prosthesis, (8) arch form, and (9) soft tissue evaluation. Pretreatment prostheses are also used in an implant prosthetic evaluation process (Box 16-6).

BOX 16-6 Treatment Sequence for Implant-Supported Reconstructions

The proposed treatment for implant-supported reconstructions performed by the implant team can be as follows:

Initial Appointments
Medical and dental history
Dental evaluation and x-ray examinations
Diagnostic casts
Preliminary discussion of treatment alternatives
Decision to proceed with treatment
Initial treatment plan, case presentation, and alternatives
Clinical and laboratory procedures before additional diagnostic records
Extra-office diagnostic orders (e.g., setup, computed tomography scans, tests for medical evaluation, consultation, and team members)
Diagnostic wax-up of final results on duplicate diagnostic casts
Final treatment plan and alternatives
Medical laboratory tests evaluated
Prescriptions and postoperative instructions
Consent forms and request for treatment forms
Pictures of existing condition

Phase I Dentistry
Presurgical restorative appointment—initial caries removal, extractions, temporary teeth
Periodontal treatment, endodontic therapy, orthodontics
Occlusal vertical dimension
Occlusal plane correction, treatment prosthesis, recontour existing teeth, enameloplasty
Transitional prosthesis (removable or fixed) or diagnostic try-in; tissue conditioning
Impression for surgical guide template (if oral condition altered from initial diagnostic cast)

Preimplant Reconstructive Surgery Osseous (Grafting), Soft Tissue
Implant surgery

Stage I: Implant Placement
Healing phase

Stage II: Secondary Permucosal Extension, Initial Loading
Prosthodontics: progressive bone loading
Initial abutment preparation and impression
Final abutment preparation and impression
Metal try-in or waxed teeth try-in
Initial delivery—occlusal
Final delivery—occlusal adjustment
Night guard

Maintenance
First year: every 3 to 4 months
Radiographs at 6 months, then annually for 3 years, then as required
Home care education
Fluoride on teeth
Chlorhexidine on implants

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The prosthodontic evaluation of an implant candidate borrows several conventional criteria from the evaluation of natural abutments. In addition, many of these situations require a unique approach for implant prosthodontics and may influence the implant treatment plan. The goal of the implant surgeon is to achieve predictable, rigid fixation of endosteal implants. The restoring dentist's responsibility is to maintain the implant–bone interface in an environment that satisfies all the traditional prosthodontic criteria.

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CHAPTER 17

Natural Teeth Adjacent to an Implant Site: Joining Implants to Teeth

Carl E. Misch

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A common prosthetic axiom is to provide a partially edentulous patient with a fixed prosthesis whenever possible. Implant dentistry may often provide the additional abutments necessary to fulfill this goal regardless of the number of teeth missing. The ability to add abutments in specific locations, rather than being limited to a particular remaining natural abutment that may not always be in optimum health, enables the dentist to expand this prosthetic axiom to most partially edentulous patients.

The dentist most often uses implants as independent support for the restoration. On rare occasion, the implant may be splinted to the natural teeth in the same prosthesis. In either situation, the treatment plan is strongly influenced by the dental evaluation of the remaining natural abutments adjacent to the edentulous site.

Natural teeth may require additional therapy before the final prosthesis can be completed. It is best to communicate with the patient regarding all required treatment involved in the rehabilitation process before the surgical placement of the implants. Otherwise, treatment outcome, sequences, and cost may conflict with the originally projected result and lead to dissatisfaction, the need to modify the original treatment plan, or a poorer prognosis.

Whether considered for abutment support or not, teeth adjacent to a partially edentulous site are evaluated thoroughly and from a different perspective than the rest of the dentition.[1,2] In the previous chapter, the conditions that warrant extraction of the tooth are presented. In this chapter, the tooth adjacent to the edentulous site is planned to be maintained. However, on occasion, the adjacent tooth exhibits bone loss next to the edentulous site and presents a less than optimal quality of health. As a consequence, the available bone characteristics immediately adjacent to the tooth are highly influenced by its presence. Often this is a determining factor in the choice between an independent implant prosthesis, a traditional fixed partial denture (FPD), or a removable restoration. When multiple teeth are missing, the treatment becomes even more complex with additional restorative options, such as whether implants and natural teeth may serve as abutments in the same prosthesis.

The dental criteria of the adjacent tooth to an edentulous space addressed in this chapter are (1) abutment options, (2) adjacent bone and soft tissue anatomy, (3) cantilevers, (4) implants connected to teeth, (4a) mobility (of teeth and implants, (4b) splinting natural abutments, (4c) natural and implant pier abutments, and (5) transitional abutments (Box 17-1).

Abutment Options

Several options are available for the adequate restoration of an edentulous segment. Before the 1990s, when implants were used in a partially edentulous patient, a three- or four-unit FPD was fabricated with an implant used as one terminal abutment along with a natural tooth separated by one or two pontics[3,4](Figure 17-1). When the osseointegrated implant concept for completely edentulous fixed prostheses was introduced in the mid 1980s, the concept was modified for partially edentulous arches to make an implant prosthesis as an independent unit. The primary reason for this approach was to limit the cantilever effect of a "mobile" tooth joined to a "rigid"

BOX 17-1 Teeth Adjacent to Implant Site

1. Abutment options
2. Adjacent bone and soft tissue anatomy
3. Cantilevers
4. Implants connected to teeth
   a. Mobility (of teeth and implants)
   b. Splinting natural abutments
   c. Natural and implant pier abutments
5. Transitional abutments

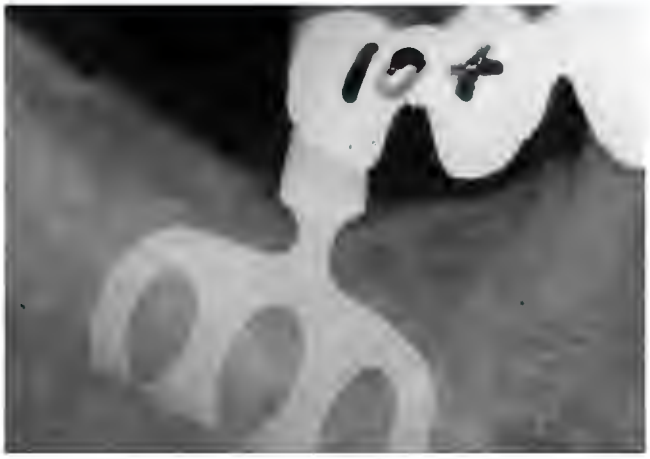


FIGURE 17-1. Before the 1990s, implants were often inserted into the jaws of partially edentulous patients and splinted to a natural tooth in the same fixed prosthesis.

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implant[5,6] (Figure 17-2). However, the primary advantage of two separate prosthetic units is more related to reduced biologic complications of the tooth rather than biomechanical implications on the implant.

Under ideal conditions, placing implant abutments in sufficient number to fabricate a completely separate implant-supported prosthesis has several biologic advantages. The most common cause of failure of tooth-supported fixed prostheses is caries of the abutment teeth.[7] Unrestored natural teeth do not decay as often as restored teeth, and implant abutments do not decay. In addition, the pontic between splinted abutments (whether natural teeth or a tooth and an implant) acts as a plaque trap. As a result, whereas a crown on a natural tooth has a decay rate of 1% at 10 to 15 years, an abutment for a FPD has a caries rate of more than 20% (Figure 17-3). The second most common cause of fixed prosthesis failure is endodontic failure or complications of a natural tooth abutment. Implant abutments do not need endodontic therapy. Unrestored natural teeth are less likely to require endodontics. Therefore, the natural tooth should not be splinted to an implant under ideal conditions. The 10-year survival rates indicate a greater than 25% improved survival rate for implant prosthesis compared with FPDs supported by natural teeth (or natural teeth splinted to implants) because the natural tooth is more prone to biologic complications.[8,9]

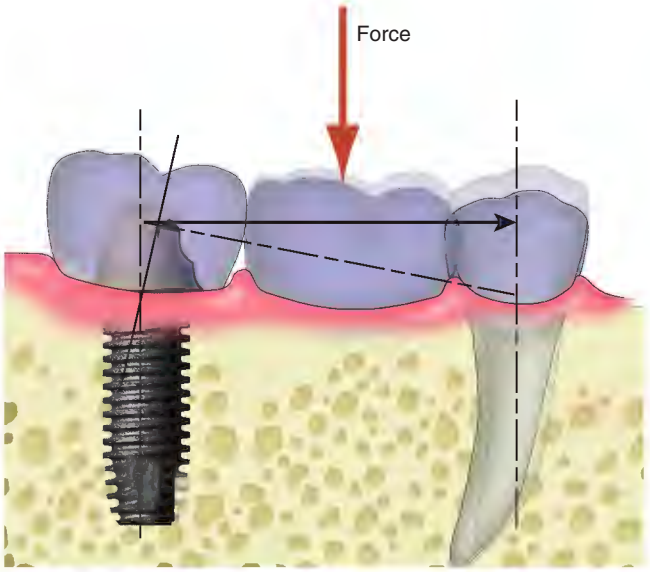


FIGURE 17-2. Splinting a rigid implant to a natural tooth has caused concerns relative to the biomechanical differential in movement between the implant and tooth. Because the tooth moves more than the implant, the implant may receive a moment force created by the "cantilever" of the prosthesis.

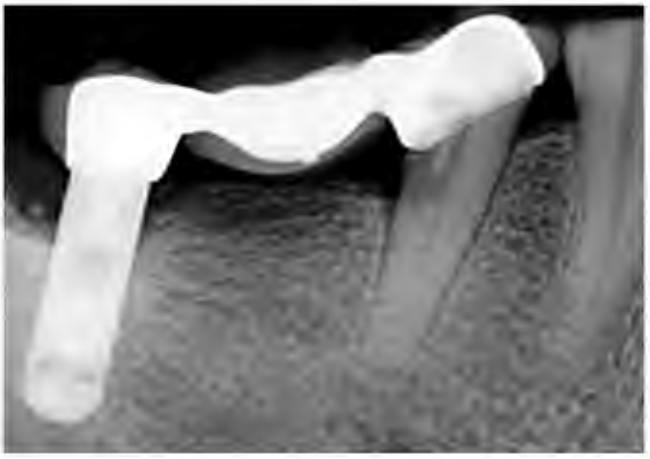


FIGURE 17-3. When an implant is splinted to a natural tooth, separated by a pontic, the pontic acts as a plaque trap and increases the risk of decay on the natural tooth.

Compared with unrestored natural teeth, natural teeth abutments are more difficult to clean; collect and retain more plaque; are often more temperature or contact sensitive; and are more subject to future prosthetic, periodontal, or endodontic treatment. Caries, endodontic problems, or both may cause not only a loss of the fixed prosthesis but also almost as often lead to the failure and extraction of at least one of the natural tooth abutments. As a result, an independent implant restoration is the treatment of choice for almost every multiple-tooth edentulous site in a partially edentulous patient. In addition to the biologic advantage of independent implant prostheses, there is also a biomechanical advantage. Natural teeth respond to occlusal forces differently than implants. Whereas a light force produces most of the recorded movement of a tooth, the amplitude of implant movement is related directly to the force applied.[6–8,10–11] In arches with implant and natural abutments, it is easier to adjust the occlusion when these entities are two independent units.

When planning an independent implant prosthesis, instead of using a natural tooth as one of the terminal abutments, the dentist usually requires the addition of at least one more implant. An increase in implant abutment number enhances the implant–bone interface and therefore reduces the stress to the support system and improves the ability of the fixed restoration to withstand additional forces when necessary. In addition, because of the additional retentive units, uncemented or unretained restorations occur with less frequency. Unretained restorations are the third most common complication reported in fixed prosthodontics.[7,8]

Abutment screw loosening is a complication reported for implant prostheses, especially during the first year.[9,11,12] The increase in implant number also decreases the amount of forces on the abutment screws and thus reduces the risk of abutment screw loosening. As a result, many reasons justify the use of a sufficient number of implants for an independent prosthesis. So many advantages exist for an independent implant-supported fixed prosthesis with multiple units that such a treatment is always the first choice when possible (Figure 17-4).

Unfortunately, completely implant-supported fixed prostheses in partially edentulous patients are not always feasible and on occasion carry a higher surgical risk. Thus, the natural tooth occasionally may be considered a potential abutment. However, the dentist should consider splinting of implants and natural teeth within the same prosthesis only when the surface area of the implant support does not permit replacement of the total number of missing teeth and additional implant placement is not indicated.

Adjacent Bone Anatomy

When one or more missing teeth are between existing teeth, the bone position on the adjacent roots is thoroughly evaluated, especially when the missing tooth is in the esthetic zone. Ideally, the bone on each adjacent anterior tooth next to the edentulous site should be 2.0 mm or less from the interproximal

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FIGURE 17-4. An independent implant prosthesis is the treatment of choice even when the adjacent tooth requires a crown.



FIGURE 17-6. Orthodontic extrusion of a tooth adjacent to an implant site may advance the interproximal bone more coronally and modify the soft tissue drape.

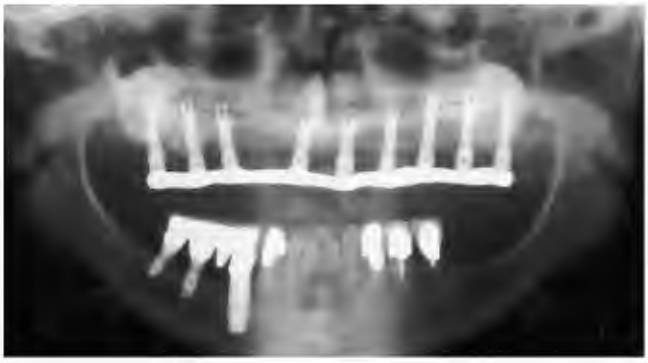


FIGURE 17-5. The implant in the mandibular right first premolar site is positioned more than 6 mm below the canine cementoenamel junction. Although bone is present on the distal of the canine, the soft tissue slope around the implant creates a soft tissue pocket greater than 5 mm and increases the risk of periimplant complications.

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cementoenamel junction (CEJ) (which is 3 mm above the facial CEJ). When this anatomy is present, the interdental papilla adjacent to the edentulous site will be ideal because it is supported by the interproximal bone on the tooth.

The edentulous bony structure adjacent to a natural tooth varies in height, width, length, and angulation and is a reflection of the history of the former tooth, its extraction, and the period of time the site has been edentulous. If the ridge topography is not ideal for endosteal implant placement in the site immediately adjacent to the natural abutment, the dentist should consider a bone graft or a pontic. An osteoplasty needed to obtain adequate bone width in the area adjacent to a natural tooth often compromises the adjacent natural root support; increases the crown height of the final implant restoration; and affects the esthetic outcome, especially in the interdental papilla region (Figure 17-5). Therefore, osteoplasty to gain additional width is usually not indicated adjacent to a natural tooth.

If an ideal prosthodontic abutment position is adjacent to a natural tooth and inadequate bone width is available, augmentation of the edentulous site before implant insertion may improve the bone anatomy without compromising the natural abutment. In case of inadequate bone width volume adjacent to a tooth with adequate bone on the root next to the site, the dentist considers treatment options to graft the site in width to permit division A or B implant placement.

Inadequate bone height adjacent to a tooth offers a poorer prognosis for augmentation than in other situations. In general, to grow bone in height is more difficult than to grow it in width. In addition, when the inadequate bone height of the edentulous site includes the region adjacent to a natural root (and results in horizontal bone loss on the tooth root), the ability to grow additional bone height becomes even more unpredictable and is usually unsuccessful.

Bone height augmentation is not predictable on a natural tooth root with a horizontal defect. If the natural tooth root has lost bone adjacent to the site, the bone augmentation in height usually will not occur above the existing position of bone on the root. There are four alternatives for inadequate bone height adjacent to a natural tooth. The first option is orthodontic extrusion of the tooth before the bone graft. When one of the teeth has a poor adjacent bone anatomy, orthodontic extrusion to elevate the interproximal bone of the tooth is considered. The orthodontic movement will increase bone height next to the tooth and improve the bone graft prognosis. After this is accomplished, a bone graft in the implant site is more predictable (Figure 17-6). However, the tooth or teeth usually require endodontics and restoration after the orthodontic extrusion process.

A second option is extraction of the adjacent tooth and augmentation of the adjacent edentulous site and the extraction socket. This is more often indicated when only one tooth adjacent to the implant site is compromised and the orthodontic extrusion is not indicated on this tooth because the amount of root in the bone is inadequate. In such cases, after the orthodontic extrusion, endodontics, and restoration, the end result is still a compromised tooth as a consequence (Figure 17-7).

The third treatment option is the fabrication of the three-unit FPD. This is often the most predictable and less expensive treatment option. In a study by Tarnow et al., if the interproximal bone to interproximal contact region of the crown is more than 5 mm, the interdental papilla will often be depressed.[13] However, when this distance is 6 mm, 40% of the papilla regions will appear within normal limits, and when 7 mm, 25% of the adjacent papilla will appear normal. When the interproximal bone between the two teeth adjacent to an edentulous site is not ideal on both of the adjacent teeth but the interdental

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FIGURE 17-7. When one tooth adjacent to the edentulous site is compromised (the central incisor), an option is to extract the tooth (when orthodontic extrusion is not indicated) and graft two adjacent sites before implant insertion.



FIGURE 17-9. When an implant is surgically placed when the adjacent tooth does not have adequate height of bone on the adjacent root surface, the tissue often shrinks and compromises the soft tissue drape.



FIGURE 17-8. The edentulous site has bone height loss and the bone is lost on the roots of the adjacent teeth to an edentulous site, but the soft tissue drape is adequate. A three-unit fixed partial denture is often the treatment of choice to replace the missing tooth. In this case, the maxillary right central incisor is a pontic, supported by the adjacent teeth.

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papilla is within ideal limits, consideration is given to leaving the soft tissue as it is and fabricating a three-unit FPD (Figure 17-8). If an implant is attempted and the interproximal bone is not ideal, the soft tissue often shrinks after the surgery, and the soft tissue drape is compromised around the implant and, as important, exposes the root of the adjacent teeth.

The fourth option is to place a pontic next to the natural tooth (Figure 17-9). An implant apically positioned more than 3 to 4 mm below the CEJ and interproximal bone level of the adjacent natural tooth root presents potential soft tissue contour problems (Figure 17-10). When the most distal natural tooth has inadequate bone height on the root, the soft tissue between the tooth and adjacent implant creates a more shallow slope, unlike the steep drop of the level of the bony crest between the elements. Under these conditions, a soft tissue pocket greater than 6 mm may result around the implant crown adjacent to the natural tooth (see Figure 17-5). Therefore, when a bone graft for height around a multitooth edentulous site is required to place an implant adequately adjacent to a natural root, the dentist should consider a pontic to replace the missing element next to the natural tooth. The pontic may be supported by a cantilever from implants or teeth or using dual support from teeth and implants.

In summary, if the bone is inadequate in height on the tooth root and implant site, the following should be done: (1) orthodontic extrusion and graft, (2) extract and graft two sites, (3) fabricate a three-unit FPD, or (4a) cantilever a pontic from two or more natural teeth or two or more division A implants or (4b) fabricate a fixed prosthesis with one pontic connecting an implant with one or two adjacent teeth, depending on the adjacent tooth status.

Cantilevers in Partial Edentulism

Cantilevers in fixed prostheses result in moment loads or torque on the abutments.[14] They are used more frequently for implant-supported prostheses than natural teeth abutments.[15,16] Several widely diverging guidelines have been recommended for the use of cantilevers in partially edentulous patients, ranging from almost no extension at all to the cantilever of several teeth.[16,17] The cantilevered prosthesis is often problematic. The most common complication for a cantilevered restoration from natural teeth is uncementation of the abutment farthest from the cantilever.[8,18] When a pontic is cantilevered, the abutment next to the pontics is a fulcrum, and an occlusal force on the pontic places a tensile and shear force on the more distal abutment (Figure 17-11). Cement is almost 20 times weaker in tension compared with compression forces. For example, the compressive strength of zinc phosphate cement is 12,000 psi, but its tensile strength before fracture is only 500 psi. As a result, the most common complication is an unretained crown on the more distal abutment; then the fulcrum abutment becomes mobile and loses bone, fractures, or both.

It is interesting to note that cantilevers with natural teeth abutments are rarely used in conventional prosthetics. The failure rate of a traditional three-unit FPD at 5 years is often less than 5%. However, the 5-year failure rate of cantilevered three-unit FPD is 25%, and 60% have complications.[8,19] The failure

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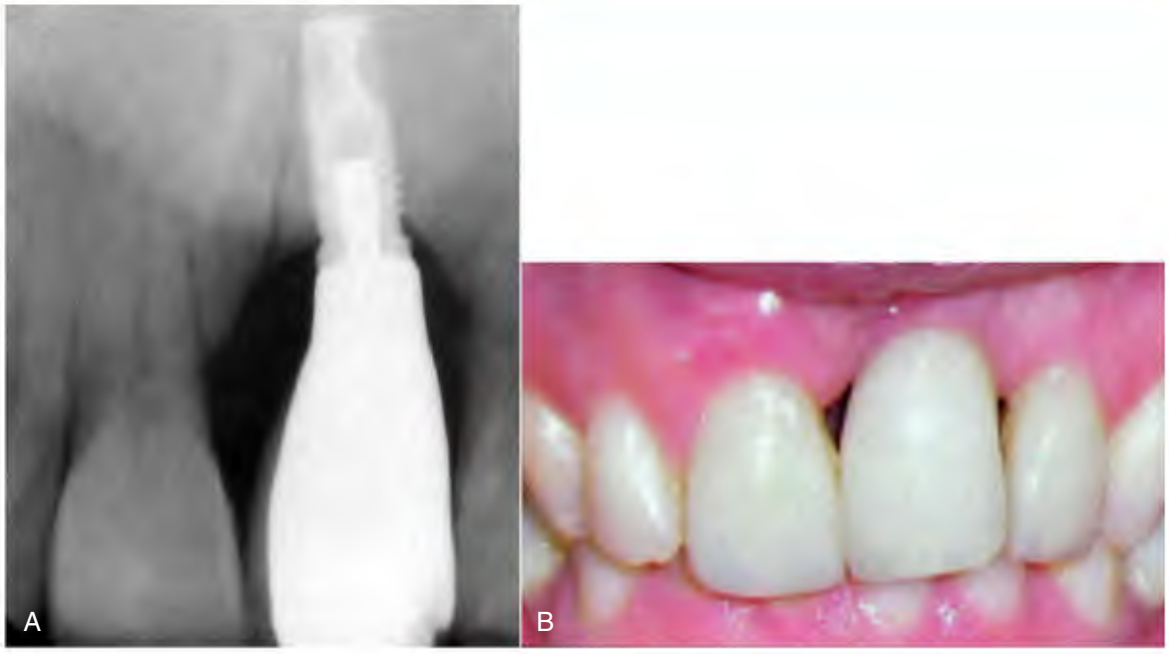


FIGURE 17-10. **A,** The implant is positioned several millimeters below the adjacent cementoenamel junctions of the adjacent teeth. **B,** The soft tissue drape had receded and compromised the cervical and interproximal esthetics.

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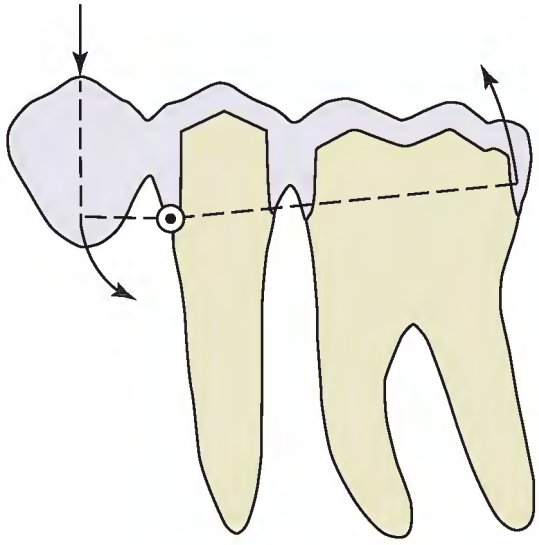


FIGURE 17-11. The most complications for a cantilevered pontic from two natural teeth is an unretained prosthesis. A compressive force on the pontic transfers a shear and tensile force to the distal abutment.

is usually related to an uncemented abutment (farthest abutment from the cantilever), and the failure is biomechanical in nature. The traditional three-unit FPD fails more often from biologic conditions (e.g., decay, endodontics), which takes longer to occur. Implants are more rigid than teeth. As a consequence, the force to the cement seal is *greater* with implant abutments than teeth! The adjacent implant to the pontic acts even more as a fulcrum. In other words, it is worse to cantilever on implants than natural teeth (Figure 17-12).

The force on the cantilever may be compared with a class I lever. The distance between the most anterior and most distal abutments is divided by the length of the cantilever to determine

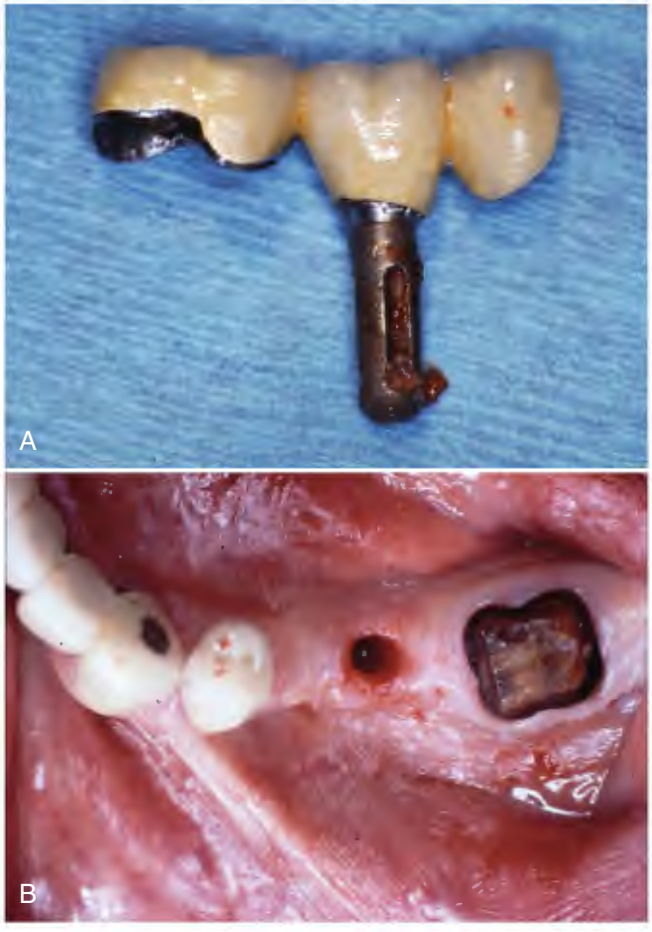


FIGURE 17-12. **A,** A failed implant and three-unit fixed partial denture. The implant served as an abutment next to the pontic. **B,** The cement seal broke and resulted in the prosthesis entirely supported by the implant, which failed. There is also decay on the natural tooth.

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the mechanical advantage to the farthest abutment from the cantilever. Takayama has suggested that the cantilever should not extend beyond the distance between the implants to keep the mechanical advantage less than one times this distance.[20] The most common distance between two implant centers is 7 to 8 mm so that the outer dimensions of the implants may be 3 mm apart and the crowns on the implants are similar in size to a premolar. Thus, the size of the cantilever (when considered) should not be greater than a premolar of similar size when two implants support the three-unit prosthesis.

The most important factor in determining the safe length of the cantilever is the amount of force the patient places on the cantilever. For example, a cantilever may have a mechanical advantage (force multiplier) of two times. Hence, if a 25-lb load is applied to the pontic, a 50-lb force (tensile) is applied to the distal abutment, and 75 lb is applied to the fulcrum (class I lever mechanics). Hence the force is magnified two to three times. However, if the load on the pontic is 100 lb, it is magnified to 200-lb force on the distal abutment and a 300-lb force on the fulcrum or four times more than the first example. In other words, the amount of the force applied to the cantilever is even more important than the length of the cantilever or the distance between the implants.

Cantilevers on implants are more problematic than on teeth for several reasons. The magnification of forces are to the entire implant system. The cement or screw that retains the prosthesis may fail (Figure 17-13). The implant may fracture (Figure 17-14). The implant may become mobile and lost. These complications are often more significant than a cantilevered restoration supported by natural teeth.

Ideally, if a cantilever is necessary, it should extend mesially, rather than distally, to reduce the amount of occlusal force on the lever.[6] (Figure 17-15). A cantilever of a lateral incisor from two or more adjacent implants is the least at risk because the canine tooth (implant) can protect lateral forces on the cantilever and the anterior region has less bite forces and the lateral incisor is the smallest tooth in the arch.

The crown height also influences the amount of the force on the cantilever to the cement and bone interface. The force is magnified by the crown height when any lateral force or cantilever is present[14] (Figure 17-16). An angled force on a cantilever is more detrimental than a force in the long axis of the abutments. As such, the cantilever magnifies any other force factor presented and therefore should be used with caution. When cantilevers are used in the final restoration, the occlusion on the cantilevered pontics should be reduced, with no contact on the cantilevered pontic during mandibular excursions.

Cantilevers on two implants should not be used when force factors are moderate to severe or when other force factors are present. Instead, additional implants or grafting and implants positioned without cantilevers typically reduce complications. When the cantilever forces are too great, the dentist should consider joining the implants to adjacent teeth to eliminate the cantilever effect (Figure 17-17). There is often less biomechanical risk of joining an implant to a tooth than using a cantilever to replace the missing tooth or teeth.

Implants Connected to Teeth

As previously mentioned, before 1988, many practitioners connected an implant to one or two natural teeth.[3,4] These implants were designed to have either a fibrous tissue or a direct bone interface.[21,22] When the root form osseointegration concept of Brånemark for full-arch edentulous fixed prostheses became



FIGURE 17-13. **A,** A distal cantilevered three-unit FPD from two implant abutments. **B,** The prosthesis became uncemented from the most distal abutment from the pontic, and bone loss occurred on the fulcrum abutment.

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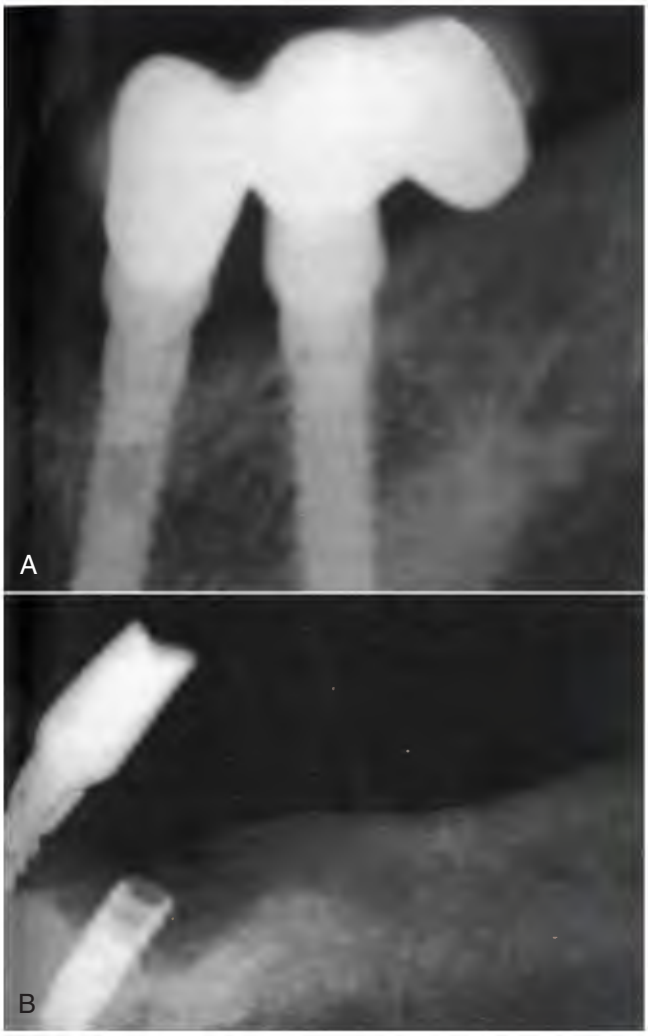


FIGURE 17-14. **A,** A three-unit fixed partial denture cantilevered to the distal. **B,** The prosthesis became unretained from the abutment most distal from the cantilever, and the fulcrum implant fractured.

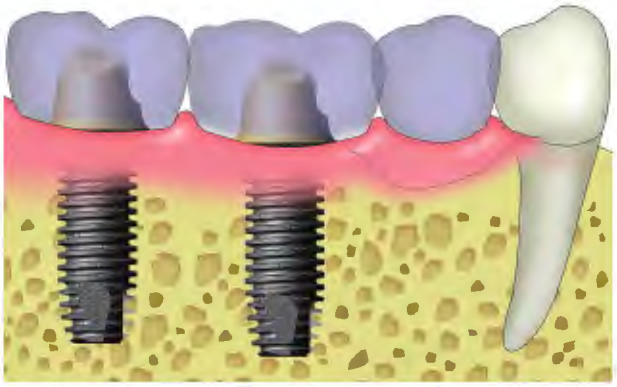


FIGURE 17-15. If a cantilever is required, it is beneficial to cantilever to the anterior to reduce the bite force.



FIGURE 17-16. A crown height increase further magnified the force on a cantilevered restoration. The two implants fractured within a few years as a result of the cantilever and increase in crown height.



FIGURE 17-17. **A,** A posterior implant with a cantilevered crown to the mesial. **B,** The implant fractured within a few years. It is often more predictable to join an implant to a natural tooth than to cantilever from one implant.

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more dominate in the mid 1980s, these implants came to be used in partially edentulous arches. It was hypothesized at the time that joining a rigid implant to a natural tooth would cause biomechanical complications on the implant, implant prosthesis, or both.[5,6] Since that time, several reports have indicated that a rigid implant may be joined to a natural tooth in the same prosthesis.[16,23,24] In fact, implant-cantilevered prostheses in partial edentulous patients have more reported complications than when implants are joined to teeth.

There are more partially edentulous patients missing posterior teeth than anterior teeth. As a result, the most common scenario for which a root form implant may be joined to a natural tooth is in the posterior regions. Of these cases, the most common scenario is as a terminal abutment in a patient missing the molars. For example, if a patient is missing the first and second molars in a quadrant (with no third molar present), the segment requires at least two implants of proper size and design to independently restore these two teeth. If adequate bone exists in the second molar and distal half of the first molar but inadequate bone exists in the mesial half of the first molar, a premolar-size pontic is required. The pontic may be cantilevered from the anterior natural teeth or the posterior implants. Either of these options may result in complications because of tensile forces on the cement seal of the abutment farthest from the pontic.

An alternative may be to join the implant(s) to a natural tooth if all other factors are favorable. This treatment option is more likely in the presence of a division C–h ridge in the pontic region when inadequate bone height adjacent to the natural tooth decreases the prognosis of a vertical bone graft. This option is also available when a posterior implant is positioned too distal to restore with a single crown. It is almost always better to splint the implant to the adjacent tooth rather than fabricating a cantilevered crown from one implant. Another scenario in favor of this treatment plan is when the posterior implants are of a narrower diameter than usual. When two division B root forms are used in the posterior mandible to replace molars, there should be no cantilever to magnify the force on the implants. Posterior pontics should not be cantilevered from even two splinted division B root form implants because they will have a greater biomechanical risk. An additional root form implant or a natural tooth is usually required as an abutment for the fixed prosthesis. When an additional implant insertion is not an option, the posterior implants may be joined by a rigid connector (i.e., a solder joint) to a natural tooth or teeth within the prosthesis, provided all dental factors are favorable.

The connection of natural teeth and osseointegrated implants within a single rigid prosthesis has generated concern and publications, with studies and guidelines for both extremes (Figure 17-18).[5,6,24,25] In other words, some articles report problems, but others state that no problem exists. To be more specific to a particular situation, more information is required to design a successful treatment plan. Two prosthetic designs are available for the connection of implants and teeth within the same prosthesis: a conventional FPD or a FPD with a nonrigid connector. To address this issue, the mobility of the natural abutment should be assessed.

Mobility: Vertical Movement

Implant and Tooth

The mobility of potential natural abutments greatly influences the decision to join implants and teeth more than any other factor. In the implant-tooth rigid fixed prosthesis, five

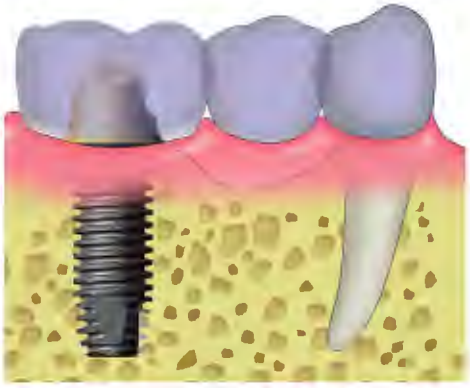


FIGURE 17-18. Joining an implant to a natural tooth, separated by a pontic, may be an acceptable treatment option.

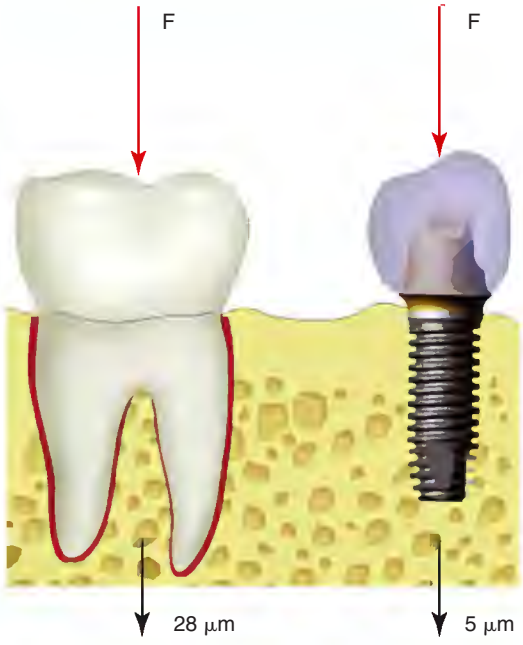


FIGURE 17-19. Whereas a vertical force (F) on a tooth results with 28-micron movement, an implant moves only 2 to 5 microns.

components may contribute movement to the system: the implant, the bone, the tooth, the prosthesis, and implant and prosthetic components.

The tooth exhibits normal physiologic movements in vertical, horizontal, and rotational directions. The amount of movement of a natural tooth is related to its surface area and root design. Therefore, the number and length of the roots; their diameter, shape, and positions; and the health of the periodontal ligament primarily influence tooth mobility.[26] A healthy tooth exhibits no clinical mobility in a vertical direction. Actual initial vertical tooth movement is about 28 microns and is the same for anterior and posterior teeth.[15] The immediate rebound of the tooth is about 7 microns and requires almost 4 hours for full recovery, so additional forces applied within 4 hours depress the tooth less than the original force.[27] The vertical movement of a rigid implant has been measured as 2 to 5 microns under a 10-lb force and is mostly attributable to the viscoelastic properties of the underlying bone[28] (Figure 17-19). The implant movement is not as rapid as the tooth movement because the

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tooth movement is a consequence of the periodontal ligament, not the surrounding bone elasticity.

Prosthesis Movement

The fixed prosthesis that connects a tooth and implant also illustrates movement. Under a 25-lb vertical force, a prosthesis with a 2-mm connector fabricated in noble metal results in a 12-micron movement for one pontic and 97-micron movement for a two-pontic span.[29,30] (Figure 17-20). Therefore, the FPD movement helps compensate for some difference in vertical mobility of a healthy tooth and implant.

Implant and Prosthetic Components

Rangert et al. reported an in vitro study of a fixed prosthesis supported by one implant and one natural tooth and showed that the abutment or gold cylinder screw joint of the system also acts as a flexible element.[31] The inherent flexibility matched the vertical mobility of the natural tooth. Therefore, the minimal movement of the tooth and the fact that implant, prosthesis, and abutment components have some mobility indicate that the risk is small in the vertical direction with the biomechanical difference of an implant and a tooth in the same prosthesis when one or two pontics separate these units.

Horizontal Movement

Tooth Mobility

Horizontal tooth mobility is greater than vertical movement. A very light force (500 g) moves the tooth horizontally 56 to 108 microns (Figure 17-21). The initial horizontal mobility of a healthy, nonmobile posterior tooth is less than that of an anterior tooth and ranges from 56 to 75 microns, which is two to nine times the vertical movement of the tooth.[10] Initial horizontal mobility is even greater in anterior teeth and ranges from 90 to 108 microns in healthy teeth.[27]

Muhlemann found that tooth movement may be divided into initial mobility and secondary movement.[10] The initial mobility is observed with a light force, occurs immediately, and is a consequence of the periodontal ligament. If an additional force is applied to the tooth, a secondary movement is observed, which is related directly to the amount of force. The secondary tooth movement is related to the viscoelasticity of the bone and measures up to 40 microns under considerably greater force (Figure 17-22). The secondary tooth movement is similar to implant movement.

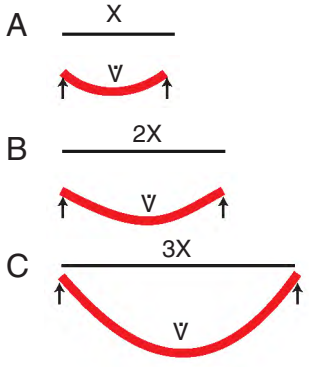


FIGURE 17-20. Bridge flexure is related to the cube of the span between abutments. Whereas a one-pontic prosthesis may flex 12 microns, a two-pontic prosthesis flexes up to 97 microns.

Implant Mobility

The implant–bone interface also exhibits lateral movement. Sekine et al. evaluated the movement of endosteal implants with rigid fixation and found a range of 12 to 66 microns of movement in the labiolingual direction.[28] Komiyama measured 40 to 115 microns of implant movement in the mesiodistal direction under a force of 2000 g (≈4.5 psi) and a labiolingual range of 11 to 66 mm[32] (Figure 17-23). The greater implant movement in the mesiodistal dimension corresponds to the lack of cortical bone around the implants in this direction compared with the thicker lateral cortical plates present in the labiolingual dimension. Therefore, the mobility of implants varies in direct proportion to the load applied and the bone density and reflects the elastic deformation of bone tissue.

Although the implant has a range of mobility, the mobility is related to the viscoelastic component of bone, not the physiologic aspect of a periodontal membrane. As such, when the

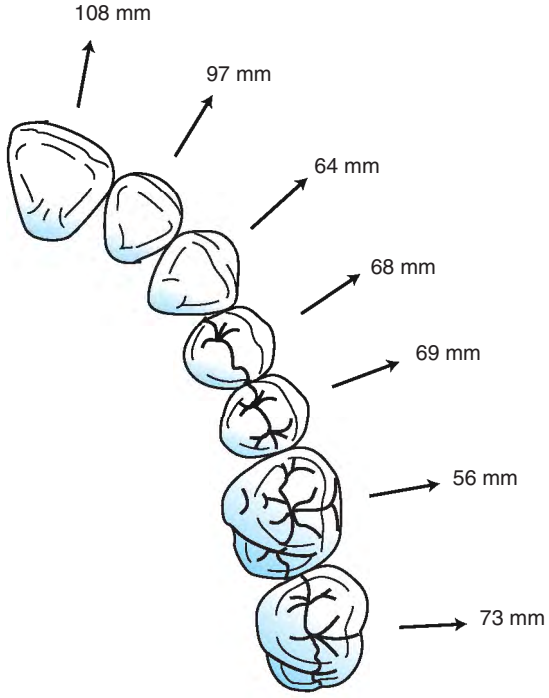


FIGURE 17-21. A healthy natural tooth may move laterally from 56 to 108 microns, with anterior teeth moving more than posterior teeth.

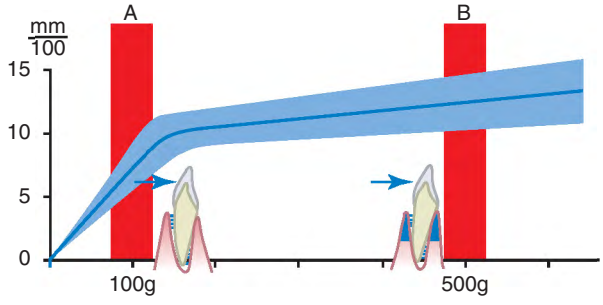


FIGURE 17-22. Teeth have a primary tooth movement related to a periodontal ligament. This accounts for the 28-micron apical and 56- to 108-micron lateral movement. They also have a delayed secondary mobility related to the viscoelastic nature of bone.

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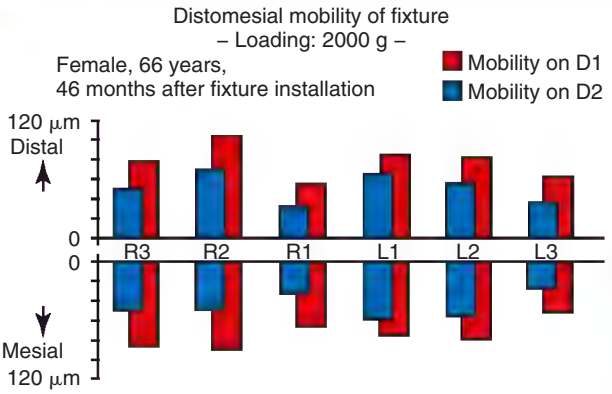


FIGURE 17-23. Implant movement is more mesiodistal than faciolingual, reaching values between 40 and 115 microns.[32]

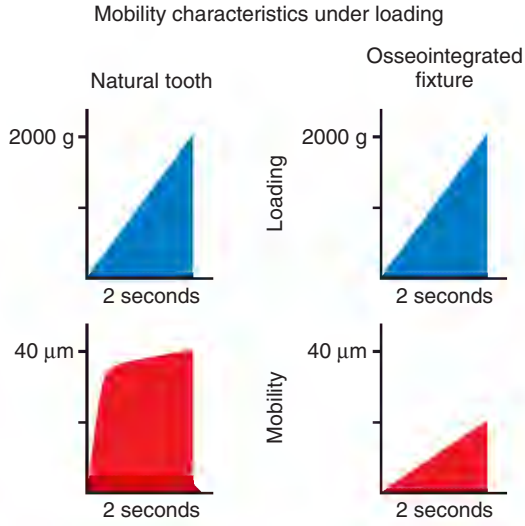


FIGURE 17-24. Sekine compared tooth movement with a gradual load over 2 seconds *(left)* with implant movement.[28] The secondary tooth movement was similar to implant movement.

implant and tooth are loaded in the same prosthesis, the tooth immediately moves (primary tooth movement), and then the tooth and implant move together. In other words, secondary tooth movement is similar to implant movement because they both depend on the viscoelasticity of the bone. In a study by Sekine et al., when a tooth was gradually loaded over a 2-second period, the tooth immediately moved 36 microns and then gradually moved an additional 6 microns.[28] The implant gradually loaded had movement directly related to the amount of load and eventually moved as much as 22 microns. Hence, the secondary tooth movement was similar to the implant movement (Figure 17-24).

An interesting note in implant mobility is that no significant difference was related to implant length. This finding further confirms that implant length is not the primary factor for implant support even in the presence of lateral loads. Bone density affects this condition more than implant length. These mobility characteristics are consistent with the findings of Fenton et al., who applied a 500-g load for 4 seconds to maxillary anterior teeth and osseointegrated implants.[33] The implants were displaced a mean 10 microns with a rapid elastic return (less than 1 msec), but the teeth showed a mean displacement of 57 microns with a prolonged viscoelastic return.

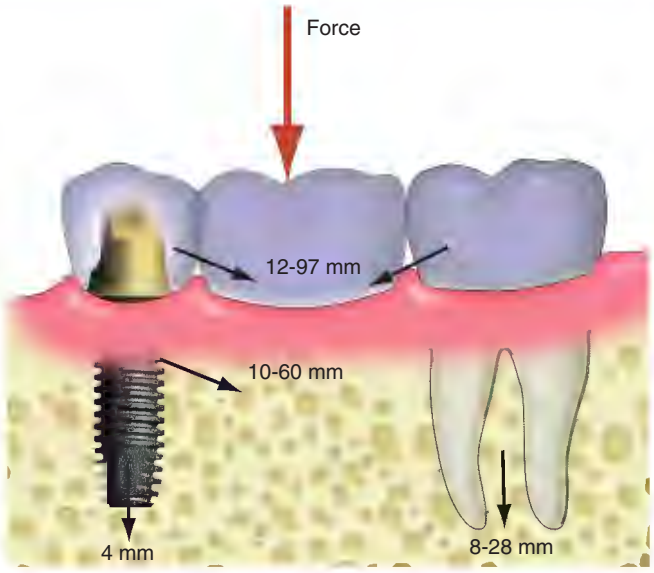


FIGURE 17-25. A three- or four-unit precious metal prosthesis with an implant and a posterior tooth rigidly splinted has some inherent movement. The implant moves apically 0 to 5 mm, and the tooth moves apically 8 to 28 mm but can rotate up to 75 mm toward the implant because of a moment force. The metal in the prosthesis can flex from 12 to 97 mm, depending on the length of the span and the width of the connecting joints. The abutment-to-implant component movement may be up to 60 microns because of abutment prosthetic screw flexure. As a result, a vertical load on the prosthesis creates little biomechanical risk when joined to a nonmobile tooth.

Therefore, when all factors are considered, an implant moves vertically and horizontally, the abutments and prosthesis flex, and the tooth has apical and lateral movements. However, the major difference in movement between implants and teeth is more related to the direction of movement (the horizontal dimension is more compared to much less difference in the vertical dimension).

Guidelines for Joining Implants to Teeth

To decrease biomechanical conditions, which increase the risk of complications, a requisite to join an implant to a natural tooth is that no lateral force should be designed on a unilateral prosthesis. Lateral forces increase the amount of tooth movement and decrease the amount of implant movement (faciolingual vs. mesiodistal). Horizontal forces placed on an implant also magnify the amount of stress at the crestal bone region.[34]

A vertical movement or force placed on a posterior implant joined to a healthy posterior tooth causes mesial tension on the implant. The implant can move vertically 3 to 5 microns and mesially 40 to 115 microns, and a noble metal–fixed prosthesis with one pontic allows mesiodistal movement of 6 microns (Figure 17-25). Therefore, a natural tooth with no clinical mobility could be connected rigidly to an osseointegrated implant with no lateral forces because the implant, bone, and prosthesis compensate for the slight tooth movement. Finite element, photoelastic, and clinical documentation confirm that implants can be connected rigidly to stable teeth.[35-38] However, the occlusion should be modified to allow the initial occlusal contacts on the natural tooth so that the implant does not bear the major portion of the initial load.[34]

The lateral mobility of healthy anterior incisor teeth often is recorded as (+) with a range of movement from 90 to

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108 micron. Therefore, visual clinical evaluation by the human eye can detect movement greater than 90 microns. When the horizontal mobility of a natural tooth (anterior or posterior) can be observed, mobility is greater than 90 microns and too great to be compensated by the implant, bone, and prosthesis movement. When the vertical posterior tooth movement, vertical implant movement, mesiodistal implant movement, and prosthesis movement are compared with the same conditions of a "mobile" tooth with lateral loads, the biomechanical risk factors are not the same. Therefore, one of the primary conditions for joining an implant to natural teeth is the lack of observable clinical movement of the natural abutment during functional movement. Hence, nonmobile posterior teeth with no lateral forces on the prosthesis may join rigid implants. However, implants rarely should be connected to an individual anterior tooth because (1) anterior teeth exhibit more than 10-fold greater clinical mobility than the implant, and (2) the lateral forces applied to the restoration during mandibular excursions are transmitted to the natural tooth and implant abutments (Figure 17-26).

Implants should not be joined to mobile teeth with rigid attachments, which basically adds a cantilever on the implant (the tooth acting as a living pontic). If the natural teeth are too mobile in relation to the implant in the same prosthesis, several complications may occur and be detrimental to the tooth and implant. If the prosthesis is cemented, movement may break the cement–implant abutment seal. Cement does not adhere as well to titanium as to dentin. In addition, the mobile tooth will move (which decreases the impact force) rather than break the cement seal on the tooth. However, the rigid implant will have greater stresses applied to the cement (or screw) retained crown. After the prosthesis is loose from the implant, greater stress is applied to the natural mobile tooth. The tooth may increase in mobility as a result or fracture as a consequence (especially when endodontic procedures were performed).



FIGURE 17-26. An implant joined to an anterior tooth or lateral forces applied to a natural tooth is at greater risk of biomechanical overload. The lateral force on the tooth causes greater movement than a vertical force. Anterior teeth receive more lateral loads than posterior teeth. The lateral loads are transferred to the implant. Lateral loads on the implant increase the amount of crestal bone stresses.

A mobile attachment between the implant and natural tooth is usually not a benefit. A mobile attachment moves more than an implant or a tooth. Therefore, it is not an "attachment." The pontic is cantilevered from the implant with little to no support from the tooth. It is usually better to have a rigid connector between implants and teeth than a mobile attachment.

When the natural abutment exhibits clinical horizontal movement or conditions promote horizontal forces against the abutment tooth, two options can be selected for the final prosthesis. The first, and the option of choice, is to place additional implants and to avoid the inclusion of natural abutments in the final prosthesis. This may include the extraction of the mobile tooth and replacement with an implant. The other option is to improve stress distribution by splinting additional natural abutments until no clinical mobility of the splinted units is observed.

Guidelines for Splinting Dental Units

Splinting natural teeth does not decrease the mobility of a tooth significantly after the prosthesis is removed; however, the overall prosthesis movement is decreased, especially when the splinted units form an arch. If posterior contacts cannot be eliminated in lateral excursions as a result of skeletal relationships or when opposing a removable prosthesis, splinting a mobile tooth often is safer to reduce the risk of long-term complications. In addition, splinting natural abutments also decreases the amount of load to each abutment (when a 150-psi load is distributed to all splinted abutments, the resultant force on each abutment is decreased)[39] (Figure 17-27).

The number of teeth to splint together is the number required to eliminate prosthesis movement. The initial dental evaluation may include acid etching and bonding potential mobile natural abutments to each other to determine how many teeth must be joined to reduce the abutment–prosthesis clinical mobility to zero. The dentist should also apply the following prosthetic guidelines when splinting teeth together:

1. The last tooth connected in the splint should not be mobile. In other words, to decrease mobility, at least the last tooth in the splint (and sometimes more) should be rigid.
2. The terminal abutments in the splint should not have poor retention form of the crown.
3. Adjacent teeth splinted together should be parallel enough to have the same path of insertion for the prosthesis.
4. Adjacent teeth should not be crowded or overlapped and should have enough room for splinted crowns to have adequate interproximal hygiene.

A classic axiom for splinting teeth in prosthodontics reads, "It is unadvisable to employ the last tooth as a splinted abutment if it lacks a degree of firmness comparable to its healthy neighbor, because the strain on the firm abutment could be destructive."[18] Implant prostheses may use additional secondary natural abutments to decrease the movement of the prosthesis so that rigid fixation of the implant will not be compromised. However, if the last abutment is mobile, it does not serve the intended purpose. Therefore, a general guideline is not to end a fixed prosthesis on the weakest splinted abutment. The weak tooth does not offer additional support and further burdens the healthier abutments. In addition, if cement failure occurs or the restoration needs retrieval, the partially retained prosthesis is more difficult to retrieve from the mobile abutment, resulting in more frequent coronal fracture and other complications.

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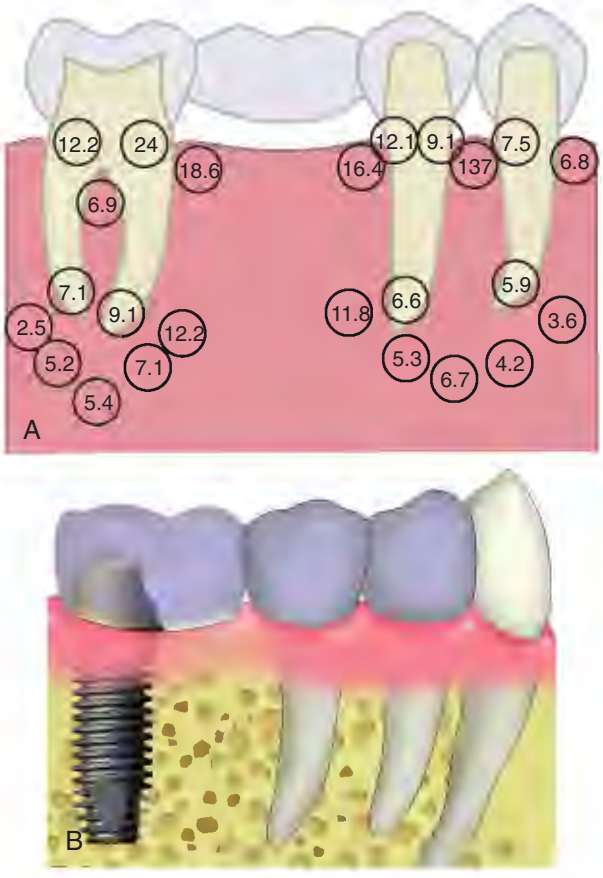


FIGURE 17-27. **A,** Splinting natural teeth together decreases their mobility and reduces the amount of stress transferred to the support system. (From Y. Ismail, Pittsburgh, PA). **B,** When the terminal natural tooth is slightly mobile, splinting an adjacent tooth is indicated.

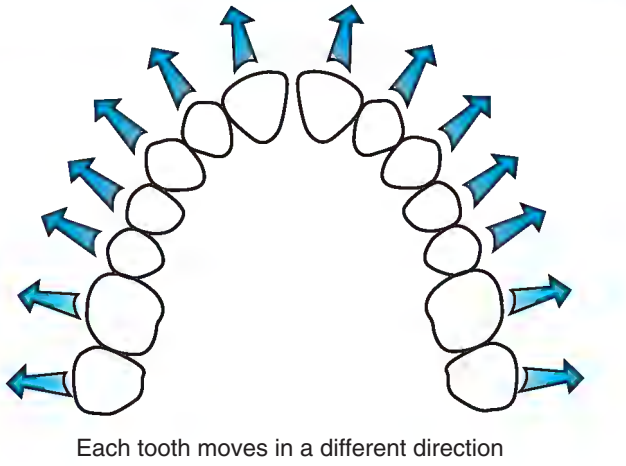


FIGURE 17-28. Because the teeth are positioned around an arch, their faciolingual movement is not in the same plane.

The natural teeth exhibit some faciolingual movement, which varies from 56 to 108 microns in health. The discussion here is to reduce tooth movement when it is visible so that the mobile teeth may be connected to the implants. Although the teeth move in a faciolingual direction, different regions of the arch have different directions of movement relative to each other. In other words, the faciolingual direction of the anterior teeth corresponds to the mesiodistal direction of the posterior teeth; therefore, if these dental units are splinted to each other, the splint may become nonmobile (Figure 17-28).

A dental arch may be described as a five-sided structure.[1] The posterior teeth on one side move in a similar direction to each other, the canine moves in a different direction, the anterior teeth move in a third direction, the contralateral canine moves in yet a different direction in comparison, and the other posterior component of the arch moves in a similar direction as the first. The more dental sections are connected, the more rigid the structure. As a general rule, three or more sections rigidly connected create an overall nonmobile dental structure. Even mild to moderate individual mobile dental units may become a nonmobile single unit.

The approach of joining implants to mobile teeth in several different arch positions is usually limited to conditions when the multiple sections of the dental arch already require restoration. Rarely would one consider crowning eight or more teeth solely to splint to the implant component. Instead, the use of a natural tooth pier abutment may be indicated.

The last tooth in a splinted prosthesis should not have poor retentive form. When a force is applied to the terminal region of a multiple-splinted restoration, the pier abutments may act as a fulcrum. As a consequence, tensile and shear forces may be applied to the cement seal. Because the cements are 20 times weaker in shear compared with compressive forces, the cement seal may break. As a consequence, the natural abutment often decays and may be lost. Hence, the most distal tooth in a splinted restoration should have adequate height and retentive form.

The adjacent teeth should be able to have the path of insertion as all the dental units in the prosthesis (Figure 17-29). It may be necessary to perform endodontics or even extract an offending tooth to accomplish the goal of splinting across an arch.

The adjacent teeth that are splinted together should not be overlapped or crowded (Figure 17-30). It may be necessary to have orthodontics or selective extractions to prepare the teeth for a similar path of insertion as the implant prosthesis. When the adjacent teeth are splinted, enough interproximal tooth tissues must be removed to permit adjacent metal crowns, connectors, and porcelain to be applied and maintain interproximal hygiene (Figure 17-31).

In conclusion, the natural abutment connected to a rigidly fixated implant should not exhibit clinical mobility or poor retentive form. These same two criteria should be considered for the natural tooth used as a secondary abutment when splinting teeth in a FPD.

Nonrigid Connectors

Although nonrigid connectors have been advocated in the literature,[18,40] a nonrigid connector in a unilateral prosthesis rarely is indicated for implant-fixed prostheses and may be detrimental. Nonrigid connection does not improve the stress distribution between the different abutments[36,38] and has been reported to have caused migration of the natural teeth.[41-43] If the nonrigid connector exhibits any clinically observed mobility, it moves more than the implant. As such, the implant-supported part of the restoration is cantilevered to the attachment. In addition, the nonrigid (or mobile) attachment adds cost, creates overcontoured abutments, impairs daily hygiene, and does not decrease the clinical tooth movement.

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FIGURE 17-29. The teeth splinted together should be parallel enough to the implants, so they all have the same path of insertion for the prosthesis.



FIGURE 17-30. Potential teeth that will be splinted together should not have rotations or overlapping.



FIGURE 17-31. Enough space between the roots of teeth should exist so when splinted together, interproximal hygiene is possible.

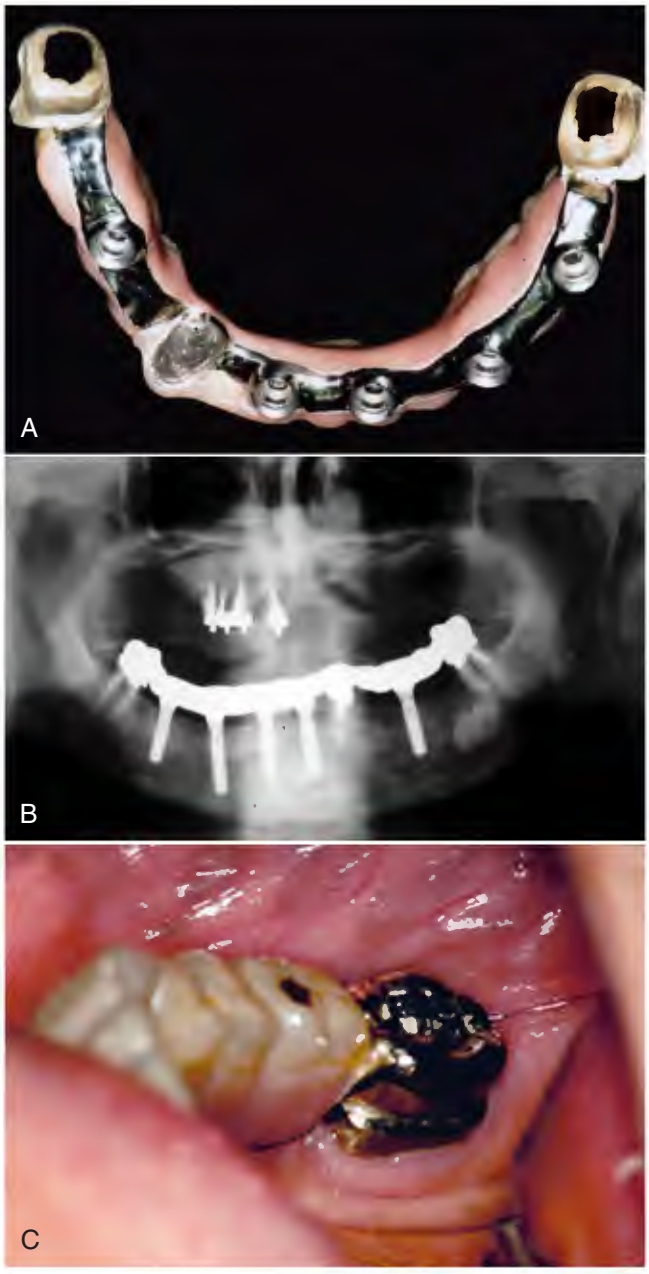


FIGURE 17-32. **A,** An implant prosthesis fabricated to join implants and teeth in the same prosthesis. Copings were designed for the teeth. **B,** A panoramic radiograph of the implants and prosthesis in place. **C,** The teeth intruded from the prosthesis. The cement seal must separate in order for the tooth to intrude (or a nonrigid connection exists between the units).

Reports of intrusion of the natural tooth connected to an implant usually include the use of temporary cement to lute a coping to the natural abutment, leaving the final restoration uncemented on the coping, or the use of a nonrigid connector[41] (Figure 17-32). When implants are joined to teeth that act as a terminal abutment, a definitive cement should be used for the natural tooth. The tooth cannot intrude unless it becomes unretained from the abutment (or has a nonrigid connector between the units).

A possible explanation for tooth intrusion may be that the tooth is pushed vertically 28 microns but wants to rebound only 8 microns. The fixed prosthesis rebounds immediately and pulls on the tooth. The cement seal eventually breaks, causing a space to develop, which is first occupied by air. The prosthesis then acts as an orthodontic appliance and continually pushes the tooth in a vertical direction. Eventually, the space is occupied by saliva, and hydraulics continue the downward force

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during mastication. The tooth eventually submerges or intrudes from the prosthesis.

Implant Pier (Intermediary) Abutments

A pier abutment is one between two other abutments, sometimes referred to as an intermediate abutment. The intermediate abutment may be an implant or a natural tooth, and each type plays a different role in the overall treatment. When an implant serves as a pier abutment between two natural teeth, the difference in movement between implant and tooth may increase the complication rate compared with one intermediate tooth joined to two terminal implants (Figure 17-33). The pier implant abutment exhibits less movement than the natural teeth terminal abutments and acts as the fulcrum of a class I lever. As a consequence, a compressive force on one end of the prosthesis is converted to a tensile or shear force on the other terminal abutment.[18] The cement tensile strength is often 20 or more times less than the compressive strength. Therefore, when the implant acts as a fulcrum, an uncemented abutment (usually the least mobile tooth or least retentive crown) is a common consequence, with decay being the next most common occurrence.

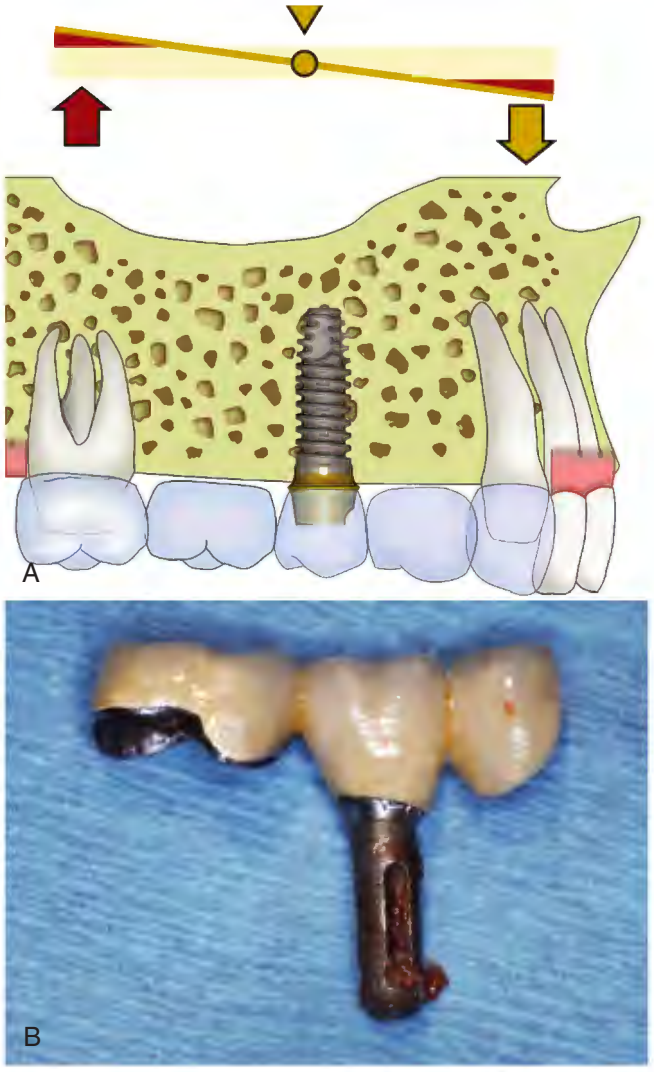


FIGURE 17-33. A pier implant abutment between two natural teeth may cause a cement seal to break on the teeth, especially if one is more mobile than the other.

This problem is magnified by a longer lever arm such as a pontic between the implant and tooth, when the natural tooth or teeth have clinical mobility, the force is lateral on the prosthesis, or the forces are greater than usual. A pier implant abutment may cause complications even when joined to nonmobile teeth as terminal abutments.

Uncemented restorations are a common complication in FPDs even when all aspects of treatment are within acceptable limits. Any condition that may increase this problem, such as the one presently addressed, should be carefully avoided. When bone grafting is not an option and additional implants cannot be inserted, a mobile attachment can be used to help restore the implant pier abutment (Figure 17-34). A nonrigid attachment connects the implant and the least nonmobile tooth to prevent the implant pier abutment from acting as a fulcrum.

The nonrigid attachment is used between the implant and the more mobile tooth. In conventional fixed prostheses, the "male" portion of a nonrigid attachment usually is located on the mesial aspect of the posterior pontic, and the "female" portion is in the distal aspect of the natural pier abutment tooth. This prevents mesial drift from unseating the attachment.[40] However, an implant does not undergo mesial drifting, and the nonrigid connector location is more variable in location.

Natural Tooth Pier Abutments

When a natural tooth rather than an implant serves as a pier abutment between two or more implants, the situation is completely different from the previous scenario. When the two or more implants may support the load of the prosthesis alone, the natural tooth becomes a "living pontic" (Figure 17-35). In other words, the tooth is not needed to support the prosthesis, and the rigid terminal abutments constitute the entire support system for the prosthesis. In absence of the tooth, the dental unit would be a pontic without compromise. Because the tooth has greater mobility than the terminal implants and does little to contribute to the support of the prosthetic load, it is referred to as a pontic with a root, or a "living pontic." No more than one adjacent site should be a pontic, so a three-"pontic" span does not exist. Therefore, this scenario is best when no

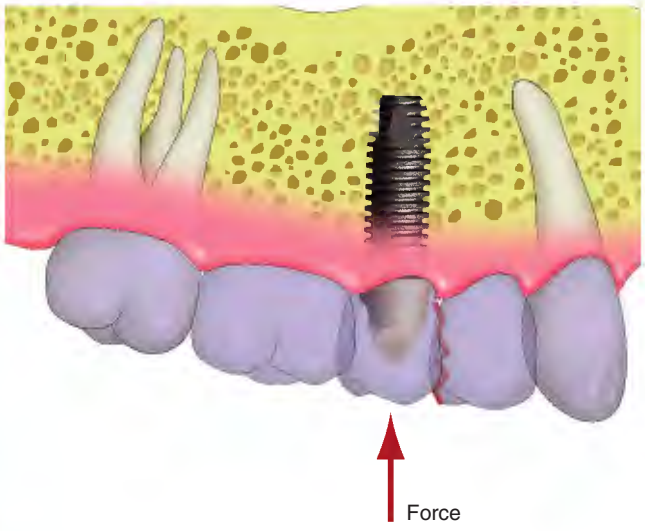


FIGURE 17-34. When grafting and additional implants are not an option, a mobile attachment may be used to prevent the pier implant from acting as a fulcrum.

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additional pontics are between the implants and the tooth. For a natural pier abutment between two implants, a stress breaker is not indicated.

On occasion, multiple implants in a full-arch prosthesis are splinted together to cantilever one or two pontics, yet a healthy, natural tooth is positioned between the implants. The tooth essentially is ignored in the development of the treatment plan, other than the dentist having to fabricate a crown rather than a pontic in the splinted prosthesis (Figure 17-36). One advantage of keeping the natural tooth, even though it does not contribute to the support of the prosthesis, is the proprioceptive aspect of the periodontal complex.[34] Implant prostheses have higher bite forces during mastication than natural tooth restorations because of the decrease in occlusal awareness. A living pontic may decrease the interaction of the forces found during function.

Transitional Natural Abutments

On occasion, because of the lengthy aspect of implant treatment, especially when bone regeneration procedures are indicated before implant placement, initially maintaining strategic teeth (even with a poor prognosis) as interim restoration abutments may be desirable. These teeth are often terminal abutments that support a fixed temporary restoration, protect edentulous implant or graft areas from mastication trauma, and avoid the use of a removable soft tissue–borne partial interim prosthesis. These teeth are extracted after initial implant healing, and often these teeth are in an ideal implant site for the final restoration. When this occurs, the implant then is placed in the extraction site as a second surgical phase. This approach is beneficial to provide the patient with a fixed transitional prosthesis and to avoid soft tissue–supported restorations on bone augmentation sites but may extend the overall treatment by 6 months.

The transitional abutment scenario is most common in a full-arch rehabilitation patient who has a full-arch fixed transitional restoration on periodontally involved teeth. The prognosis of these abutments may be poor, mandating their extraction (less than 5-year survival category). However, if all the compromised teeth are extracted, the patient must wear a full immediate denture as a temporary prosthesis while grafting and implant insertion phases are performed. The psychologic and physiologic changes associated with a denture, even if a temporary solution, may have dramatic consequences for the patient. These patients may benefit greatly from a stepped approach in which a few poor, short-term, asymptomatic dental elements are maintained while all others are extracted for the sole purpose of providing the patient with a fixed temporary restoration[44] (Figure 17-37).

The careful selection of the transitional abutments must not hinder the implant treatment. However, an extended treatment time with additional implant placement surgery may be required. For example, four compromised teeth dispersed throughout the arch may be kept for a fixed transitional restoration. Meanwhile, other sites are extracted, grafted, and implanted. When these implants are healed and ready to be restored, the "temporary" natural abutments may be extracted and additional implants placed. The healed implants now may support the transitional prosthesis. The new implants, on occasion when the bone density and biomechanical factors permit, may be immediately restored with a modified transitional restoration.

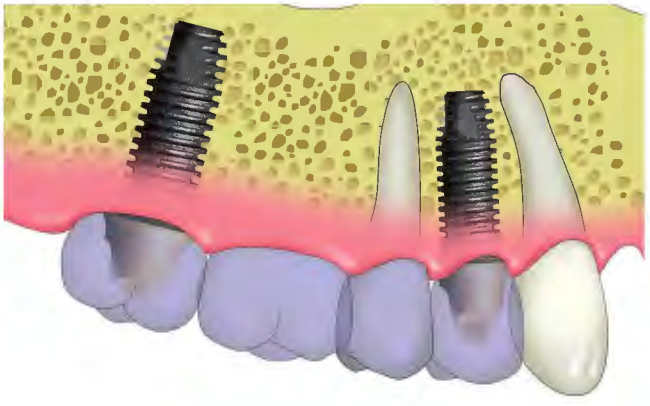


FIGURE 17-35. When a natural tooth serves as a pier abutment between two or more implants, the tooth may act as a "living pontic." No stress breaker is needed in this situation.

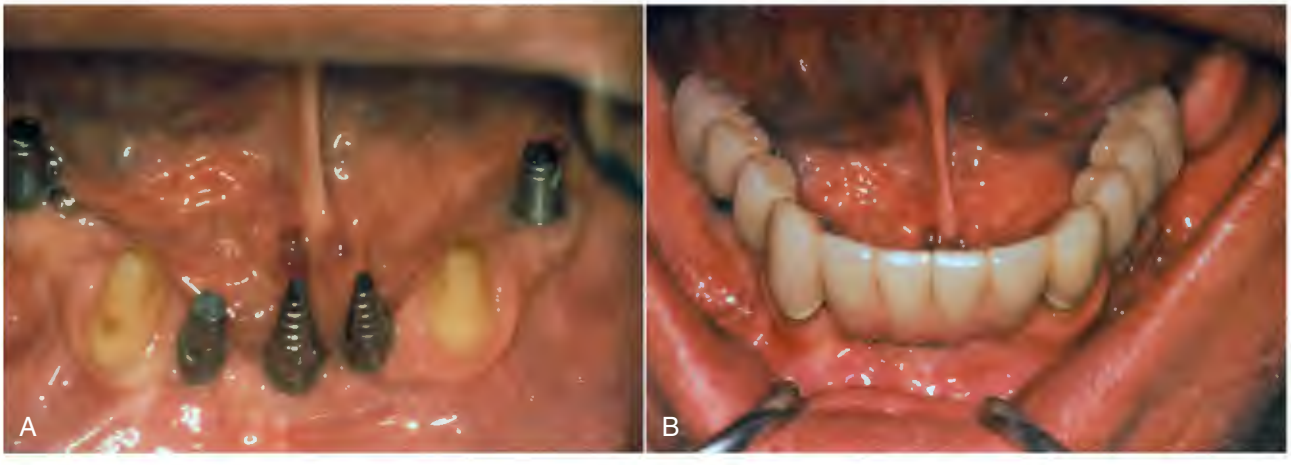


FIGURE 17-36. **A,** The mandibular restoration has five implants and two natural teeth splinted together, so a cantilever may be used to replace the posterior teeth. The five implants support the load of the restoration. The natural teeth pier abutments act as living pontics. **B,** An intraoral view of the fixed prosthesis. The natural teeth may give some proprioception to the restoration, especially when in the canine position. The support of the restoration is primarily from the implants, which surround the teeth and are splinted together.

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FIGURE 17-37. **A,** A panoramic radiograph of hopeless maxillary teeth. **B,** The teeth were splinted together with a transitional acrylic restoration to replace the missing teeth. **C,** The prosthesis was removed. **D,** Implants were inserted in strategic extraction sites, and three teeth remained to support the transitional prosthesis during initial integration of the implants. **E,** The transitional prosthesis was relined and recemented on the three transitional teeth.

The advantage of the transitional abutment procedures is that a fixed prosthesis maintains the patient throughout treatment, protecting the implant surgical site during the submerged healing phase. Disadvantages include additional cost, increased time, risk of implant site contamination if any problem or flare-up of natural abutments occurs, and increased risk for the initial implants because the foundation is not completely sufficient for support until the additional implants are healed. The dentist should weigh the advantages and risks of such a treatment carefully before proposing it to a patient.

A fixed interim prosthesis in an edentulous arch also may be supported by three to six additional implants placed in function immediately at insertion to permit the fabrication of a temporary fixed prosthesis while all other implants are submerged.[45] The dentist evaluates these additional implants at the time of final prosthesis fabrication and may or may not include them in the final restoration, depending on their status at that time. Transitional mini-implants also have been developed to that effect.

Caution is needed in using additional implants of normal or minimized dimensions because the volume of bone used for their placement may be of strategic value during treatment and risks being destroyed by fibrous tissue formation or bone resorption when immediately loaded, which may affect a final

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prognosis. Such treatment options are indicated only on a case-by-case basis.

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CHAPTER **18**

Diagnostic Casts, Surgical Templates, and Provisionalization

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The long-term success of dental implant treatment begins with comprehensive treatment planning and ideal implant placement surgery. It is widely accepted that the ideal implant position is driven by the final prosthetics according to esthetics, function, and biomechanical factors. If dental implants are not surgically placed ideally with respect to these factors, prosthetic complications may result, increasing the morbidity of the case. Thus, to minimize the possibility of malpositioned implants, a comprehensive diagnostic treatment plan ideally should be completed often with the use of radiographic and surgical templates.

This chapter emphasizes important components of the diagnostic phase of implant treatment planning. Guidelines for ideal implant positioning are discussed and implemented into treatment planning principles along with fabrication of radiographic and surgical templates. In addition, various types of postoperative provisionalization prosthesis techniques are described to assist clinicians in the interim replacement of the edentulous areas after surgical procedures.

Diagnostic Casts

The first step in the process of treatment planning for dental implants is the fabrication of accurate diagnostic casts. The value of diagnostic casts or study models is crucial in all phases of dentistry, especially in oral implantology. When edentulous sites exist, the combination of continued bone loss and dentition changes related to missing teeth greatly increase the number of factors that must be considered for oral rehabilitation compared with traditional prosthodontic treatment. The implant dentist must determine the type of implant prosthesis initially (i.e., FP-1, FP-2, FP-3, RP-4, RP-5)[1] followed by the number and location of ideal and optional abutment sites and the final occlusal scheme.

Diagnostic casts must be accurate reproductions of the maxillary and mandibular arches with complete representation of the edentulous areas (Figure 18-1). Diagnostic casts mounted on an articulator allow for an initial evaluation for implant site selection, angulation requirements, prosthesis selection, existing occlusion, and fabrication of a surgical template. In addition, these study casts allow for a preoperative assessment of treatment options that may be discussed with other practitioners, laboratory technicians, and patient consultations.

Articulators

To accurately assess the maxillomandibular relationship of the implant patient, proper mounting of the study casts must be completed using an articulator. An articulator is defined as a "mechanical instrument that represents the temporomandibular joints (TMJs) and jaws, to which maxillary and mandibular casts may be attached to simulate some or all mandibular movements."[2] Today, the use and indications for the various types of articulators used in prosthetic dentistry are very controversial.

Currently, wide arrays of articulator types are available, with multiple ranges of movements and adjustments, making classification and nomenclature very confusing. In the dental literature, many different classifications exist; however, today the most simplistic and most often used classification parallels the one in the "Glossary of Prosthodontic Terms."[2] Articulators may be categorized into four groups according to the adjustability of the articulators. This classification is based on the ability of the articulator to accept the five most common patient records: (1) facebow transfer, (2) centric jaw record, (3) protrusive record, (4) lateral records (Bennett movement), and (5) intercondylar distance[3] (Table 18-1).



FIGURE 18-1. It is paramount that diagnostic casts be an accurate representation of the entire dental anatomy, including the edentulous ridges.

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TABLE 18-1
Articulator Options

	Hinge Axis (Facebow)	CR Record	Protrusive Movement	Lateral Excursion	Bennett Movement
NONADJUSTABLE (Simple and Average)	No	Yes	No	No	No
SEMI ADJUSTABLE	Approximate (Arbitrary)	Yes	Yes (Straight line)	Yes (Straight line)	Approximate
FULLY ADJUSTABLE	Yes (Kinematic)	Yes	Yes (Curved)	Yes (Curved)	Yes



FIGURE 18-2. Examples of various articulators used in implant dentistry. **A,** Simple hinge. **B,** Arbitrary plane line. **C,** Semiadjustable. **D,** Fully adjustable.

Nonadjustable[2]

Class 1: Simple Hinge

This type of articulator uses the arbitrary mounting of study casts without a facebow transfer. Maximum intercuspation position (MIP) is the only position that may be produced accurately because its fixed hinge axis is inaccurate because of the opening and closing movement predicated on a fixed axis (with no correlation to the hinge axis of the patient) (Figure 18-2, *A*).

Class 2: Arbitrary Plane Line (Average Value)

This type of articulator has evolved from the simple hinge that does allow restricted lateral movement. Arbitrary plane line articulators have fixed arbitrary condylar inclinations, vertical axes of rotation settings, and Bennett angles. The main disadvantage of nonadjustable articulators is the significant differences between the hinge closure of the articulator compared with the patient's anatomy. A closed-mouth MIP recording of

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the patient is made because an open-bite registration in centric relation does not correspond to the arc of mandibular closure with a nonadjustable articulator. The distance between the hinge and teeth is less on a nonadjustable articulator; therefore, a steeper curve exists upon closing, which results in premature contacts and incorrect ridge and groove direction in the final prosthesis (Figure 18-2, *B*).

Adjustable[2]

Class 3: Semiadjustable Articulators

These types of articulators can be set to closely simulate various mandibular movements that are usually sufficient for most prosthetic cases. They do require the use of a facebow transfer and maxillomandibular records. Simulation of lateral, protrusive, and Bennett movements are available with these types of articulators. There exist two different designs of semi-adjustable articulators, the Arcon (condylar element in maxillary member) and the non-Arcon (condylar element in mandibular member). The Arcon type more closely represents the anatomical location of the natural condyle and the glenoid fossa assembly (Figure 18-2, *C*).

Semiadjustable articulators are usually indicated for most types of routine fixed partial dentures in both partial and fully edentulous cases. Because semiadjustable articulators closely parallel the size and distances of the anatomical structures they represent, articulated casts can be mounted with sufficient accuracy to determine and reduce possible occlusal interferences.

Class 4: Fully Adjustable

This type of Arcon articulator is very complex, accepts a wide range of positions, and can be set to simulate the patient's border movements. For an articulator to be defined as fully adjustable, it must be able to accept all records, including a facebow transfer, centric jaw record, protrusive record, lateral records, and intercondylar distance.[4] Fully adjustable articulators rely on special pantographic tracings instead of wax occlusal records. A kinetic facebow is used along with complex pantographic registrations. Because the fully adjustable articulator can duplicate border movements and irregular pathways of movement, complex prostheses with a change in vertical dimension can be accomplished with minimal adjustments (Figure 18-2, *D*).

The accuracy of this articulator depends on the skill of the practitioner and laboratory technician, inherent errors in the articulation and recording devices, and any possible malalignment caused by musculature and flexure of the mandible.

Facebow Transfers

Facebow transfers are used in prosthetic dentistry to record the anteroposterior and mediolateral spatial positions of the maxillary occlusal cusps in relation to the transverse opening and closing of the patient's mandible.[5] Two types of facebows are recognized in the field of prosthodontics, arbitrary and kinematic.

Arbitrary

This type of facebow transfers the approximate horizontal transverse axis and relies on anatomical averages. Typically, an anatomical landmark such as the external auditory meatus is used to stabilize the facebow and assist in the mounting of the study casts. The arbitrary facebow is sufficiently accurate for most diagnostic and prosthodontic procedures with a semiadjustable articulator (Figure 18-3, *A*).

Kinematic

This type of facebow is mainly used when a more precise location of the horizontal axis is required such as complex fixed partial dentures or full-mouth reconstruction that uses the patient's true hinge axis. All mandibular border movements are recorded from the most retruded position to the lateral and most anterior position. This type of facebow is only used in conjunction with a fully adjustable articulator (Figure 18-3, *B*).

Selection of Articulator Type

As can be seen, articulators vary dramatically on their abilities to reproduce biomechanical factors that are associated with the various mandibular movements. There exists no one articulator that is "correct" for every dental condition, and great controversy is present surrounding the type of articulator that should be used in various situations. The selection of an articulator with a treatment type is highly dependent on the patient's occlusal requirements, prosthesis type, practitioner's philosophy, experience and knowledge, and the skill of the laboratory used.[6]

Additionally, the practitioner needs to differentiate the intended goal and need for the use of the articulator. If the goal includes only the diagnostic phase (diagnostic wax-up for a surgical template), this is much different than the use of an articulator in the prosthodontic phase (fabrication of the final

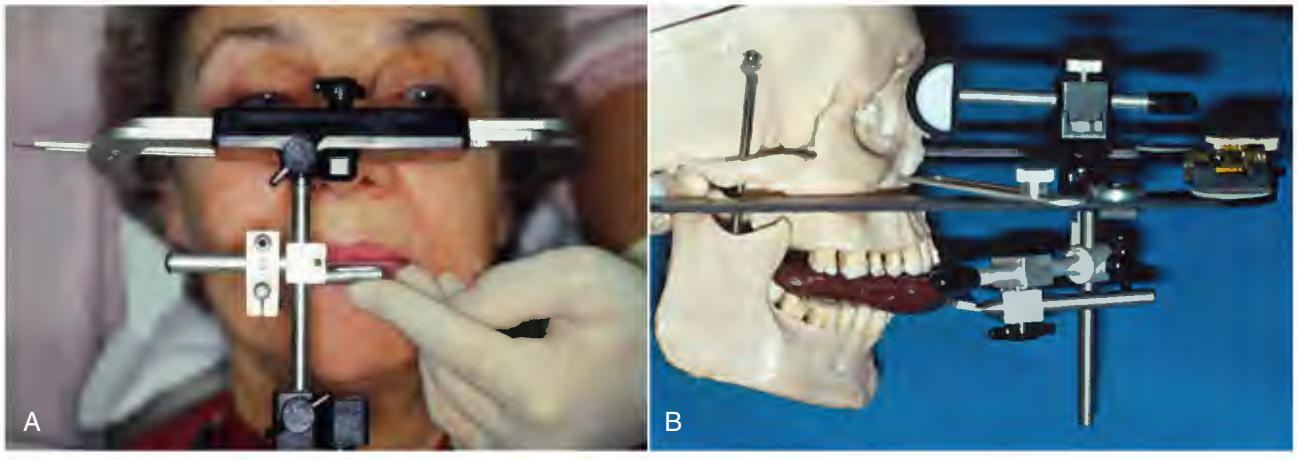


FIGURE 18-3. **A,** Arbitrary hinge axis. **B,** Kinematic facebow transfer.

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prosthesis). As a generalized guide, the following classification of uses and indications for various types of articulators may be used.

Nonadjustable (Class 1 and 2)

When the patient has no occlusal pathology and the desire of the final implant restoration is to fit within the existing occlusion, a nonadjustable articulator may be used. This most often represents single or small edentulous sites that allow for accurate maximum intercuspation of the study casts (tripod occlusal stability); a nonadjustable articulator may be used.

Indications

Diagnostic phase: Single edentulous areas, multiple edentulous spaces with tripod stability, and no change in occlusal relationship indicated

Prosthodontic phase: Single and multiple edentulous spaces with tripod stability with no change in occlusal relationship indicated

Semiadjustable (Class 3)

When there exist multiple edentulous areas or complete edentulism, a semiadjustable articulator is recommended. Because large segments of occlusion need to be replaced, a semiadjustable articulator allows for greater accuracy of the laboratory condition and the actual patient condition. Use of a facebow transfer minimizes tooth-hinge axis errors along with lateral check bites and protrusive records. Furthermore, if any change in vertical dimension is warranted or a cant in the occlusal table exists, a semiadjustable articulator should most definitely be used. When partially edentulous patients are evaluated, an open-mouth bite registration is recommended to evaluate the existing occlusion for premature contacts upon closure of the casts.

Indications

Diagnostic phase: Single and multiple edentulous spaces without tripod stability, significant changes in occlusion or vertical dimension, and all edentulous patients

Prosthodontic phase: Single and multiple edentulous spaces without tripod stability, occlusal or vertical dimension instability, and all edentulous patients

Fully Adjustable (Class 4)

This type of articulator is indicated for full-mouth rehabilitation, extensive treatment in which opposing arches are being restored, restoration of vertical dimension, patients with significant side-shift during lateral movements, and patients exhibiting severe parafunction and TMJ disorders. Practitioner knowledge and skill in obtaining a kinematically located hinge axis along with accurate recordings of mandibular movement is mandatory to achieve a high degree of accuracy with this articulator.

Indications

Diagnostic phase: Usually not indicated

Prosthodontic phase: Full-mouth rehabilitation requiring significant change in maxillomandibular relationships; practitioner and laboratory technician expertise

Maxillomandibular Relationships

Proper mounting of diagnostic casts with an open-bite registration and facebow transfer allows for the static and dynamic (class 3 and 4 articulators) relationships of the teeth and edentulous ridges without interference from protective neuromuscular reflexes. In addition, abnormalities or interferences that are not easily detectable intraorally can be determined. Table 18-1 details comprehensive information that may be obtained that may be paramount in dental implant treatment planning[7–9] (Box 18-1).

Occlusal Interferences

The implant dentist should evaluate the existing occlusion before implant surgical placement. Partially edentulous patients often have occlusal interferences as a result of tooth migration. Ideally, all abnormal contacts should be identified and eliminated before the implant prosthodontic phase. This is especially appropriate when any occlusal disease is present. In prosthetics, there exist four types of occlusal interferences: (1) centric occlusal interferences, (2) working occlusal interferences, (3) nonworking occlusal interferences, and (4) protrusive occlusal interferences.[6]

With centric occlusal interferences, the premature contact causes the mandible to deflect forward or laterally from the mandibular condyles' optimum superior position in the glenoid fossa. These types of interferences may cause parafunctional habits such as clenching or bruxism with associated muscle fatigue and TMJ pain.[10]

Working occlusal interferences occur between the maxillary and mandibular teeth during lateral movement on the side corresponding to the direction in which the mandible is moving. A nonworking occlusal interference is a deflective contact that occurs on the opposite side of the direction of mandibular

BOX 18-1 Diagnostic Information Obtained from the Proper Mounting of Study Casts in Implant Dentistry

1. Occlusal centric relation position, including premature occlusal contacts
2. Edentulous ridge relationships with respect to adjacent teeth and opposing arches
3. Position and location of potential natural abutment sites, including inclination, rotation, extrusion, spacing, parallelism, and esthetic considerations
4. Tooth morphology and signs of parafunction (e.g., wear facets, fractures)
5. Evaluation of potential force direction in future implant sites
6. Present occlusal scheme, including the presence of balancing or working contacts
7. Edentulous soft and hard tissue angulation, length, width, locations, permucosal esthetic position, muscle attachments, and bony protuberances (tori, tuberosities)
8. Interarch space
9. Occlusal curve of Wilson and curve of Spee
10. Skeletal arch relationships
11. Evaluation of opposing dentition
12. Potential future occlusal schemes
13. Site evaluation of edentulous sites
14. Arch location of future abutments
15. Arch form and asymmetry
16. Interdental contact location
17. Used for a diagnostic wax-up

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movement. These types of forces are potentially damaging to the masticatory apparatus (especially with implants) because they place shear forces outside the long axis of the teeth (or implants) and may cause bone loss and disruption of normal muscle function. They also increase the amount of force to the dentition during the excursions because more muscle mass fires in the masseter and temporal musculature.

The protrusive occlusal interference usually includes deflective contact between the mesial aspects of the mandibular posterior teeth and the distal aspects of maxillary posterior teeth during a protrusive mandibular movement. This is not a border movement and is usually less damaging to the stomatognathic system. However, these types of interferences may be damaging to teeth and implants because they result in shear forces because they prevent the posterior teeth from being disoccluded by the incisors.

Premature contacts may be ascertained after proper mounting of the study casts with the use of a wax spacer or bite registration (open-mouth bite). Upon removal of the occlusal records that separate the teeth, the premature or irregular contacts may be determined and verified when the casts are closed and then modified intraorally.[11]

A considerable prosthetic advantage is present when centric relation occlusion is harmonious with maximal intercuspal position. Lack of change in the occlusal vertical dimension permits a closed-mouth centric recording during prosthetic reconstruction for the fabrication of the prosthesis without the need for an accurate hinge axis recording of the condyles or fully adjustable articulators. When the incisal edge position of the maxilla is determined, its position usually causes a steeper protrusive or excursive position than the condylar disc assembly on semiadjustable articulators. As a result, posterior disocclusion can be easily established. These conditions permit the prosthetic reconstruction to be fabricated in the laboratory and transferred accurately to the patient.

The occlusion may require complete rehabilitation to eliminate potential unfavorable forces for the implant restoration. Both arches may require prosthodontic treatment to establish the desired occlusal schemes. Parafunctional bruxism with loss of incisal guidance from attrition or an opposing single denture are the most common conditions that mandate more comprehensive opposing dentition modification. Whereas the first condition often indicates a need to increase the anterior guidance for posterior disocclusion in excursions, the second warrants bilateral balance occlusion (Box 18-2).

Diagnostic Treatment Planning

Techniques used to determine the location, angulation, and contours of the final prosthesis are initiated by the completion of a diagnostic wax-up. Procedures vary from being simplistic (single missing tooth) to rather complex (full-mouth rehabilitation).

Partially Edentulous

Diagnostic Wax-Up

Duplicate diagnostic casts are mounted on an articulator, and a diagnostic wax-up is completed for the desired contour, occlusal scheme, and esthetic aspects of the final restoration. Attention should be given to individual tooth morphology, tooth axis, gingival contours, and interdental contacts. The diagnostic wax-up technique is especially recommended when full-mouth rehabilitation is indicated, particularly if a change in vertical dimension is desired (Figure 18-4 and Box 18-3).

BOX 18-2 Common Occlusion Definitions Used in Prosthodontic Dentistry[7]

Centric relation: The maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective discs with the complex in the anterosuperior position against the shapes of the articular eminences. This position is independent of tooth contact.

Centric occlusion: The occlusion of opposing teeth when the mandible is in centric relation. This may or may not coincide with the maximal intercuspal position.

Maximal intercuspal position: The complete intercuspation of the opposing teeth independent of condylar position; sometimes referred to as the best fit of the teeth regardless of the condylar position.

Anterior (incisal) guidance: The influence of the contacting surfaces of the mandibular and maxillary anterior teeth on mandibular movements.

BOX 18-3 Technique: Diagnostic Wax-Up

1. **Fabrication of diagnostic casts:** Impressions are made of the maxillary and mandibular ridges. It is more important that the impressions have no voids than the dental casts because they result in a positive mistake compared with a negative representation. If indicated, a facebow transfer is completed to relate the maxillary cast to the articulator along with a centric relation interocclusal record. The impressions should be poured in dental stone with the proper water-to-powder ratio.
2. **Selection of an articulator:** Select the desired articulator as per the complexity of the case. Ideally, a semiadjustable articulator is to be used to simulate the jaw movements of the patient when any occlusal disease is present.
3. **Mounting of the diagnostic casts:** The maxillary and mandibular diagnostic casts are mounted with the facebow transfer and the centric bite.
4. **Diagnostic wax-up completed:** Future implant sites are evaluated for ideal implant placement, spacing, and contour restrictions. The edentulous spaces are waxed to replicate ideal positioning of the teeth and contours. Denture teeth may be used as a substitute for the wax.
5. **Duplication of the final diagnostic wax-up:** The final diagnostic cast is duplicated to allow for laboratory-fabricated surgical templates or a fully edentulous setup may be processed and used as an interim prosthesis.

Completely Edentulous

Requiring No Modification to Existing Prosthesis

For fully edentulous cases, duplication of the patient's existing prosthesis (if esthetically and functionally ideal) may be used for the mounting of the diagnostic casts. The most simple technique is the use of a denture duplicator (Figure 18-5).

Modification to Existing Prosthesis Is Indicated

If modification of the existing prosthesis is required because of a change in esthetics or function, a traditional complete denture setup is indicated. After the try-in approval, the prosthesis may

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FIGURE 18-4. **A** to **C,** Diagnostic wax-up for a partially edentulous patient. **D,** Diagnostic wax-up for a fully edentulous patient.

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be duplicated to be used as a radiographic or surgical template fabrication (see Figure 18-4, *D*).

Ideal Implant Positioning Guidelines

In the design and planning of the diagnostic wax-up, knowledge of ideal implant positioning is important to the long-term success of the implant system. Optimal dental implant positioning should consider the three-dimensional placement of implants with respect to the biomechanical and prosthetic principles related to the final implant prosthesis. The implant should be positioned in relation to existing teeth, vital structures, and other implants as well as in buccolingual, mesiodistal, and apicocoronal dimensions.[12,13]

General Positioning Guidelines from Anatomical and Vital Structures

Implant–Natural Tooth Distance

An implant placed adjacent to a natural tooth ideally should remain 1.5 to 2 mm or more away from the interproximal cementoenamel junction (CEJ) and root (Figure 18-6). This is more important in esthetic regions, where the contour of the interdental papilla is a determining factor in the esthetics of the final prosthesis. Therefore, when positioning an implant adjacent to a tooth, the pilot hole (center of the implant) should be approximately 4 mm away from the natural tooth to place a 4-mm-diameter implant at the crest module. This requires at least a 7-mm mesiodistal distance in the edentulous space.[14]

If implants are not positioned as per these guidelines, complications in the final prosthesis may result. Implants placed too close to an adjacent tooth (<1.5 mm) may cause periodontal complications, adjacent tooth damage, bone loss, or a nonideal emergence profile of the final crown (Figure 18-7). Studies have shown a correlation between increased bone loss and decreased distance of the implant from the adjacent tooth.[15] When implants are placed more than 2 mm from an adjacent tooth, a cantilever effect will result on the marginal ridge of the implant crown, which in some cases may lead to biomechanical overload or esthetic issues (Figure 18-8).

Implant–Implant Distance

The distance between two implants has been determined to be significant with respect to bone loss, the presence of an interimplant papilla, and tissue health. After final insertion, 3 mm or more of space should be present between implants. This allows for adequate room for interdental papilla and tissue health as

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FIGURE 18-5. If the patient's existing prosthesis is esthetically and functionally acceptable, the prosthesis may be used in the diagnostic process. **A,** Denture Duplicator (Lang). **B,** Duplication is completed with the use of alginate and acrylic.

well minimizing horizontal bone loss. Also, proper spacing allows the patient the ability to cleanse embrasures and allows adequate space for transfer copings during prosthetic impressions[12] (Figure 18-9).

Distance from the Inferior Alveolar Nerve Canal or Mental Foramen (Figure 18-10, *A*)

Accurate positioning of implants in approximation to the inferior alveolar canal and mental foramen is crucial in preventing neurosensory impairment. The correct location of the nerve and canal should ideally be ascertained via three-dimensional imaging, especially when the implant may be within 2 mm of the nerve. After identification of the vital structures, the implant should be placed greater than 2 mm from the inferior alveolar canal or mental foramen. Implant placement less than 2 mm increases the risk compression or traumatic injuries to the nerve trunk and neurosensory deficits.[12]

Distance from the Nasal Cavity (Figure 18-10, *B*)

Placement of implants in the anterior maxilla may be very challenging, especially when minimal height of bone is present. Ideally, implants should be positioned just short of the nasal floor. However, more advanced surgical techniques exist where the implant may extend into the nasal cavity 2 to 4 mm via a subnasal graft.[12]

Distance from the Maxillary Sinus (Inferior Border) (Figure 18-11)

One of the more challenging areas for implant placement involves the posterior maxilla. The implant dentist often encounters compromised bone height in this area because of bone loss and pneumatization of the maxillary sinus. There exist four treatment options for implants placed in this area with respect to the quantity of bone from the crest of the ridge to the inferior border of the sinus[16]:

1. **SA-1:** Greater than 12 mm of bone; a standard implant placement protocol is indicated
2. **SA-2:** When 10 to 12 mm of bone is present and the implant is placed along with antral floor elevation through the osteotomy site 0 to 2 mm
3. **SA-3:** When 5 to 10 mm of bone is present, sinus grafting is indicated with (SA-3I) or without (SA-3D) simultaneous implant placement.
4. **SA-4:** Less than 5 mm of bone is present, which necessitates a lateral wall sinus augmentation procedure before implant placement.

Implant Angulation Positioning

The placement of a dental implant in available bone is comparable to an object in space that is defined by "x," "y," and "z" coordinates. In implant dentistry, the x-axis is defined by the mesiodistal plane, the y-axis is the buccolingual dimension, and the z-axis is known as the apicocoronal (length of implant body in relation to the osseous crest).[17]

Buccolingually ("y-Axis")

The buccolingual positioning of the dental implant is very crucial to the final prosthesis. Frequently, implant positioning is dictated by the resulting available bone, leading to angulation complications. Bone remodeling after extractions is common with bone initially resorbing from the buccal, decreasing the width of bone.

Ideally, the implant position is in the center of the ridge with a minimum of 1.0 mm present on the buccal and lingual aspects of the ridges. Adequate cortical bone prevents future hard and soft tissue recession. The buccolingual positioning is also predicated on the final prosthesis.

FP-1 and FP-2

If a FP-1 prosthesis is indicated, precise implant placement is indicated. In the anterior region, the implant position allows the placement of a straight abutment directly under the incisal edge of the final crown for a cemented prosthesis. Thus, the resulting forces are along the long axis of the implant, minimizing damaging shear forces. If the implant is placed too facial, many complications will result, including loss of the facial plate of bone, tissue recession, need for an angled abutment, and esthetic issues of the final prosthesis. Implants placed too lingually can result in facial overcontouring of the final prosthesis (ridge-lap), need for an angled abutment, unesthetic restoration, and crowding of the tongue space.

For screw-retained prostheses, the implant should emerge toward the cingulum of the anterior tooth so that the access hole does not affect the esthetics. If the implant is placed too facially, the access hole will impinge on the esthetics of the restoration. If the implant is placed too far lingually, overcontouring of the final crown may result in biomechanical issues (Figure 18-12).

In the posterior region, the long axis of the implant should emerge within the approximate center of the tooth for a screw- or cement-retained FP-1 or FP-2. This allows occlusal forces to be directed ideally along the long axis of the implant (Figure 18-13).

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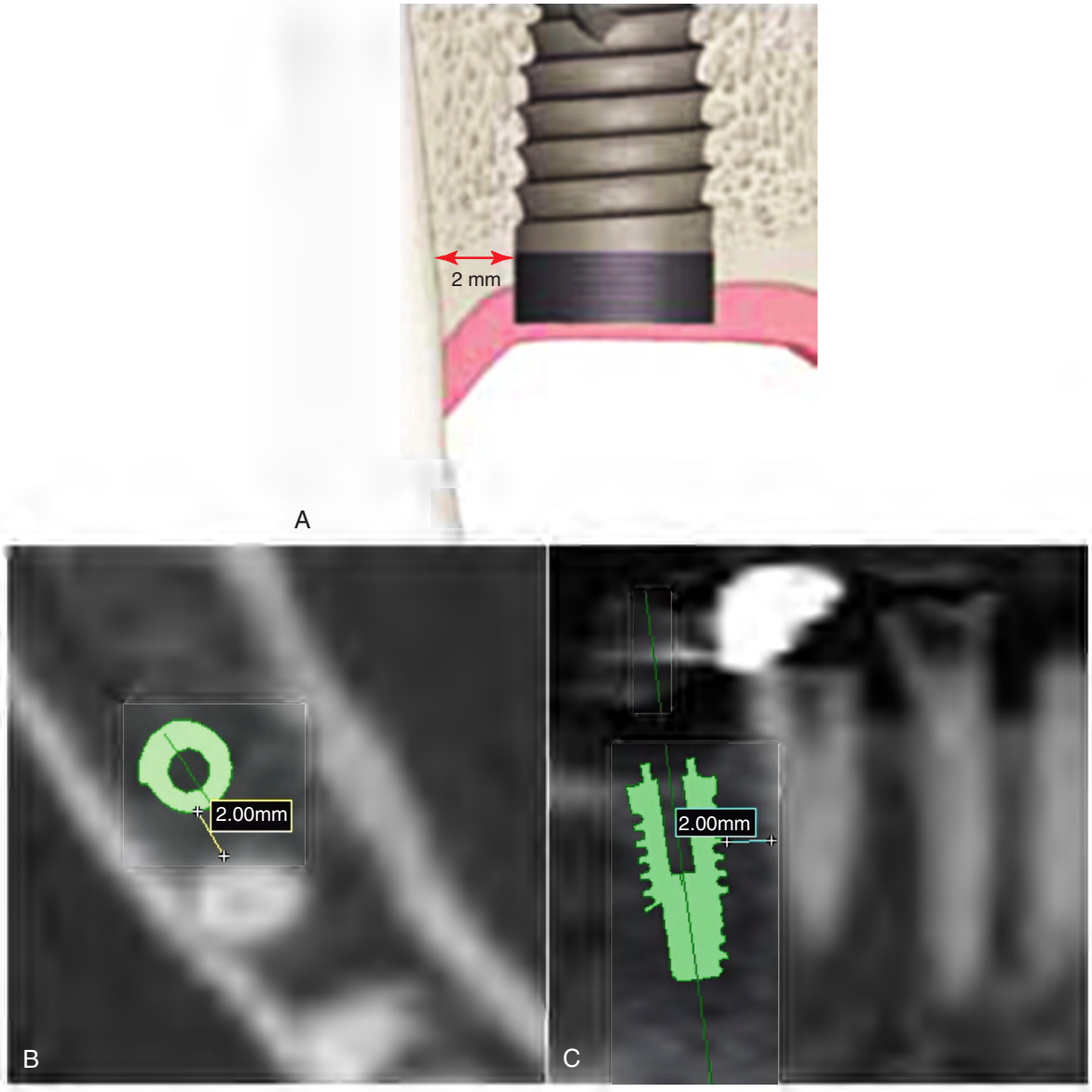


FIGURE 18-6. Virtual implant planning depicting implant distance of 2 mm from the tooth (**A**), axial computed tomography (CT) view (**B**), and panoramic CT view (**C**).

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FP-2 and FP-3

After evaluation of the articulated setup, arch form, available bone, and force factors, the FP-2 or FP-3 prostheses should be determined to be either screw retained or cement retained. For screw-retained prostheses, ideal positioning should be slightly lingual to the denture or porcelain teeth. Implants positioned too facially will impinge on the esthetics and complicate screw insertion. Implants placed too far lingually will result in an overcontoured prosthesis, resulting in possible speech problems in the maxilla and crowding of the tongue in the mandible.

For cement-retained restorations, implant positioning should be located along the incisal edge in the anterior region and in the central fossa area in the posterior. If force factors are a concern, ideal implant placement is crucial to minimize biomechanical overload. However, if force factors are low, nonideal placement is less of a problem as abutment angulation may be modified (Figure 18-14).

The mesiodistal position of implants is usually less important than the faciolingual position in FP-2 and FP-3 restorations because the implants do not have to be positioned related to teeth dimensions.

RP-4 and RP-5

Implants placed for removable overdentures should be positioned to emerge within the body of the denture base. This is important so that the components that are attached to the implant do not impinge on the ideal setting of the denture teeth. Implants that are positioned too far lingually may interfere with phonetics and an overcontoured lingual surface leading to crowding of the tongue. Implants placed too far facially will interfere with ideal denture tooth placement, leading to possible denture tooth "pop-offs." In addition, facially positioned implants often result in lack of adequate attached tissue and potential periodontal concerns because gingival recession is more likely to result.

Mesiodistal ("x-Axis")

When evaluating the position of the implant in the mesiodistal plane, the proximity to the adjacent teeth is the greatest limiting

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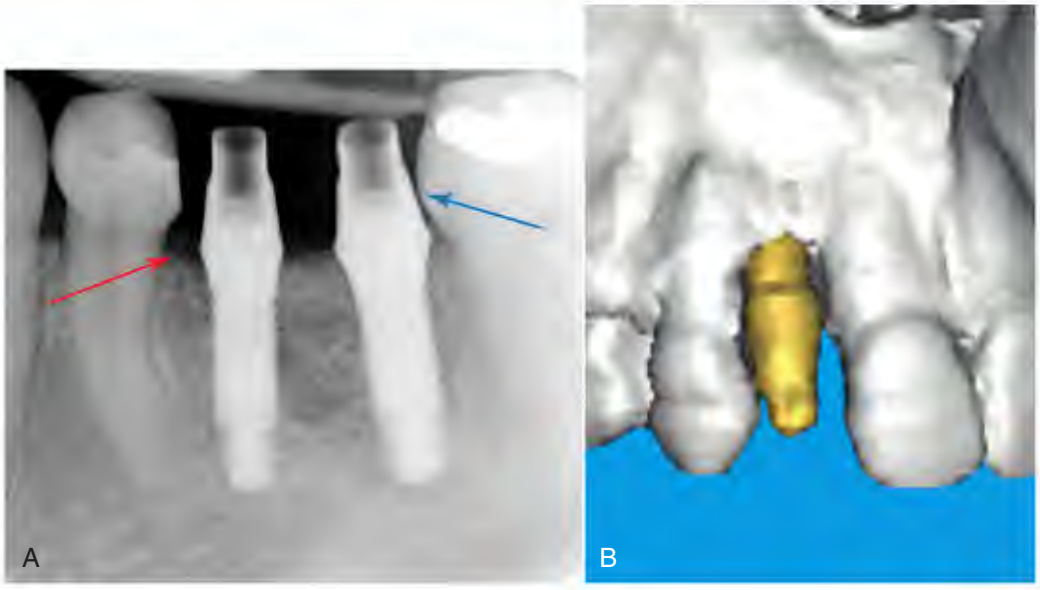


FIGURE 18-7. Natural tooth–implant distances. There should ideally be 1.5 to 2.0 mm from the implant to an adjacent tooth to maintain bone level and healthy periodontium. **A,** Ideal implant positioning (anterior implant, *red arrow*) and poor implant positioning in relation to the natural tooth (posterior implant, *blue arrow*). **B,** Poor implant positioning resulting in an inability to develop an emergence profile.

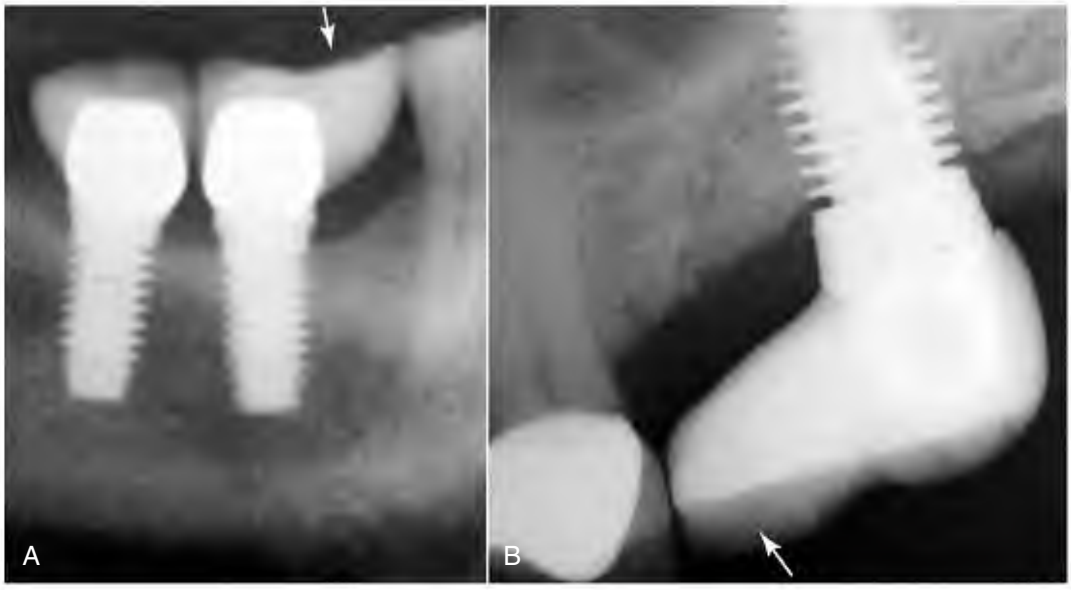


FIGURE 18-8. Implants too far from adjacent tooth will set up a biomechanical disadvantage for the prosthesis, a cantilevered effect *(arrow),* increasing the risk of biomechanical complications.

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factor followed by the prosthetic reconstruction. Ideally, the mesiodistal implant position is in the center of the ridge, equidistant from the adjacent teeth (Figure 18-15).

FP-1

In the esthetic zone, evaluation of the optimal tooth dimensions on the contralateral side must be determined. This will be paramount in placing the implant in the ideal position and the future esthetics. It is very important that the implant position is not too close or too far from the existing adjacent tooth. The average mesiodistal width of permanent teeth can be used as a guide (Table 18-2).

TABLE 18-2
Average Mesiodistal Width of Permanent Teeth[33]

Tooth	Mandibular (mm)	Maxilla (mm)
Central incisor	5.3	8.6
Lateral incisor	5.7	6.6
Cuspid	6.8	7.6
First bicuspid	7.0	7.1
Second bicuspid	7.1	6.6
First molar	11.4	10.4
Second molar	10.8	9.8

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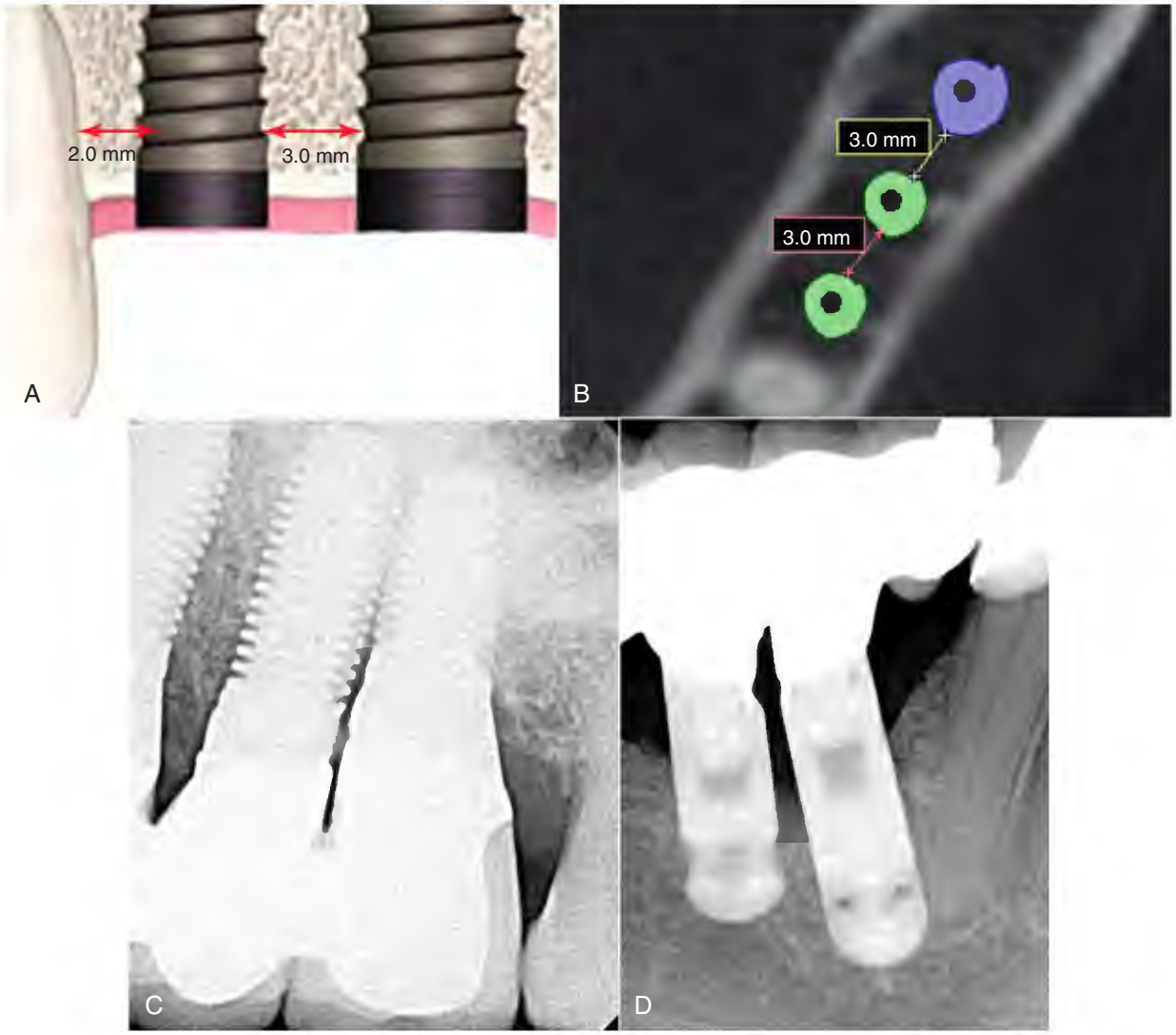


FIGURE 18-9. **A,** Ideal distances from the tooth (2 mm) and between implants (3 mm). **B,** Virtual implant planning on an axial computed tomography image. **C** and **D,** Bone loss from close proximity of implant bodies.

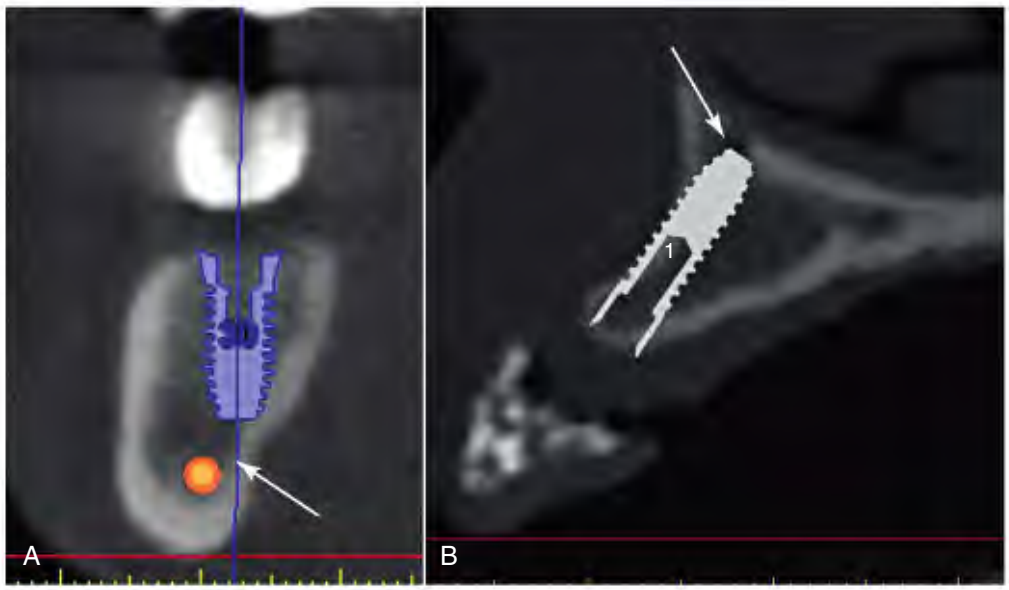


FIGURE 18-10. Ideal implant distances from inferior alveolar nerve (>2 mm) (**A**) and nasal cavity (**B**).

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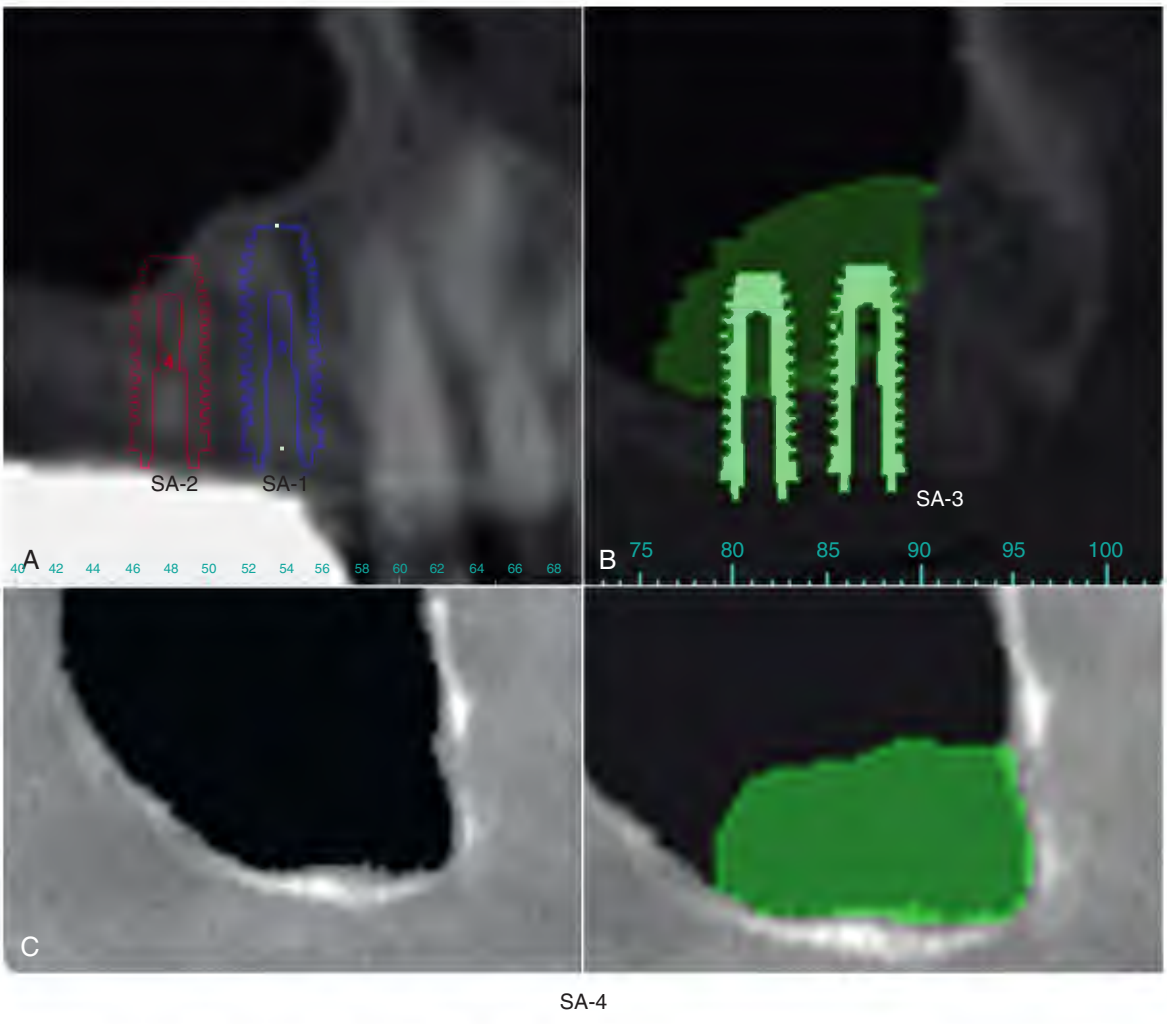


FIGURE 18-11. Posterior maxilla treatment planning: SA-1 and SA-2 (**A**), SA-3 (**B**), and SA-4 (**C**).

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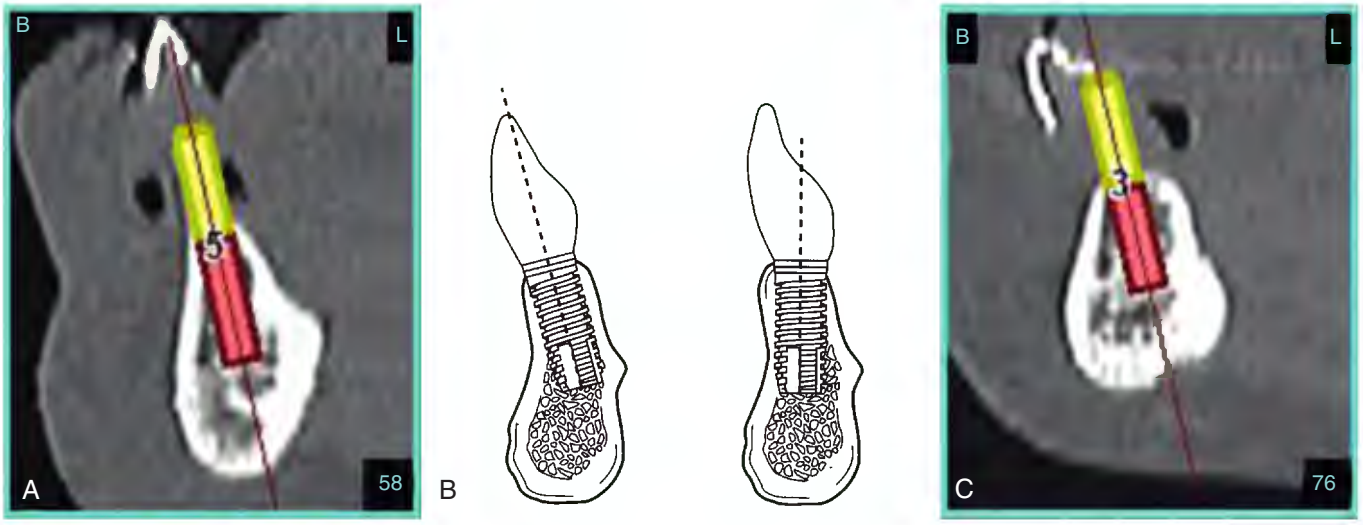


FIGURE 18-12. Ideal implant placement for anterior implants. **A,** Cement retained through the incisal edge. **B,** Screw retained through the cingulum area.

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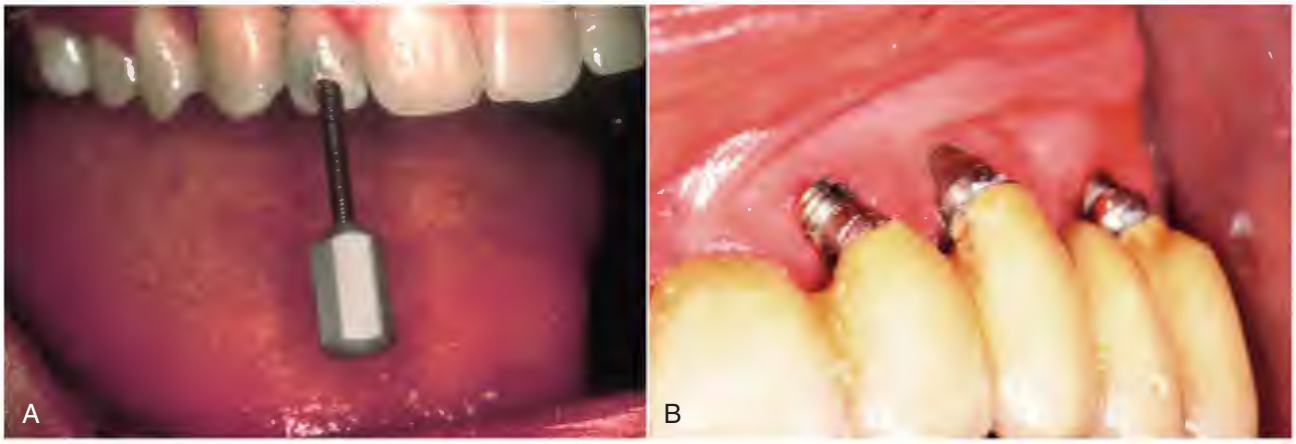


FIGURE 18-13. Implant positioning complications from a labially positioned implant leading to overcontouring (**A**) and tissue recession and crestal bone loss (**B**).

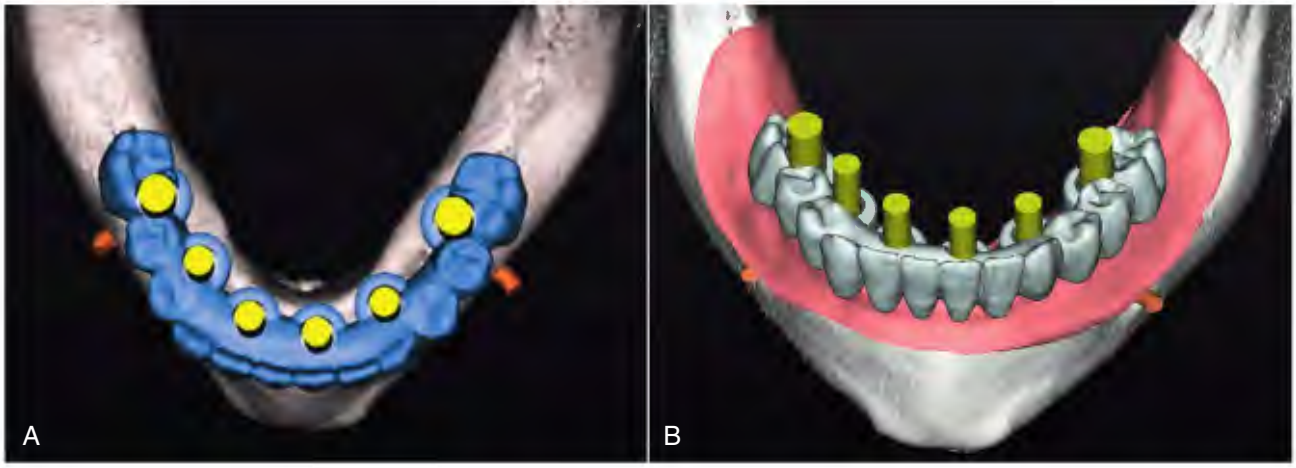


FIGURE 18-14. Ideal implant placement for a FP-3 prosthesis. **A,** Occlusal view. **B,** Anterior view.

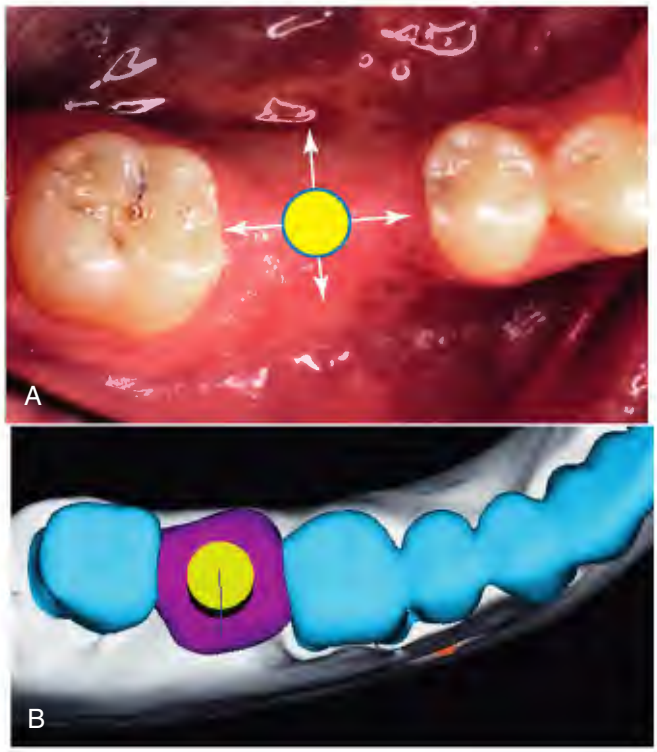


FIGURE 18-15. **A** and **B,** Ideal posterior implant placement with buccal–lingual placement in line with the central fossa.

FP-2, FP-3, RP-4, and RP-5

More latitude exists with the mesiodistal positioning of implants for FP-2, FP-3, RP-4, and RP-5 prostheses; however, the anteroposterior (A-P) spread should always be maximized. Because the soft tissue is replaced in these types of prostheses (pink acrylic or porcelain), implants need not be placed in specific tooth positions. Implant positioning is usually dictated by 3-mm spacing between implants and maximizing the A-P spread whenever possible.

Implants positioned too far lingually for FP-3, RP-4, and RP-5 prostheses will result in a bulky or overcontoured prosthesis, which may interfere with phonetics. Implants placed too far facially will result in bone loss and tissue irritation.

Variations

In many instances, ideal study cast location of the dental implant will be problematic because of root positioning. This is why ideal positioning of dental implants should be evaluated in the third dimension (with computed tomography [CT] or cone-beam computed tomography [CBCT]). One of the most common problematic areas is the replacement of congenitally missing lateral incisors. Often after orthodontic treatment, there exist normal mesiodistal distance of the clinical crowns; however, lack of space will exist between the roots. This is especially common at the apical area. Lack of space may contraindicate implant placement or require orthodontic treatment for repositioning of the roots (Figure 18-16).

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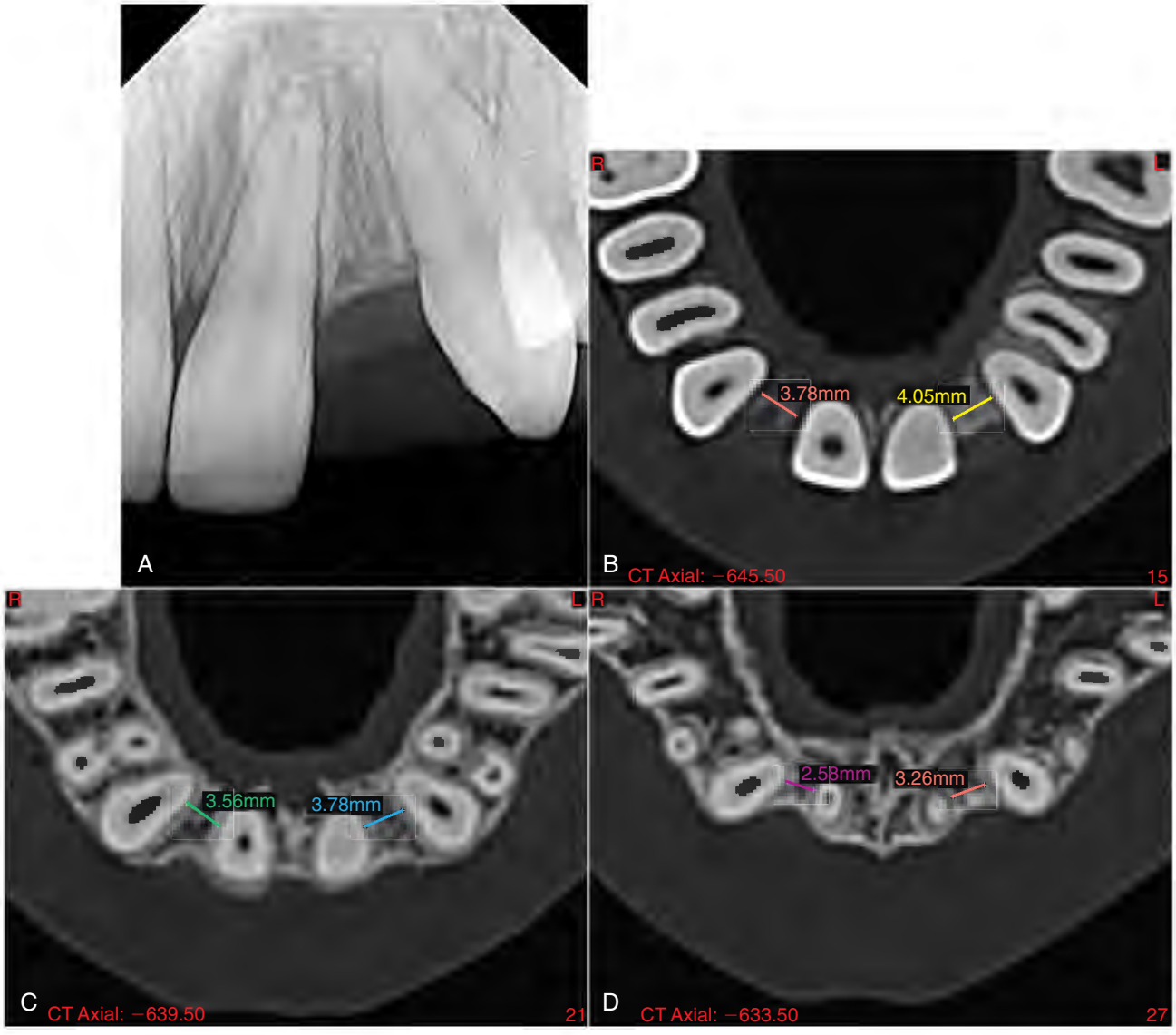


FIGURE 18-16. An often problematic positioning area involves the replacement of the maxillary lateral incisor. This situation often results after orthodontic treatment, **A,** Close proximity of roots. Ideal computed tomography evaluation should include evaluation of the axial images at the crestal (**B**), midroot (**C**), and root apex (**D**).

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Another common area for root approximation problems is in the maxillary first premolar edentulous site. Careful consideration for the angulation of a natural canine must be evaluated. The 11-degree average distal inclination and distal curvature of the canine root frequently place the apex of the root into the first premolar implant area. Therefore, the implant should be angled to follow the root of the canine and prevent contact with or perforation of the natural root. A shorter implant often is indicated, especially when a second premolar is also present.[14]

In evaluation of intraroot distances, caution must be used in exclusively using two-dimensional radiographs or study casts as the sole determinants of implant positioning. Ideally, to verify adequate intraroot distance, a three-dimensional (CT or CBCT) scan should be performed. Accurate measurements may be made in the axial images at three locations: the CEJ, midroot, and root apex.

Apicocoronal (z-Axis)

Ideally, the implant position apicocoronally should be approximately 2 mm from the top of the implant to the CEJ of the missing tooth. The rationale for this includes adequate space for the development of a biologic width, emergence profile for a smooth transition from the implant platform to the abutment and crown, and esthetic concerns related to margin placement and possible future recession.

FP-1

For FP-1 prostheses, apicocoronal positioning is crucial so there exists sufficient room for prosthetic components, adequate retention of the prosthesis, and room for an ideal emergence profile. In the esthetic zone, the implant should be 2 mm apical to the CEJ of the adjacent teeth (Figure 18-17, *A*).

Placement greater than 2 mm will result in an unfavorable crown height space (crown–implant ratio) and periodontal

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FIGURE 18-17. Implants placed in the "z-plane." **A,** Ideal placement (2 mm below the cementoenamel junction [CEJ]). **B,** Placement too apically (>2 mm from the CEJ). **C,** Placement too coronally (<2 mm from the CEJ).

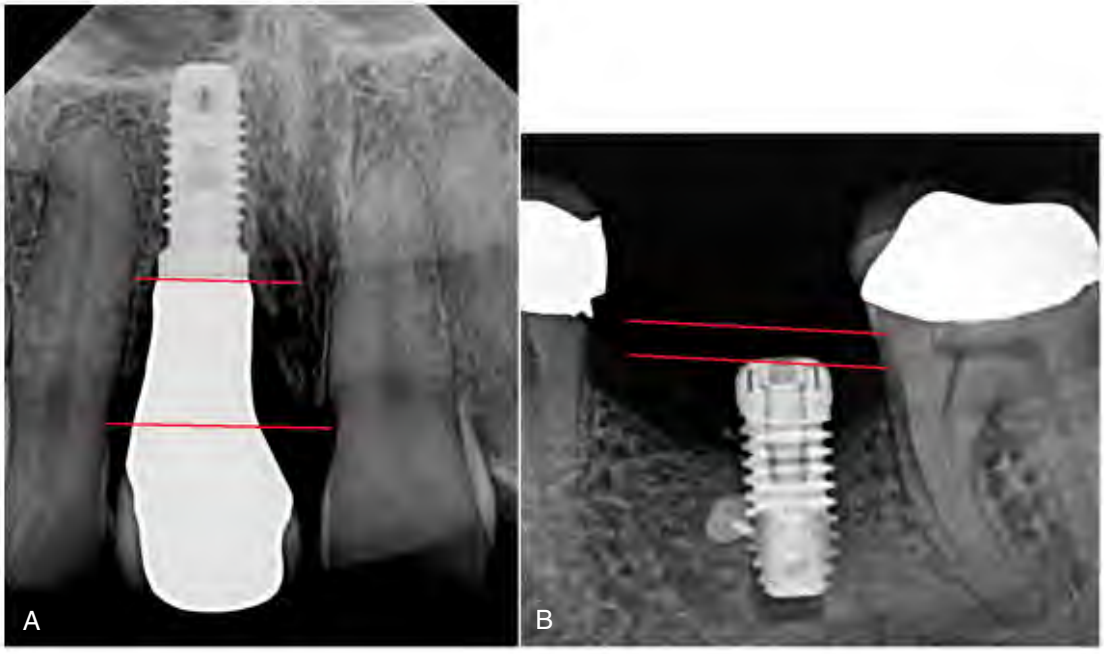


FIGURE 18-18. Apicocoronal positioning complications. **A,** Placement too apically (>2 mm from the cementoenamel junction [CEJ]), resulting in a final prosthesis with too large of a crown height space. **B,** Placement too coronally (<2 mm from the CEJ), resulting in lack of retention and inadequate emergence profile for the final prosthesis.

issues. Higher moment forces will result, which can lead to crestal bone loss (Figure 18-17, *B* and 18-18, *A*). Placement less than 2 mm will result in inadequate emergence profile (transition from the narrower diameter of the implant compared with the wider dimension of the crown) and decreased retention of the implant. Decreased retention will lead to uncementable restorations or component fracture (Figure 18-17, *C* and 18-18, *B*).

RP-4 and RP-5

Caution must be exercised so there exists adequate interocclusal space for the overdenture prosthesis, especially if a connecting bar is used. For a bar and overdenture with attachments, at least 15 mm from the crest of the ridge to the incisal edge is suggested. Less than 15 mm of space may result in lack of room for the bar or attachments, which will result in continuous prosthetic complications. A minimum of 2 mm of acrylic is required for adequate retention of denture teeth.

Radiographic Templates

Terminology

Presently, much confusion exists in the use of prosthodontic terminology and nomenclature when describing radiographic and surgical templates. The terms *stent, guides, model,* and *appliances* have been used in description of these prostheses. Additional terms sometimes used in identifying these prostheses include *scan appliance, scan stent, radiographic or surgical appliance,* and *radiopaque appliance*. However, according to the *Journal of Prosthetic Dentistry's* "Glossary of Prosthodontic Terms," the definition of *template* best describes the purpose of the prosthesis[2] (Box 18-4).

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BOX 18-4 Prosthodontic Terminology and Nomenclature[2]

Template: A thin, transparent form duplicating the tissue surface of a dental prosthesis and used as a guide for surgically shaping the alveolar process; a guide used to assist in proper surgical placement and angulation of dental implants

Stent: Named for the dentist who first described their use, Charles R. Stent, such ancillary prostheses are used to apply pressure to soft tissues to facilitate healing (i.e., periodontal stent, skin graft stent)

Appliance: A device or restoration; something developed by the application of ideas or principles that are designed to serve a special purpose or perform a special function; a broad term applied to any material or prosthesis that restores or replaces lost tooth structure, teeth, or oral tissues

Model: A facsimile used for display purposes; a miniature representation of something

Rationale for Radiographic Templates

To correlate the positioning of the implant in relation to the available bone, the ideal location of the final tooth position or prosthesis must be determined. Without a precise location, the implant may be surgically placed in an incorrect position, leading to biomechanical issues and future complications. To achieve this information, a correlation between the tooth or prosthesis location must exist with the radiographic survey. If no correlation exists, the ideal implant positioning will be difficult and may lead to final placement errors (Figure 18-19).

Most commonly used today, a CT scan with a radiographic template is used for the transfer of this information. Many different types of radiographic templates have been used in implant dentistry. After completion of the process of diagnostic tooth positioning via diagnostic waxing, denture teeth arrangement, or duplication of the existing prosthesis, this information is transferred to the template and used in the radiographic survey. In some instances, the radiopaque template is

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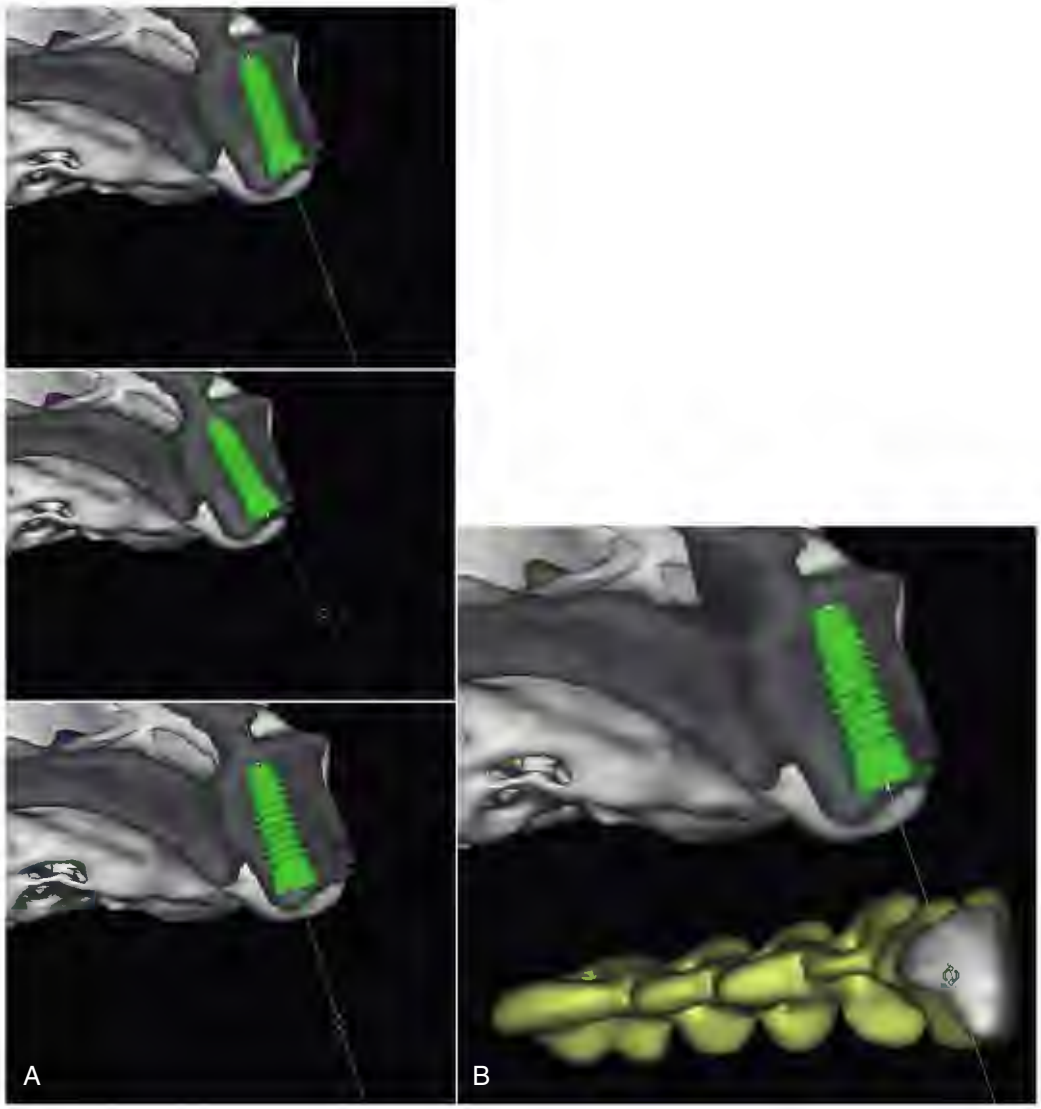


FIGURE 18-19. **A,** Without a radiopaque template, ideal buccolingual angulation cannot be determined. **B,** Radiopaque template showing ideal positioning with respect to the final prosthesis

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FIGURE 18-20. **A,** Barium sulfate (Salvin Dental). **B,** Ideal homogeneous mixture. **C,** Barium sulfate duplicated prosthesis.

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transformed into a surgical placement template for use during implant placement.

Fabrication of Radiographic Template (Scanning Template)

Radiopaque Markers

To correlate tooth position and tissue in relation to available bone and vital structures, a radiopaque material must be used. Many different materials have been described in the literature and may be used in the fabrication of a radiopaque template. The most common material used today in implant dentistry is barium sulfate ($BaSO_4$), which is an inorganic compound that is used clinically as a radiocontrast material in medical diagnostic imaging (Figure 18-20). This material is ideal for maxillofacial imaging because it may accurately depict the accurate contours of the teeth or soft tissue without scattering. Techniques to incorporate $BaSO_4$ into the radiographic template include (1) filling the edentulous area with $BaSO_4$, (2) painting the outside aspects of the buccal and lingual surfaces of the template, and (3) use of preformed $BaSO_4$ teeth. Care must be made to not use too high of a concentration of $BaSO_4$ because it may cause excessive scatter in the scan. Other radiopaque materials used include gutta percha, amalgam, lead foil, and metal sleeves. However, these materials are useful for marking the position of the final tooth position but give little information regarding the contours of the restoration[18,19] (Figure 18-21).

Single-Scan versus Double-Scan Technique

Most planning software today uses a radiopaque template with a single-scan technique (discussed later for partial and fully edentulous). The composition and design of the radiopaque template depend on the type of software used during the planning. The protocol should be obtained before the scan to avoid complications with integration of the CT data into the scanning program (Box 18-5).

Single Scan. Barium sulfate is used to identify the teeth from the diagnostic wax-up in a 20% $BaSO_4$ solution. If a soft tissue (flapless surgery) template is to be made, teeth are ideally identified with a 20% $BaSO_4$ solution, and the base (soft tissue) uses a 10% mix. This allows for differentiation of the teeth from the soft tissue. Poor mixing will result in a nonhomogeneous mixture that exhibits areas of high radiolucency.[20]

BOX 18-5 Single- and Dual-Scan Settings

1. Matrix: 512 × 512
2. Slice thickness: 0.4 to 0.8 mm
3. Slice increment: 0.3 to 0.5 mm
4. Gantry tilt: 0°
5. Resolution: High

Double Scan. Some planning software programs require the use of a "double-scan" process as the protocol for their software, which exhibits less scatter than the single-scan technique. In this technique, reference markers (radiopaque material) are embedded into the radiopaque template. The patient is scanned wearing the template, and then the template is removed from the patient's mouth and scanned separately. The software program uses the markers to correlate the images. With the double-scan technique, the denture base resin and artificial teeth can be reconstructed for planning purposes. The soft tissue can be determined as the difference between the template and bone. The number and location of markers depend on the software program being used (Box 18-6).

Fabrication of Partially Edentulous Radiopaque Template

In the literature, numerous techniques are used for fabrication of radiopaque templates. One of the most simple is the following. After fabrication of a diagnostic wax-up, the duplicate study cast is made. A clear vacuum-formed matrix is made. With the use of $BaSO_4$, the material is added to the edentulous site. The patient then wears the prosthesis during the scanning process. This prosthesis may be fabricated by a laboratory or with an in-office technique (Figure 18-22 and Box 18-7).

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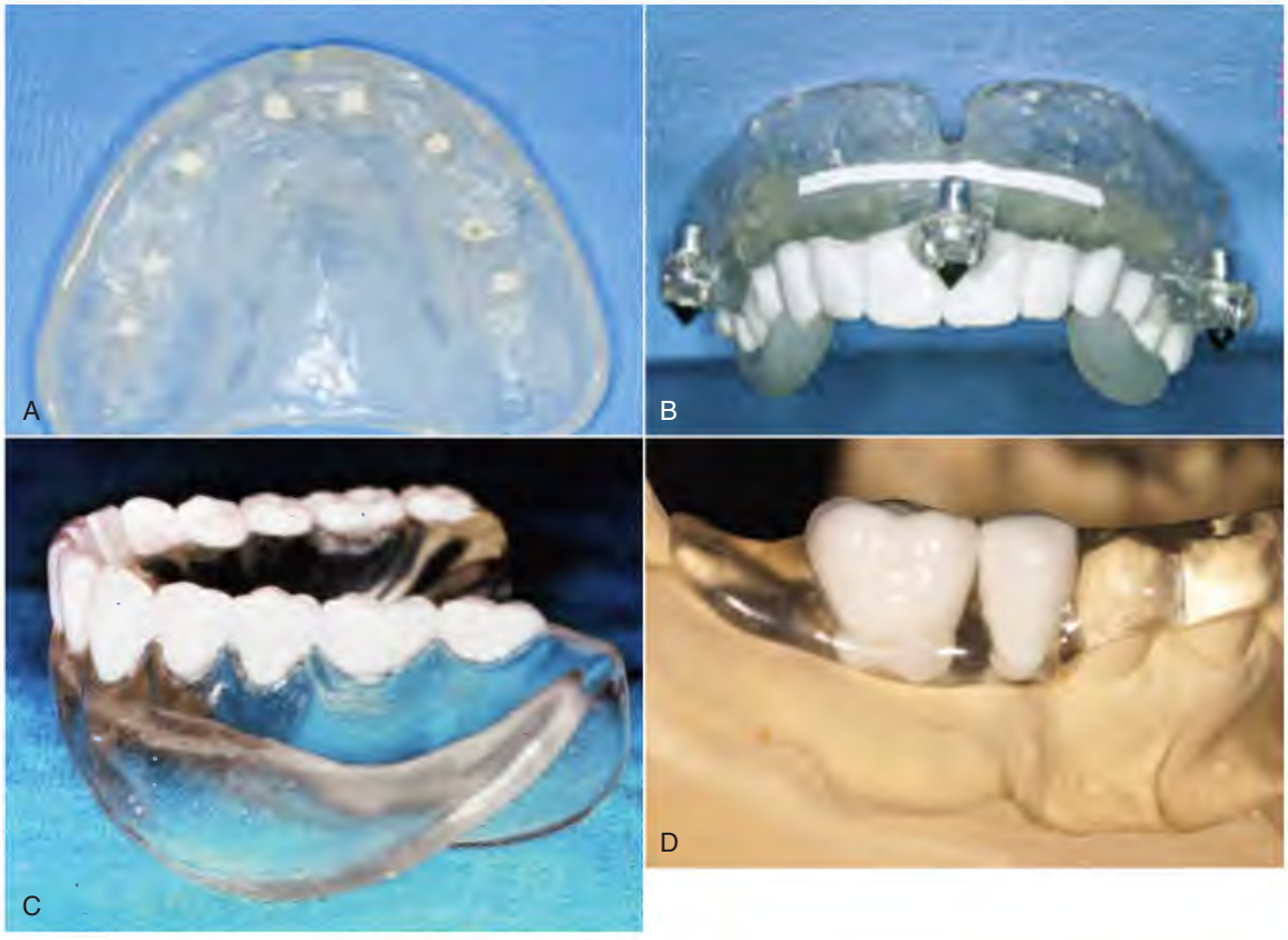


FIGURE 18-21. Various types of barium sulfate radiopaque templates.

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BOX 18-6 Dual-Scan Technique

1. The first scan is taken with the patient wearing the radiolucent prosthesis with Dual Scan Markers (Materialise) and bite registration. The bite registration is used to stabilize the prosthesis during the scanning procedure.
2. Positioning of the patient is comparable to a standard dental computed tomography scan. The transaxial slice plane must be parallel to the floor.
3. The maxilla and mandible, including the scan template, must be within the field of view.
4. The second scan is taken of the prosthesis alone, applying the same general settings that were used to obtain the first scan.
5. It is very important that the position of the prosthesis is in the same position as the mouth position. The materials to hold the prosthesis must be more radiolucent than the prosthesis itself. Polyethylene and polyurethane foam materials may be used. In addition, a cardboard box can be used to secure the prosthesis in a vertical position.

BOX 18-7 Laboratory Steps for Partially Edentulous Radiopaque Template

1. Complete a diagnostic wax-up of the edentulous area, including the full contour of the teeth to be replaced along with proper occlusion.
2. Duplicate the diagnostic wax-up using irreversible hydrocolloid and pour the impression in dental stone. Trim the duplicate cast.
3. Use clear thermoforming material (~0.060 inch, 5 × 5 inches) to fabricate a vacuum-formed clear template of the trimmed duplicate cast.
4. Trim the template to include a minimum of half coverage of the adjacent teeth and full coverage of the edentulous areas.
5. Block out the undercuts on the adjacent teeth to the edentulous area with wax or block-out compound.
6. Pour a mixture of clear tooth acrylic and barium sulfate (20%) in the edentulous areas of the template. Remove template from cast and trim and polish as needed.

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FIGURE 18-22. Laboratory steps for a radiopaque template, **A** to **D,** Diagnostic wax-up impression. **E,** Diagnostic wax-up removed. **F,** Barium sulfate added to template in the teeth position. **G** and **H,** Curing the barium sulfate teeth.

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FIGURE 18-22, cont'd. **I,** Adding acrylic to the cured teeth. **J,** Removing the duplicate wax-up. **K,** The wax-up and radiographic template.

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Fabrication of a Fully Edentulous Radiopaque Template

If the patient's current prosthesis needs no modification because of esthetics or function, the prosthesis is duplicated via a denture duplicator. The patient wears the fully edentulous radiopaque template during the scanning process. Care must be made so that the prosthesis is stable during the scanning procedure. It is highly recommended to place denture adhesive before the scan to avoid inaccuracies in the location of the teeth on the scan. Another option would acquire a bite registration slightly out of occlusion, which the patient wears during the scanning process. It is mandatory that the prosthesis is at least 3 mm thick because a thin denture base will result in fenestrations in the scan and possible weak areas if used as a surgical template (Figures 18-24 and 18-25; Box 18-8).

Alternative to Radiographic Template

With the use of SimPlant software from Materialise, the "virtual teeth" function may be used for short edentulous spans and single-tooth replacement. This function allows the clinician to design the replacement teeth via the computer program without the fabrication of a radiopaque template.[21] However, caution must be exercised because the use of this modality should be limited to ideal cases in which no maxillomandibular changes are required (Figure 18-25 and Box 18-9).

Surgical Templates

Requirements of a Surgical Template

A surgical template has many requirements:

1. The template should allow the clinician to place the implant in the ideal buccolingual, mesiodistal, and apicocoronal dimensions.
2. The template must be stable, rigid, and assessable when placed in the correct position. There should be no "rocking" or incomplete seating of the template.
3. If the arch being treated has remaining teeth, the template should encompass the teeth to stabilize the template in position. When no remaining teeth are present, the template should extend onto nonreflected soft tissue regions (i.e., the palate and tuberosities in the maxilla or the retromolar pads in the mandible) for tissue-borne templates.
4. Adequate access should be provided during surgical procedures, especially in the posterior regions. The template should be transparent and not bulky so that surgical landmarks are not obscured.
5. Access for irrigation must be allowed. Osteotomy drilling without irrigation will result in overheating the bone and lack of implant integration.
6. The template must be sterilizable to ensure surgical asepsis, transparency, and the ability to revise the template if needed. Most templates should be able to be disinfected with 3.2% gluteraldehyde and immersed in 2% chlorhexidine during the surgery.
7. The template should be reusable for a number of procedures.

Surgical Template Fabrication

Surgical template fabrication involves functional and esthetic setup of the patient's ideal occlusion via the following possible techniques:

1. Diagnostic wax-up
2. Complete or partial denture wax-up
3. Duplication of the patient's existing dentition or prosthesis
4. Transfer of the radiographic template to a surgical template

Surgical Template Classification

Surgical and radiographic templates may be categorized by the type of material used in the fabrication of the prosthesis and the amount of restriction (drill guidance) associated with the template.

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BOX 18-8 Laboratory Steps for Radiopaque (Full Edentulism) Denture Template

Option 1: Laboratory-Fabricated Template (Figure 18-23)

1. With the use of a denture duplicator flask (Lang Dental Manufacturing, Chicago), mix and fill half of the flask with alginate.
2. Place the denture (teeth first) into alginate with the teeth perpendicular to the bottom of the flask.
3. After alginate is set, trim excess that covers the denture flange.
4. Lubricate the alginate and exposed denture with separating material.
5. Fill the other half of the flask along with the ridge part of the denture with alginate.
6. Close the flask, ensuring complete closure. After the alginate is set, open and remove the denture.
7. Pour acrylic clear acrylic resin (Clear Surgical Template) or radiopaque acrylic resin (Radiopaque Template) into the incisal and occlusal surfaces, ensuring no bubbles. Pour the remainder of the mixture into the palate or vestibule area.
8. Cure for a minimum of 20 minutes on the laboratory bench or in a pressure pot at 30 psi.
9. Trim excess and polish. Note: If modifications need to be made to the existing prosthesis, the try-in denture should be duplicated after all necessary changes are made.

Option 2: Immediate Template (Figure 18-24)

1. With the patient's existing complete denture, fabricate a vacuum-formed clear template with clear thermoforming material (~0.060 inch, 5 × 5 inches).
2. Using barium sulfate monomer and polymer, paint the facial and lingual surfaces of the template. Allow it to dry.
3. Administer the cone-beam computed tomography scan with the radiopaque template

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FIGURE 18-23. Laboratory steps for duplicating a denture.

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FIGURE 18-24. Alternative technique for immediate fabrication of a radiopaque template for a fully edentulous patient. **A,** Thermoform machine. **B,** Fabricate thermoform template over existing denture. **C,** Homogeneous barium sulfate mix. **D,** Paint on buccal and lingual contours. **E,** Patient wears the radiopaque template during scan.

Material[22,23]

1. Clear vacuum-formed matrices: The advantages of clear vacuum-formed matrices are numerous, including cost effectiveness, ease of fabrication, translucency, and variability. Many different materials have been used in addition to the clear matrix such as autopolymerizing acrylic resin, gutta percha, and metal rods. These types of templates may also be subclassified as rigid, flexible, or a combination (Figure 18-26, *A*).
2. Autopolymerized acrylic resin (Figure 18-26, *B*)
3. Light polymerizing composite resin (Figure 18-26, *C*) metallic guides that closely match the diameter of the drills or implant size. These guides are fabricated with the aid of computer-aided design/computer-aided manufacturing (CAD/CAM) technology. With the use of interactive treatment planning via CBCT imaging, the accuracy and ease of fabrication have been expanded [24–26] (Figure 18-26, *D*).

Surgical Restriction

Three different surgical template designs have been described in the literature: nonlimiting, partial-limiting, and complete-limiting design.[27]

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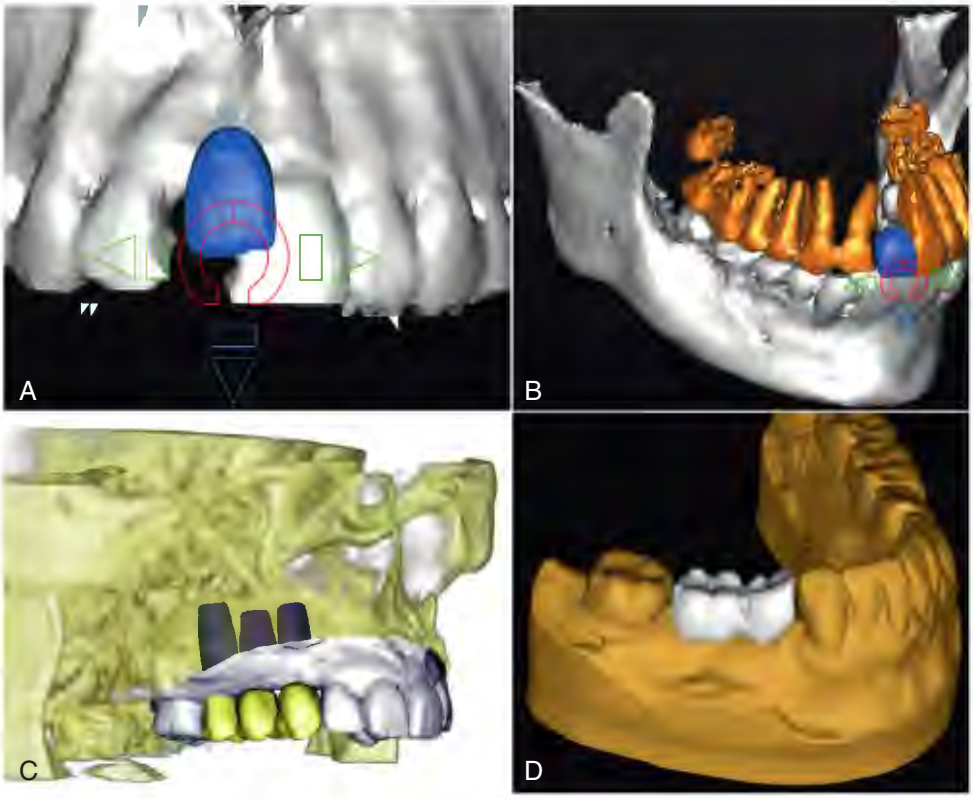


FIGURE 18-25. Examples of computed tomography "virtual teeth" from interactive treatment planning using SimPlant software.

BOX 18-9 Creating Virtual Teeth Via SimPlant Software

1. Select "Create Virtual Teeth" in the two-dimensional axial slice view window.
2. Select the (a) teeth you would like to create, (b) patient gender, and (c) panoramic curve.
3. Teeth are created, and their positions can be modified via left mouse button.
4. Size, shape, and color can be modified by positioning the mouse cursor on the corner icon and dragging the left mouse.

Nonlimiting Design

The nonlimiting template allows the implant surgeon dimensional variability in the implant location because the template indicates the ideal space for the final restoration, not the actual mesiodistal angulation. The nonlimiting template has become popular because of the ease in fabrication and the low cost involved (Figure 18-27).

Partial-Limiting Design

The partial-limiting design incorporates a guided sleeve or a slot that allows for angulation of one drill size, usually the pilot drill. Thus, after the first drill is used, the rest of the osteotomy sites are completed. Various techniques can be used, including manual laboratory-fabricated templates or templates fabricated from a radiographic template, which is then converted into a surgical guide template (Figure 18-28).

Complete-Limiting Design

With the complete-limiting design, the position, angulation, and depth of the osteotomy are dictated by the guided tubes or sleeves, thus restricting any variation by the implant surgeon. This type of guide prevents any osteotomy error in the buccolingual and mesiodistal planes. Additionally, drill stops can be incorporated to prevent from overpreparing the site. Basically, with the complete-limiting design, the final position of the implant is known before the actual surgery. This technique is becoming popular because the prosthetic final abutment or provisional restoration can be prefabricated for immediate provisionalization after implant placement.

Three techniques are commonly used for positioning the guide holes and fabricating the complete-limiting templates (Figures 18-29 and 18-30).

Freehand Technique. Placement accuracy of guide holes or sleeves with the freehand technique is operator dependent. This technique does not accurately parallel implant sites and has the most margin of error. Usually a laboratory carbide bur is used to mark the cast as a guide without the use of a fixed apparatus (surveyor). Two different designs can be used with the freehand technique, which include the "slot" and the "individual hole" technique. The slot design does not provide ideal parallelism and is highly dependent on operator experience. The hole technique allows for a wide variation in angulation as preparation is completed through a large hole[28–30] (Figure 18-31).

Milling. Milling is an accurate technique in which a milling machine is utilized to position the guide holes or sleeves. This technique requires special equipment mainly found in dental laboratory settings and accuracy is highly dependent on technician experience.[28]

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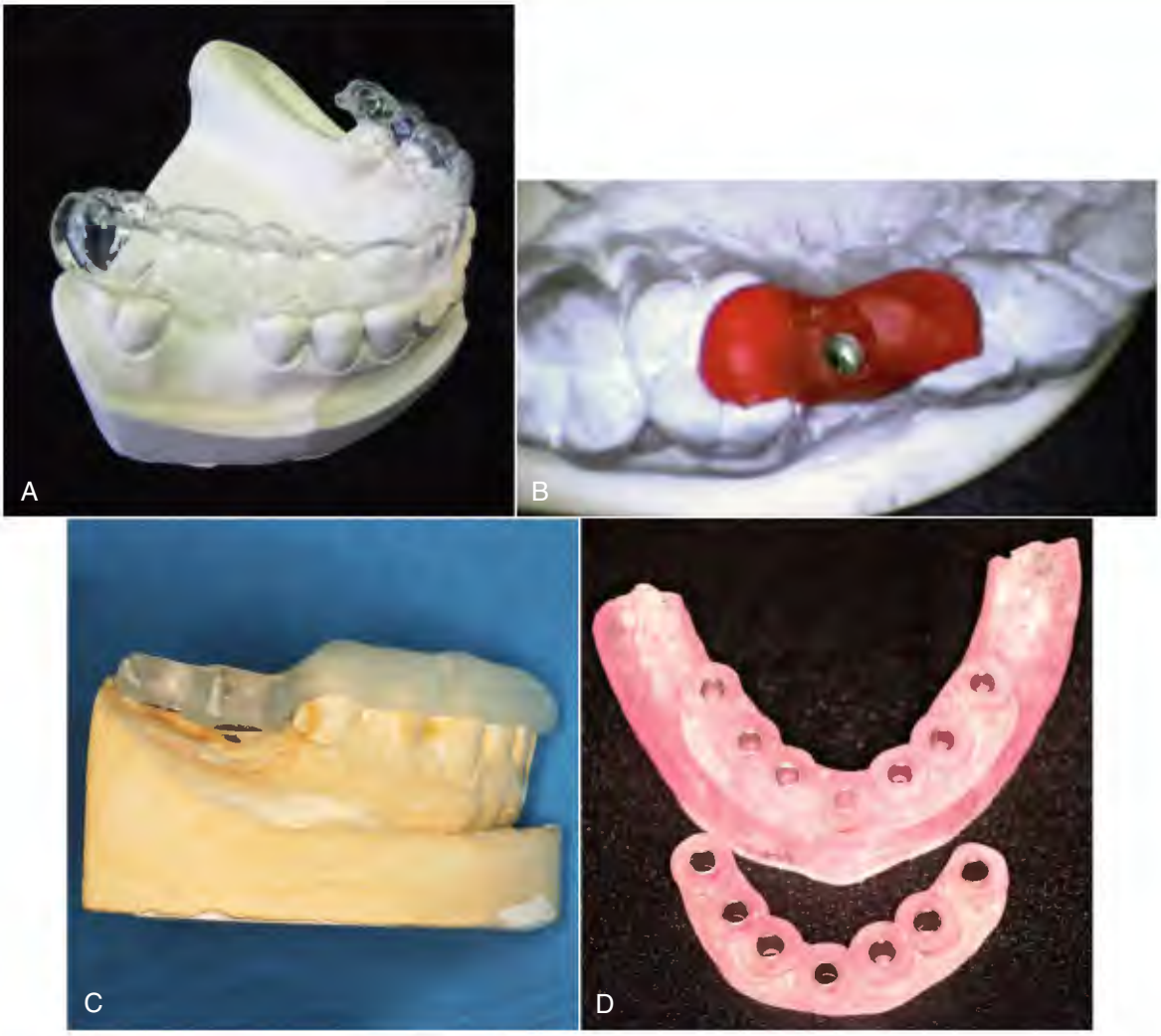


FIGURE 18-26. Surgical template classification according to material used. **A,** Clear thermoform material. **B,** Autopolymerizing acrylic. **C,** Light-cured acrylic. **D,** Computer-aided design/computer-aided manufacturing.

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Computer-Aided Design/Computer-Aided Manufacturing. This technique uses three-dimensional images with specialized software to allow precise placement of implant guide holes and sleeves. Accurate definitive positioning can be obtained using the reformatted CT images of the osseous morphology, bone density, opposing occlusion, and ideal implant positioning.[31,32]

Laboratory-Fabricated Techniques for Surgical Guides

Nonlimiting Surgical Template

A nonlimiting surgical template is a template that allows for a generalized location of the ideal implant site. No actual directional guide is built into this type of template other than possibly the buccal or lingual contours of the ideal positioning of the teeth. A simple and inexpensive method to fabricate this type of template is duplication of an existing prosthesis or modification of Preston's clear splint for the diagnosis of tooth contours, tooth position, and occlusal form.[33]

The diagnostic wax-up is completed to evaluate the tooth size, position, contour, and occlusion in the edentulous regions where implants will be inserted. A full-arch, irreversible hydrocolloid or polyvinyl siloxane impression is made of the diagnostic wax-up and poured in dental stone. On the duplicate cast of the wax-up teeth, a vacuum acrylic shell (0.060–0.080 inch) is vacuum formed to fit over the teeth and gingival contours of the buccal aspect of the ridge. If no natural teeth are present in the posterior, the posterior portion of the template should be maintained to cover the retromolar pads or tuberosities and palate to aid in positioning.

The occlusal surface is trimmed over the ideal and optional implant sites, maintaining the facial and facial-occlusal line angle of the surgical template. A black line then is drawn on the template with a marker to indicate the center of each implant and the desired angulation. This provides latitude for the implant dentist for implant placement yet communicates the ideal tooth position and angulation during surgery.

The surgical template should relate to the ideal facial contour. Many edentulous ridges have lost facial bone, and the template can assist in determining the amount of augmentation required for implant placement or support of the lips and face. The

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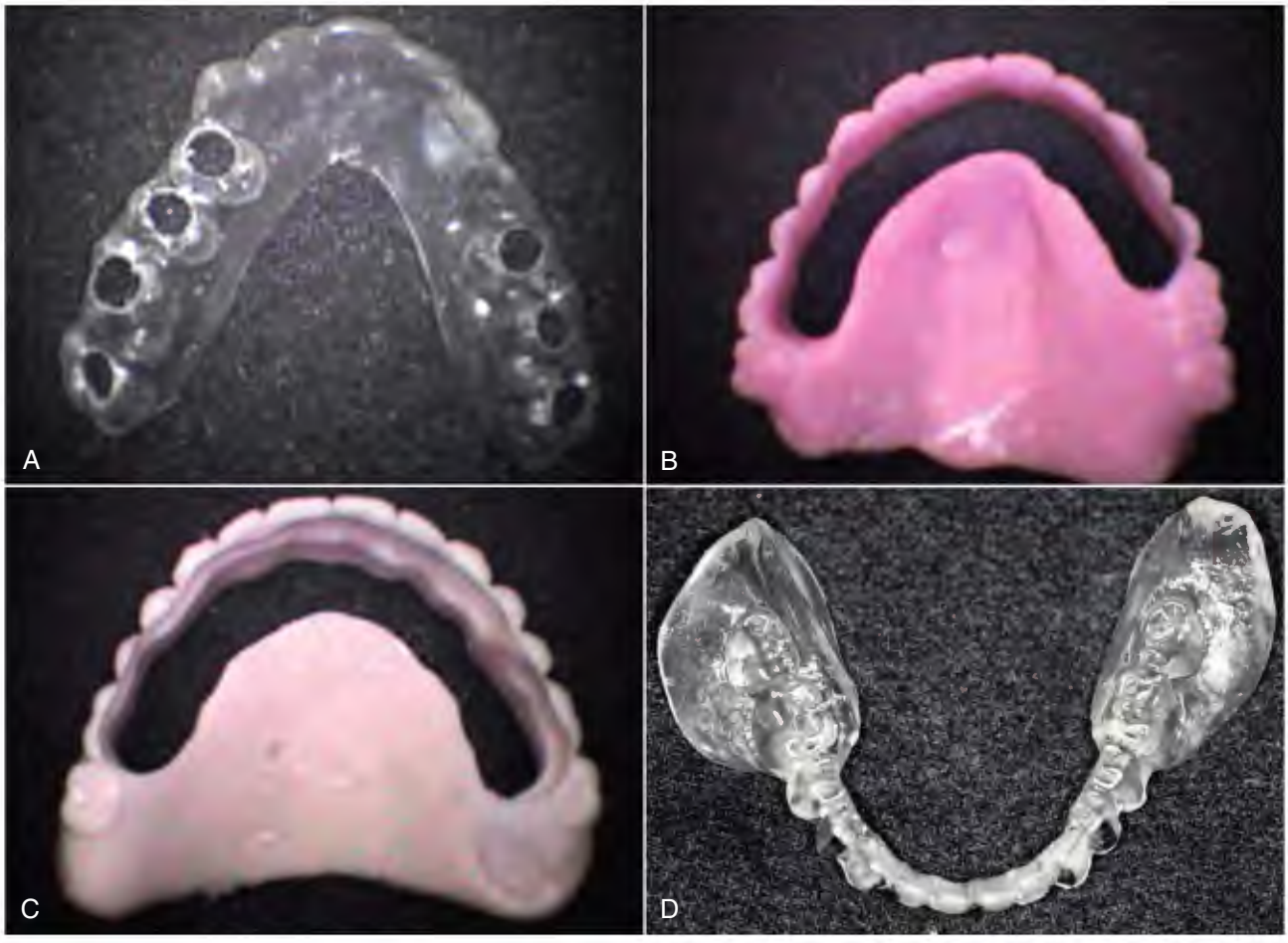


FIGURE 18-27. **A** to **D,** Examples of nonlimiting surgical templates.

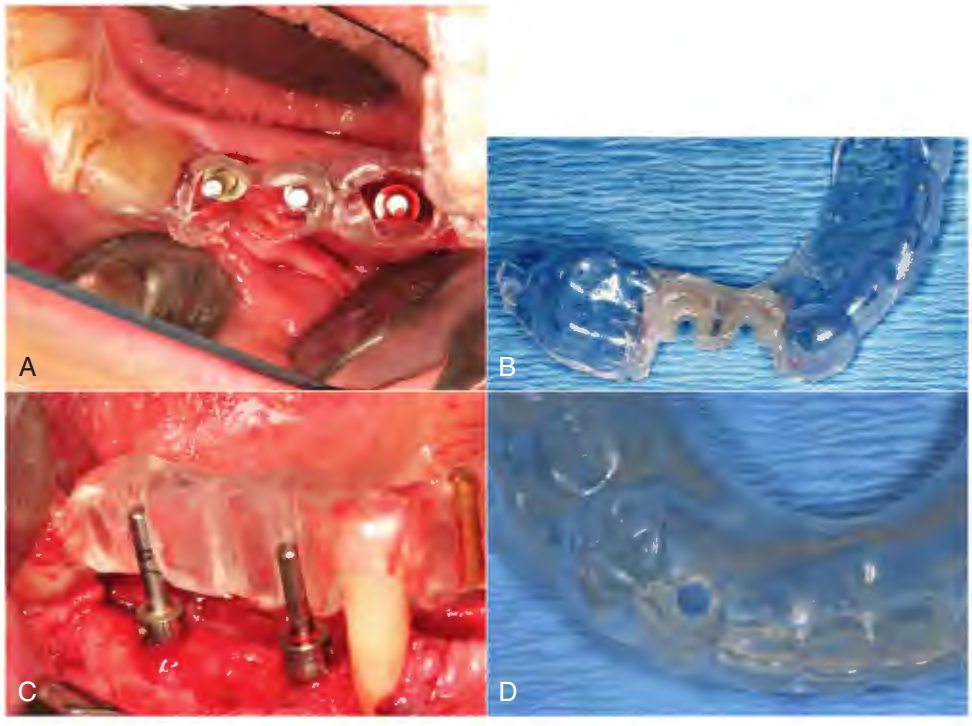


FIGURE 18-28. **A** to **D,** Examples of partial-limiting templates.

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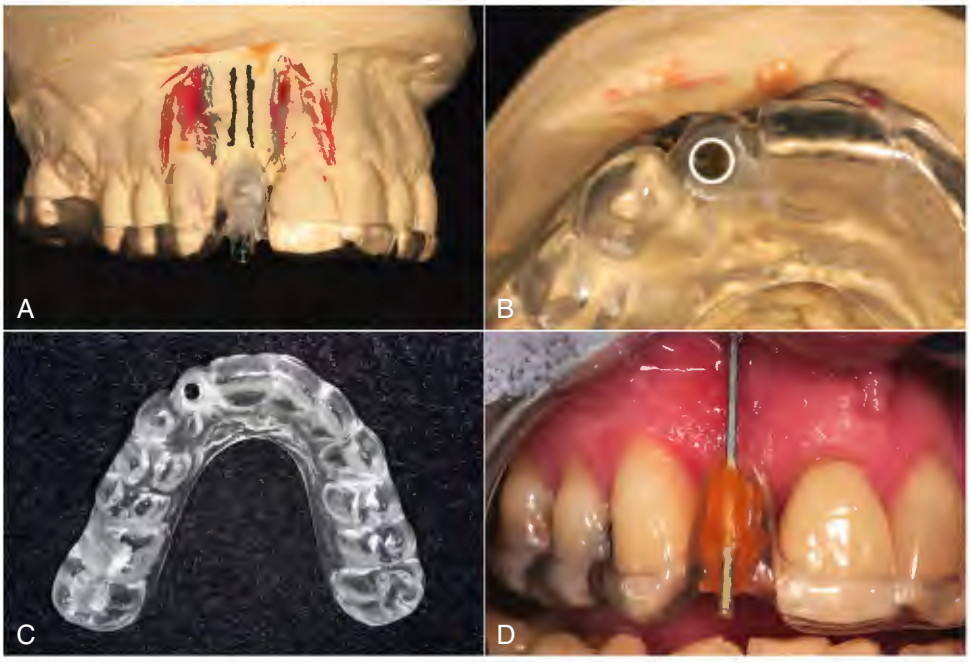


FIGURE 18-29. Complete-limiting templates for a single implant.

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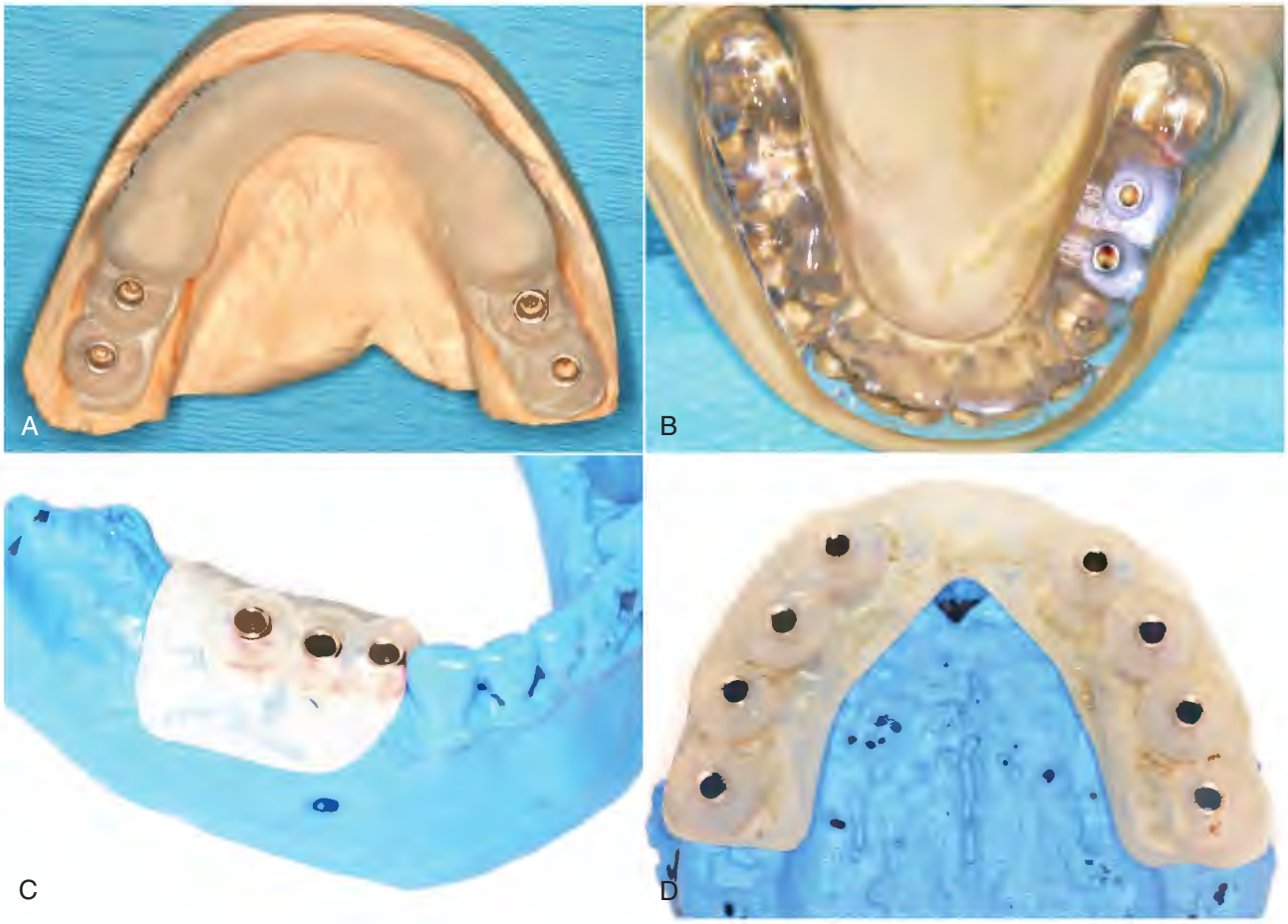


FIGURE 18-30. **A** and **B,** Tooth-supported complete-limiting templates. **C** and **D,** Bone-supported complete-limiting templates.

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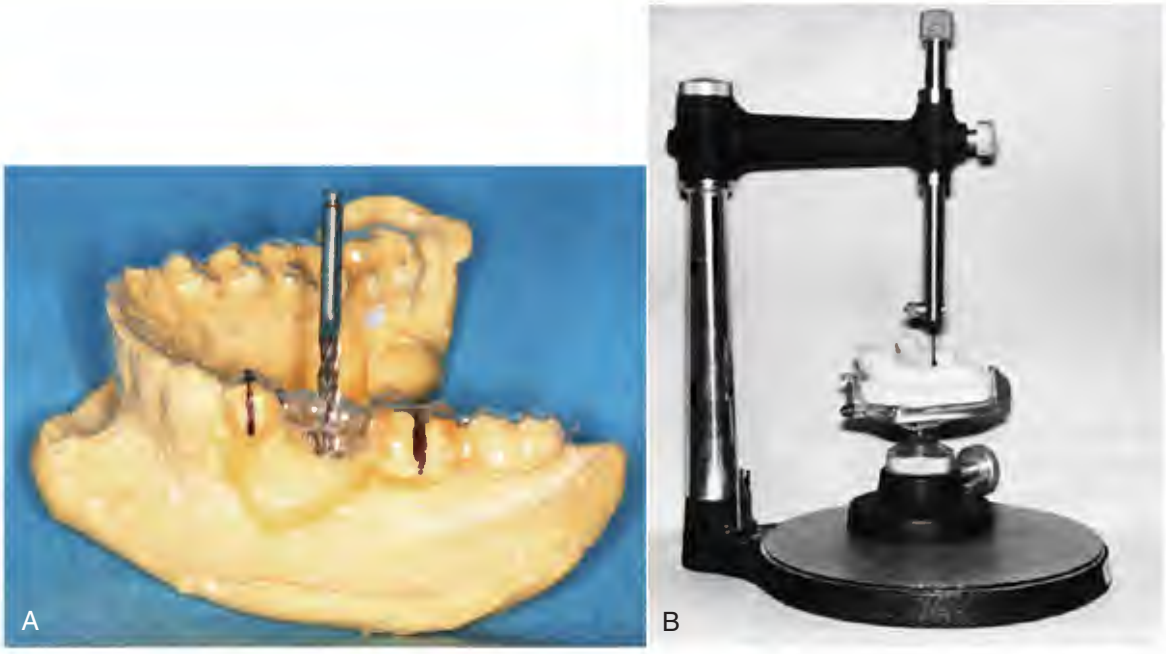


FIGURE 18-31. Freehand fabrication of guides. Caution must be exercised because the true root location cannot be determined without three-dimensional evaluation. **A,** Estimation of root location. **B,** A surveyor can be used to parallel multiple implants.

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surgical template may be used for a bone graft, and later the same template may be used for insertion of implants and again for implant uncovery.

Partial-Limiting Surgical Template

A partial-limiting surgical template is used as a directional guide for one drill size, usually the pilot drill. The rest of the osteotomy sites are then finished freehand by the implant dentist. This type of template may be fabricated by placing holes through the occlusal surface of a denture tooth or diagnostic wax-up that identifies the ideal implant placement site. For partially edentulous cases, a fabrication technique includes modifying a conventional template by placing holes (2 mm) in the ideal position or placing metal sleeves into the template.

In the edentulous arch, the vacuum form may be fabricated from the existing removable prosthesis if within accepted guidelines. A soft tissue liner then may be added in the tuberosity or retromolar pad regions and other soft tissue areas not involved in surgery. Acrylic resin then is added over the occlusal portion of the template where no implants are planned. The patient then occludes into this index after using petroleum jelly over the opposing teeth. In this manner, the template can be correctly positioned over the edentulous ridge during surgery after the tissue is reflected. Otherwise, a template position set too far facially or off to one side is likely

After the soft tissue is reflected, the template is positioned over the teeth of the opposing arch. The patient may occlude on the pins, and each one determines the ideal center position of the teeth. A pilot drill can be used to mark each implant body position. The angulation of the osteotomy also can be determined with the template. The surgical guide easily determines the implant position, yet the surgeon can have the patient's mouth open and drill into the bone with complete access and vision. The template also may be used at stage II uncovery to find the position of each implant when soft tissue carving for fixed prosthesis type 1 (FP-1) restorations is indicated rather than complete reflection of the tissue.

Complete-Limiting Surgical Templates

Most complete-limiting surgical templates are fabricated via a third party who allows for ideal placement with multiple templates or varying-diameter drilling guides.

Transforming a Radiographic Template into a Surgical Guide

It is easy to construct a surgical guide from a radiographic template. If ideal positioning of the teeth has been determined by the diagnostic wax-up, openings may be made to allow for accurate implant guidance (Figure 18-32).

Computed Tomography Surgical Templates

Although conventional surgical templates are easily fabricated, they do have the disadvantage of no correlation between the planned prosthesis and the underlying bony anatomy in the third dimension. After the virtual treatment plan is completed, the surgical template may be fabricated. The two most common surgical templates are from Materialise (SimPlant), which are termed "surgiguides," and from Nobel Biocare (NobelGuide), which are termed "surgical templates." Other commercially available software programs include ImplantMaster (I-Dent Imaging Ltd., Hod Hasharon, Israel), Easy Guide (Keystone-Dental, Burlington, MA), and coDiagnostiX (IVS Solutions AG, Chemnitiz, Germany).

With the use of CT-generated software programs (e.g., SimPlant), this anatomical relationship can be predictably

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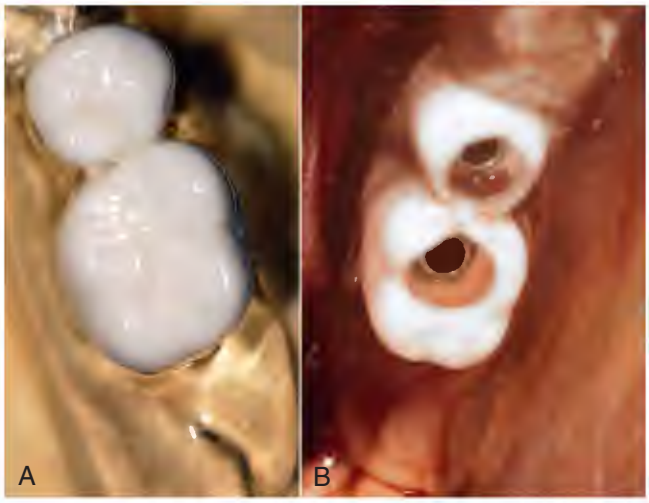


FIGURE 18-32. Radiopaque template (**A**) that is transformed into a surgical template (**B**) after completion of the scan.

determined before surgery. After the scan is completed with the radiopaque template, the data must be converted into a format that can be used by the scanning software. Every treatment planning software has its own specific protocol, but all software is compatible with DICOM (digital imaging and communication in medicine) files that are generated and downloaded from the scanner. Although third-party vendors will do the interactive treatment planning for the placement of the implants, it is highly recommended that the implant dentist be involved in this planning process.

After the files have been converted into the software program, evaluation of potential implant sites in the desired prosthetic locations can be completed. Virtual implants may be placed via comprehensive implant libraries, which include the implant brand, type, diameter, and length. The available bone dimensions may be ascertained along with the density and angulation with respect to the planned prosthesis. After completion of the final implant positions, the treatment plan is saved, and the surgical template is designed[23] (Figure 18-33).

Computer-Assisted Design and Manufacturing of Surgical Guides

Steps in Fabrication of a Computed Tomography Surgical Guide

1. A radiographic prosthesis is fabricated from a diagnostic wax-up, temporary prosthesis, or the patient's existing prosthesis. Radiopaque markers are placed in the radiographic prosthesis showing the ideal location of the teeth to be replaced.
2. The patient is scanned while wearing the radiographic prosthesis. It is imperative that an accurate scan is completed.
   a. If there is a lack of retention of the radiographic prosthesis, have the patient wear the prosthesis with denture adhesive to ensure stability. Movement or improper seating will result in errors leading to incorrect implant position.
   b. Instruct the radiographic technician to separate the arches so that the ideal contours of the teeth can be ascertained (i.e., cotton roll).
3. The CT data are then transferred to a computer software program (i.e., SimPlant) in which interactive treatment planning is completed with the ideal placement of the implants.
4. The treatment plan data are transferred to the software company (i.e., Materialise) for fabrication of the surgical guide (Figures 18-33 to 18-35).

Three different surgical guides may be used: tooth supported, bone supported, and soft tissue supported.[34]

Tooth-supported guides are the most accurate and easiest guide to use. These guides are mainly used in partially edentulous patients and are highly dependent on the accuracy of the impression and study cast. These guides typically are translucent, thus allowing visualization of the complete seating of the guide. No gaps should be present between the guide and teeth and study cast or in the mouth. In addition, the guide must be stable and have no movement when lightly manipulated (Figure 18-36).

Indications

1. Partially edentulous patients
2. Sufficient number of teeth for guide support

Bone-supported guides may be used in partially or fully edentulous patients. These guides require extensive full-thickness reflection to expose the bony ridges to allow proper seating of the guide. If bone modification is indicated, proper seating of the guide might be difficult, resulting in errors in implant placement. In some cases, a bone reduction guide may be used before seating the bone-supported guide. It should be noted that small bone protuberances may exist that are below the resolution of the scan. Therefore, meticulous evaluation of the bony contours should be evaluated before osteotomy site preparation (Figure 18-37).

Indications

1. Edentulous patients
2. Partially edentulous patients (minimum of three teeth missing)

Soft tissue–supported guides are usually indicated for completely edentulous patients in whom the guide will rest solely on the soft tissue. These types of guides are sometimes difficult to seat correctly, especially if there exists overextension beyond the vestibule or floor of the mouth. Bite registrations are often used to ensure ideal placement and positioning. It is sometimes necessary to use stabilizing pins or screws to improve stability during osteotomy and implant placement. The most challenging cases for the use of soft tissue guides are maxillae with flat palatal vaults and mandibles with high floor of the mouth with very little vestibule. Note: For a soft tissue guide, the radiographic prosthesis must be made with different proportions of radiopaque material in the base compared with the teeth to show delineation (Figure 18-38).

Indications

1. Only edentulous patients
2. Must have sufficient support
   a. Maxilla (palate)
   b. Mandible: sufficient vestibular or lingual support of prosthesis

Fabrication of Surgical Guides

There exist two types of surgical guide fabrication techniques from the treatment planning software.

1. Laser photopolymerization of liquid resin
2. CAD/CAM

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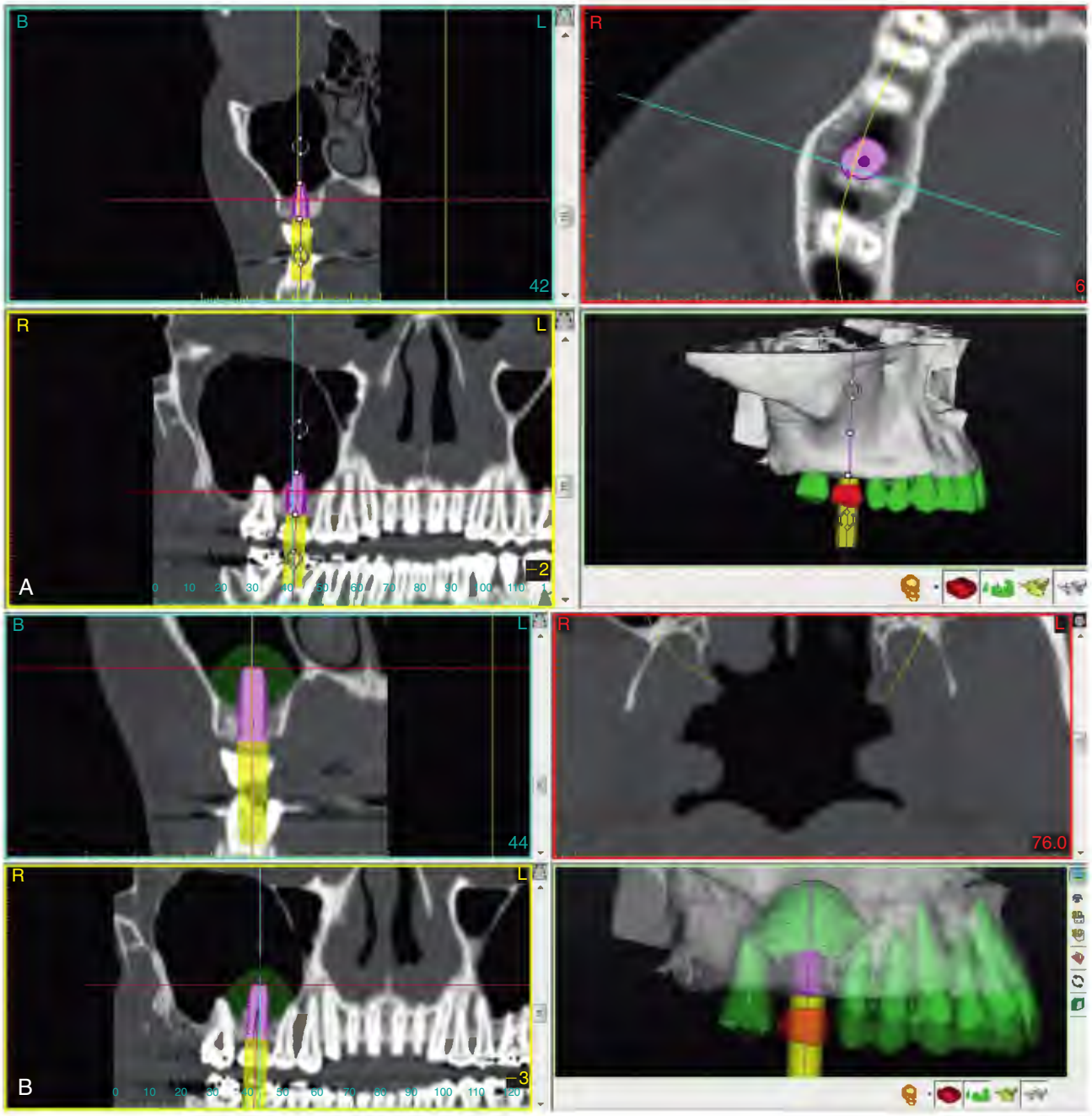


FIGURE 18-33. Treatment planning for replacement of maxillary right first molar with surgical guide fabrication. **A,** The implant is placed in the ideal position. **B,** Because of inadequate bone quantity, an SA-3 Immediate sinus augmentation is planned via software.

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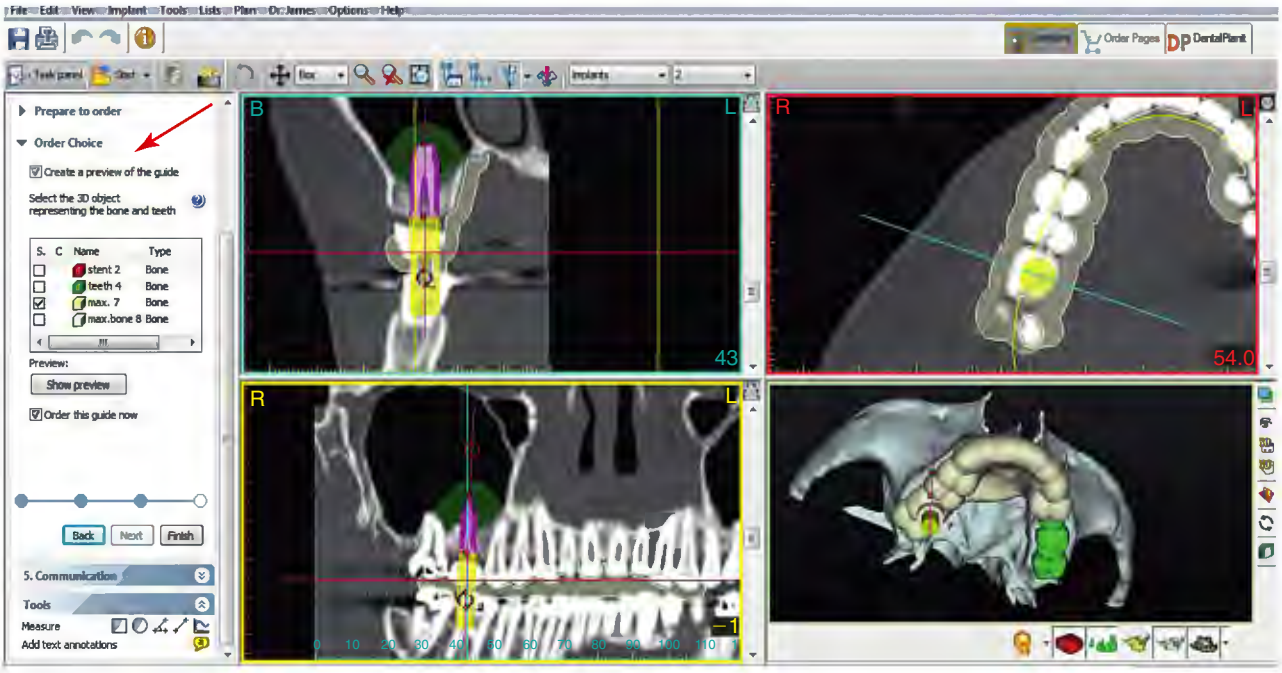


FIGURE 18-34. Implant surgical guide is ordered online *(red arrow)*, and design is verified before uploading to the surgical guide manufacturer (i.e., SimPlant, Materialise Dental).

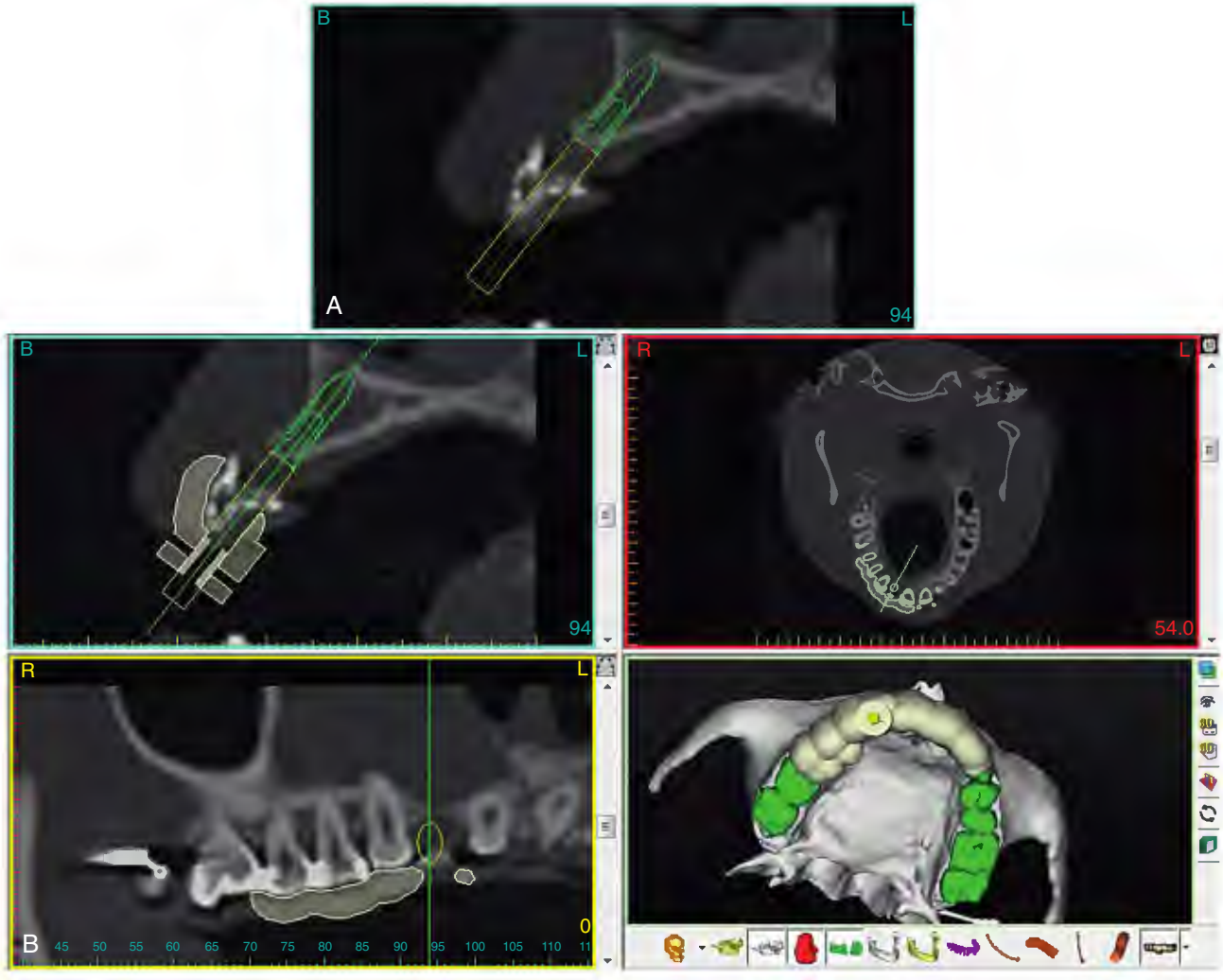


FIGURE 18-35. Design of surgical template verified.

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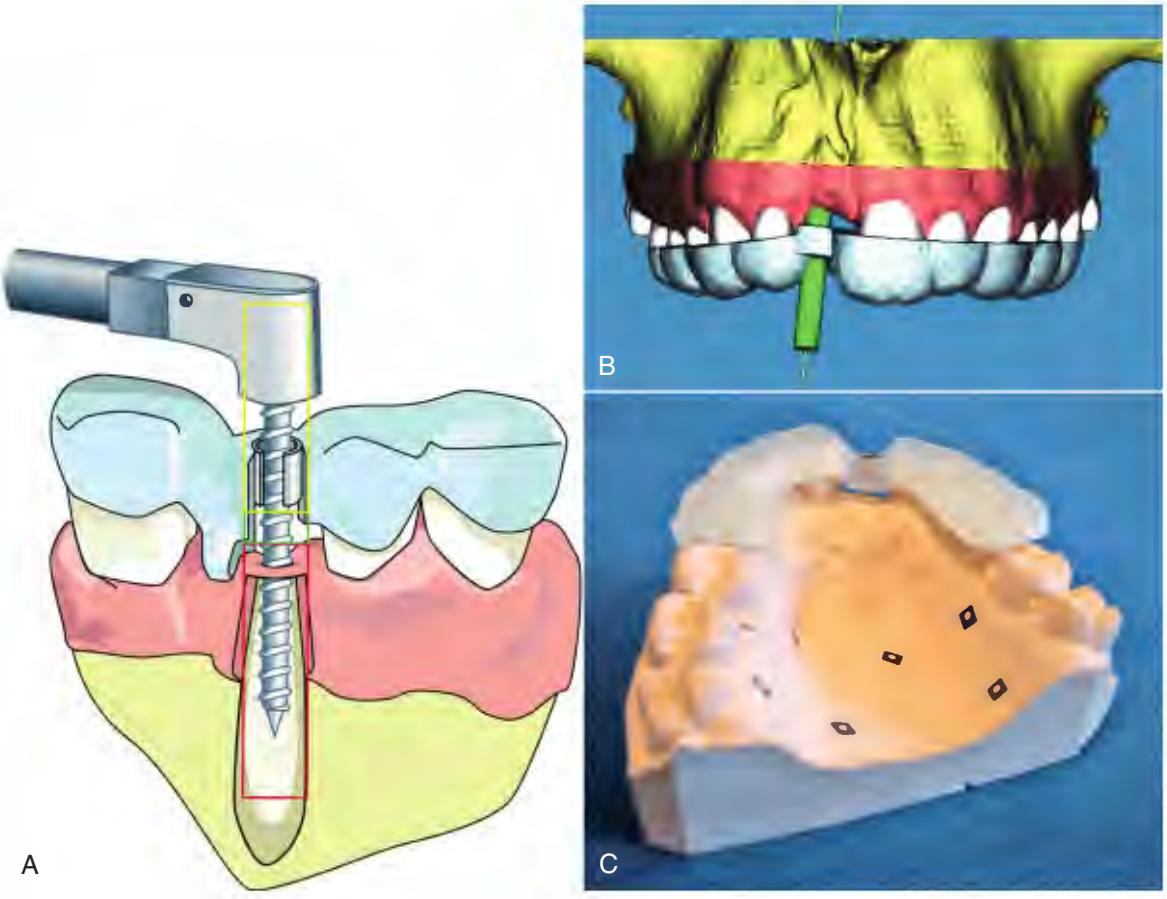


FIGURE 18-36. Tooth-supported surgical templates. **A,** Diagram of a tooth-supported template. **B,** Virtual planning of the template. **C,** Computed tomography–generated tooth-supported template.

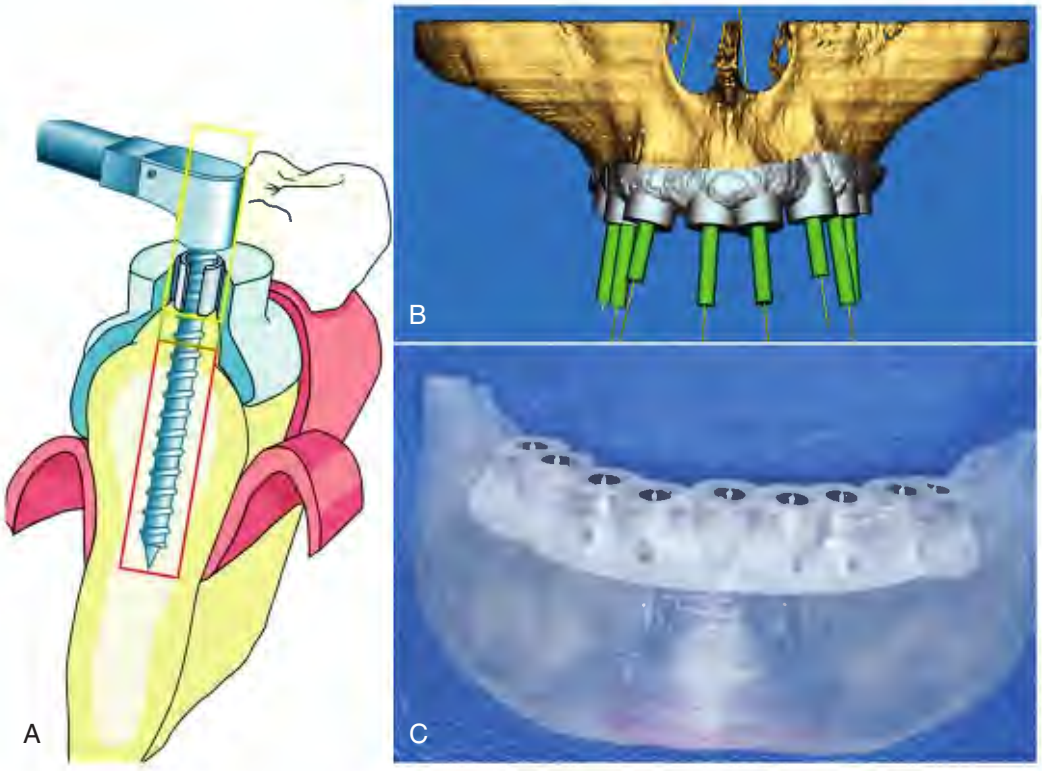


FIGURE 18-37. Bone-supported surgical templates. **A,** Diagram of a bone-supported template. **B,** Virtual planning of the template. **C,** Computed tomography–generated bone-supported template.

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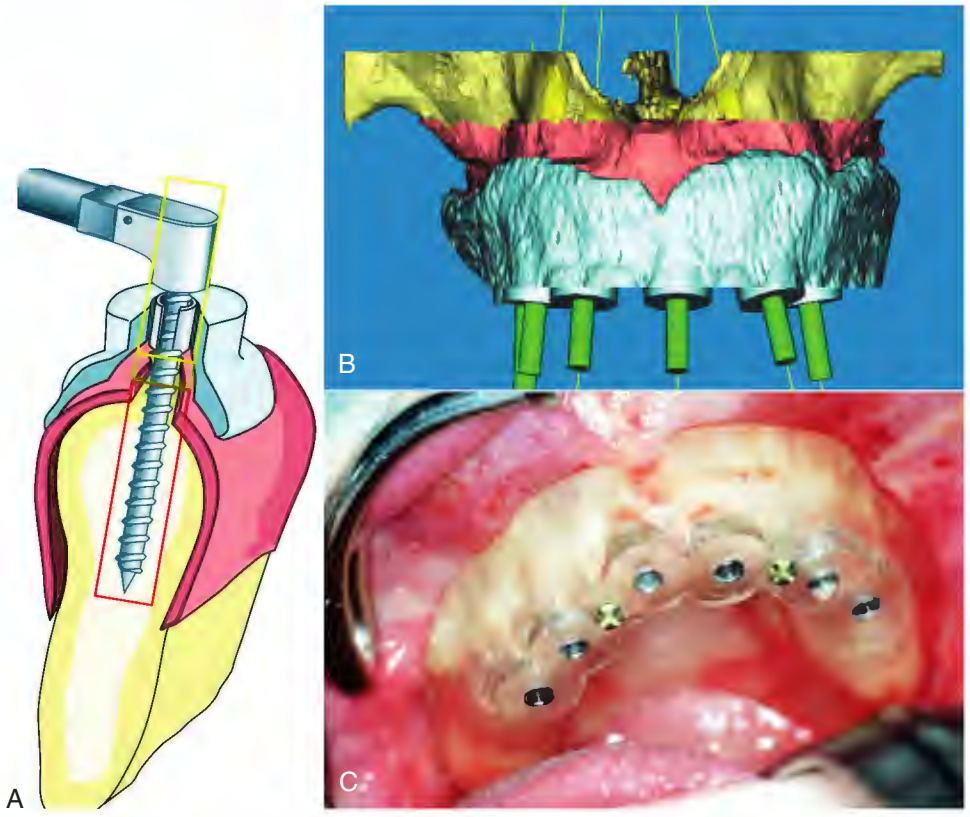


FIGURE 18-38. Mucosa-supported surgical templates. **A,** Diagram of a mucosa-supported template. **B,** Virtual planning of the template. **C,** Computed tomography–generated mucosa-supported template.

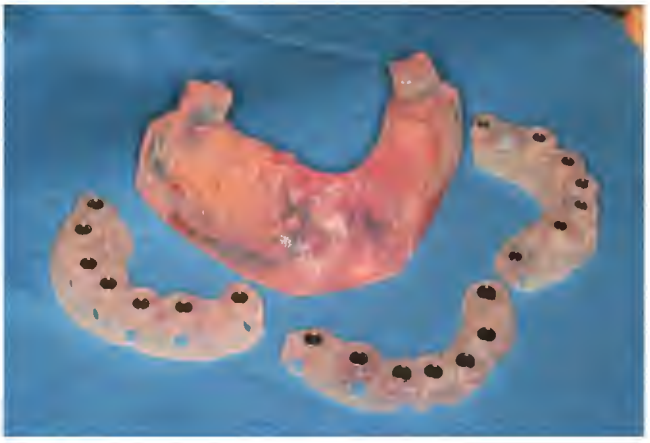


FIGURE 18-39. Stereolithographic model used in the fabrication of a bone-supported surgical guide.

Additional Types of Templates (Guides)

Stereolithographic Models

The fabrication of stereolithographic models is a laser-dependent rapid polymerization technique using sequential layers of special polymers that can duplicate the exact shape of the osseous anatomy.[31,32,35] These types of models include:

1. Surgical guide models used in the fabrication of surgical guides (Figure 18-39)
2. Presurgical models used in the preoperative evaluation for implant placement, bone grafting, and orthognathic surgery (Figures 18-40 and 18-41)
3. Bone reduction guides: similar to reduction copings in conventional crown and bridge; the bone reduction guides are used to reduce osseous height before implant placement (Figure 18-42)

Provisional Restorations: "Immediate Smiles"

Taking the CT-generated technology to the next level involves fabricating provisional restorations before implant insertion. First, the virtual treatment plan is created by the implant dentist followed by the manufacturer developing the computer-generated stereolithographic surgical guides. A dental laboratory uses the surgical guide and articulated diagnostic casts to fabricate provisional and (in some cases, final) prostheses. The implant dentist then uses the surgical guide to place the implants and abutments. The provisional (or final) prosthesis is then inserted immediately after the placement (Figure 18-43).

Provisional Restorations

One of the most common and challenging roadblocks to implant treatment acceptance is the patient's perception of the temporization (provisionalization) of the edentulous areas after implant placement or bone grafting. In most cases, pressure directly or indirectly on the surgical site, implant, or bone graft can lead to bone loss and increased morbidity. Thus, many different types of provisionalization techniques are used, all with advantages and disadvantages. The requirements of an acceptable provisional restoration are:

1. Comfortable
2. Functional

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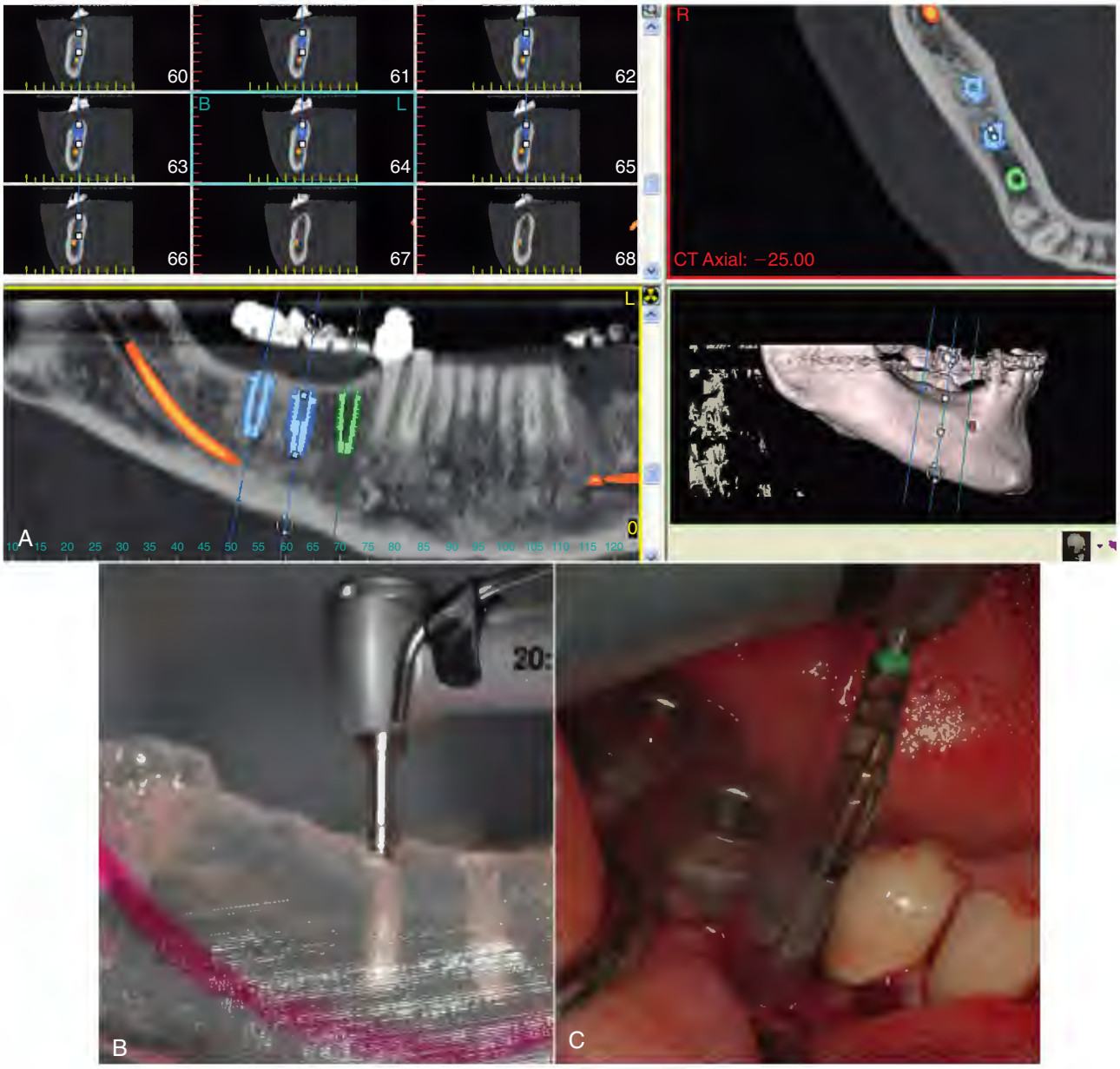


FIGURE 18-40. Stereolithographic model. **A,** Treatment planning for placement of three implants. **B,** Surgery completed on the model before surgery. **C,** Bone-supported guide used during surgery.

3. Esthetic
4. Does not impinge or place pressure on the implant or bone graft
5. Longevity

Partially Edentulous Sites

Fixed Prosthesis

Ideally, the best provisional prosthesis is a fixed prosthesis that has relief and exerts no pressure on the surgical site during the healing phase. Examples include an existing fixed partial denture, acrylic provisional, or resin-bonded bridge. Care must be taken to relieve the pontic area so no tissue impingement exists (Figures 18-44 and 18-45; Box 18-10).

Removable Prosthesis

A removable prosthesis may be fabricated in various ways, which are case dependent.

Removable Partial Denture (i.e., Flipper, Stayplate)

If a removable partial denture is to be used, the natural teeth should have adequate support from clasps and rest seats. The tissue surface over the implant or graft site should be relieved and tissue conditioner placed (Figures 18-46 and 18-47).[8]

Advantages

1. Resists pressure on surgical site
2. Esthetic
3. Tissue surface may be relieved to minimize pressure on surgical site
4. Removable

Disadvantages

1. Additional laboratory fee
2. Possible speech impairment

Essix Appliance

Thermoformed Essix appliances have multiple uses in general dentistry and orthodontics. This prosthesis is often fabricated

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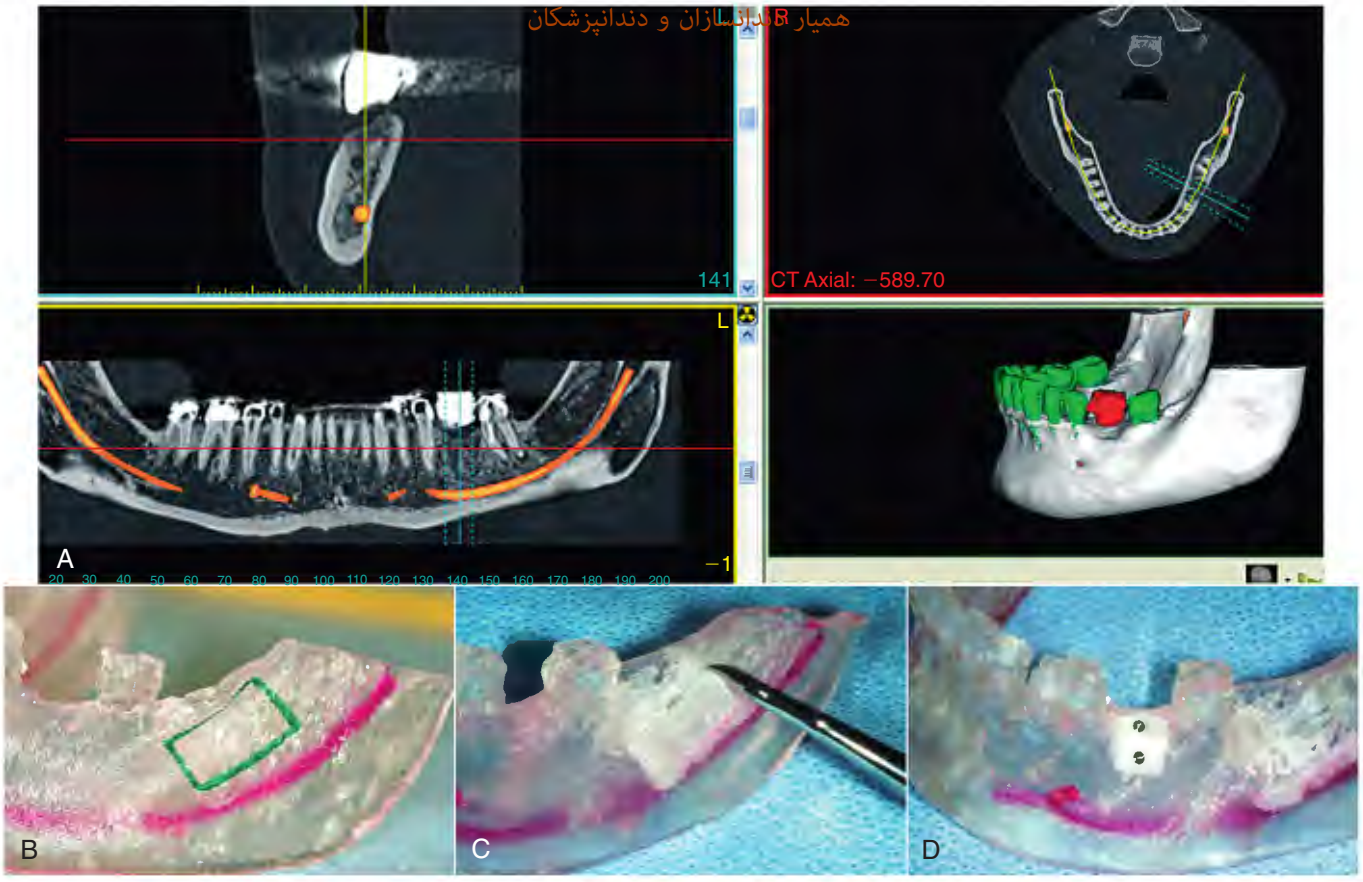


FIGURE 18-41. Stereolithographic model. **A,** Treatment planning for an autogenous bone graft from a mandibular ramus. **B** to **D,** Surgical procedure completed in a laboratory setting before surgery.

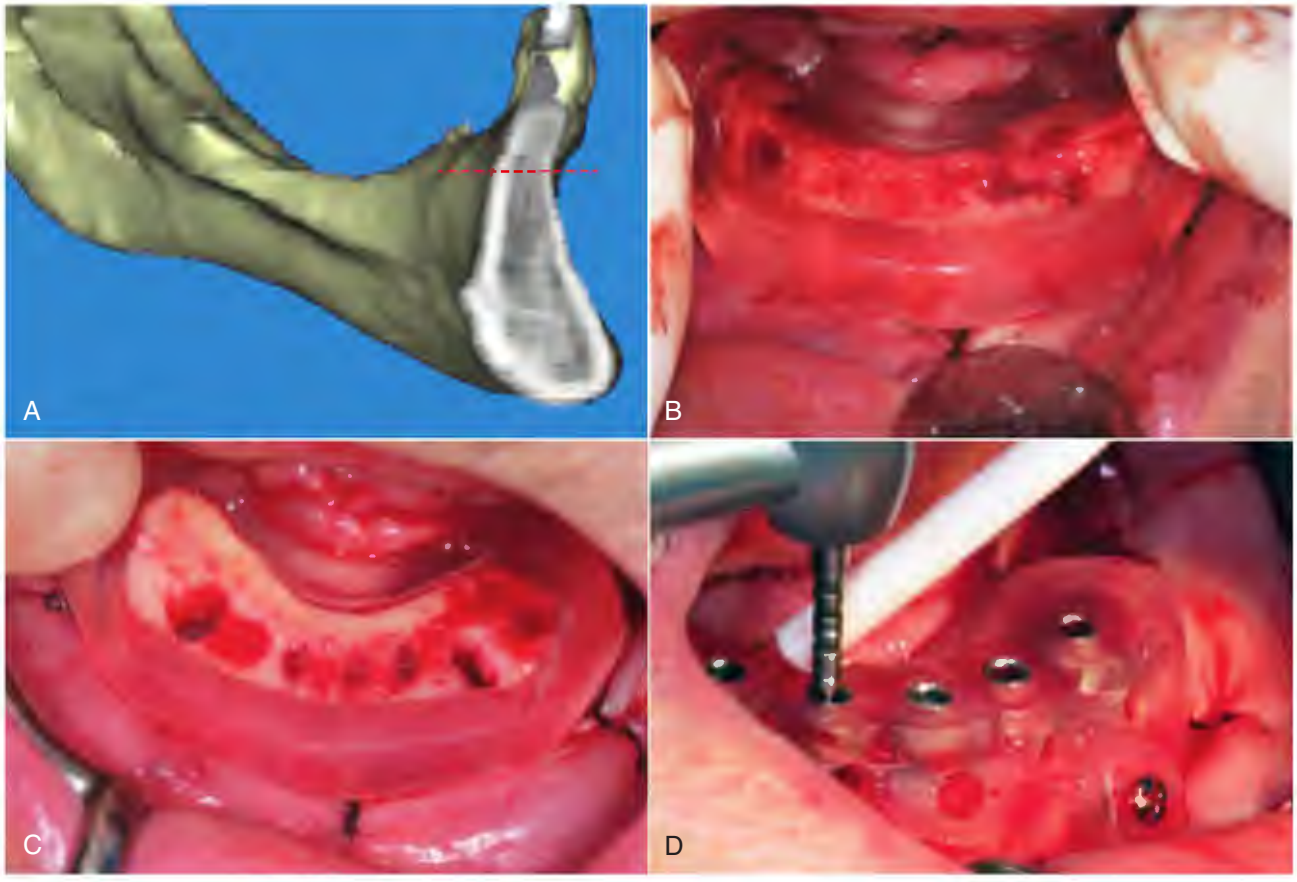


FIGURE 18-42. Bone reduction guide. **A,** Cross-section showing division B ridge requiring osteoplasty. **B,** Bone reduction guide placed during surgery. **C,** Reduction of bone. **D,** Bone-supported guide used after bone reduction.

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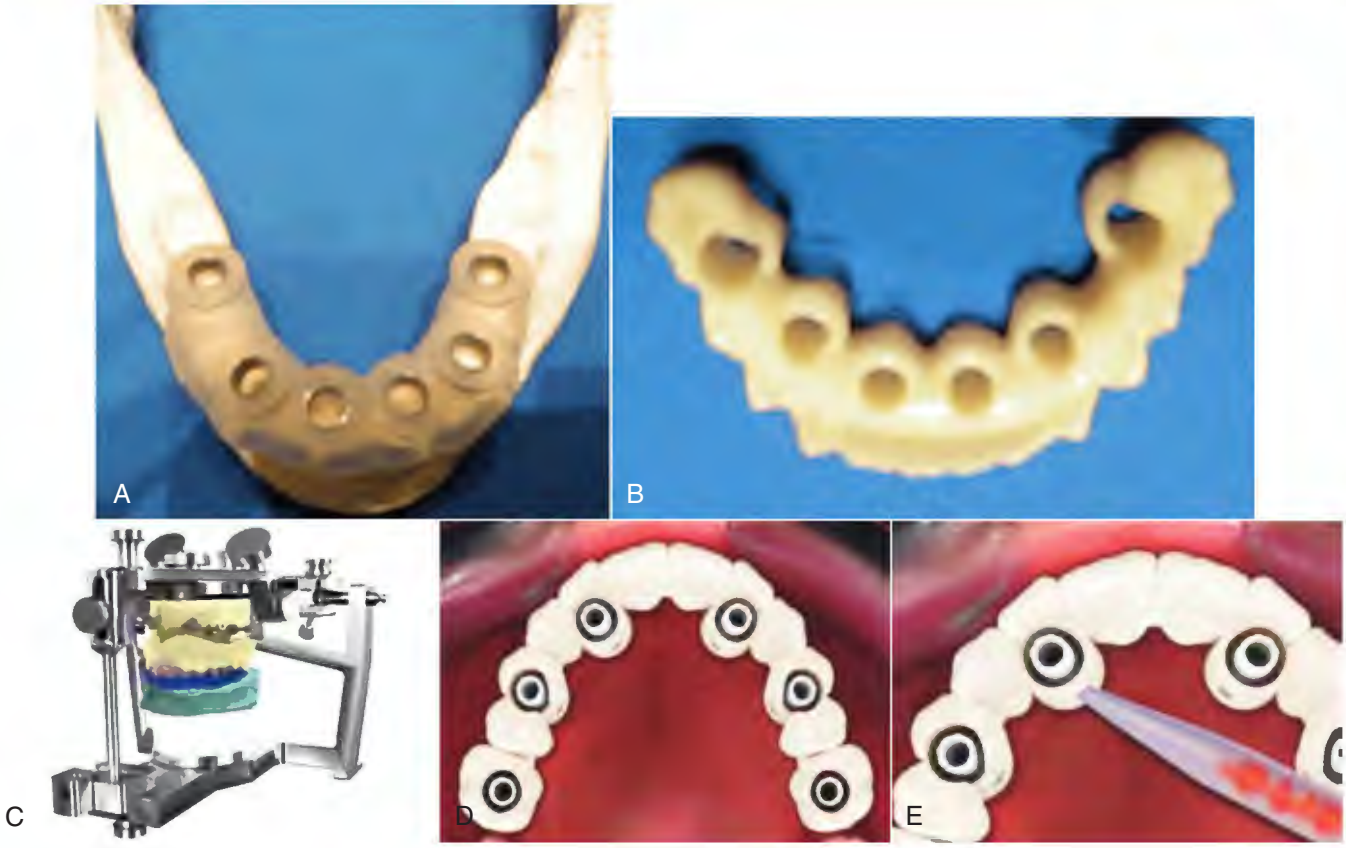


FIGURE 18-43. Immediate smile technique. **A,** Articulated diagnostic setup. **B,** Surgical template fabricated via computed tomography virtual planning. **C,** Laboratory-fabricated interim prosthesis. After implant placement, the interim prosthesis is inserted (**D**) and fixated with light-cured acrylic (**E**).



FIGURE 18-44. Partially edentulous provisional restorations: fixed (**A**), fixed prosthesis (**B**), and resin-bonded bridge (**C**).

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in-office by the dentist or staff member (Figures 18-48 and 18-49; Box 18-11).

Advantages

1. Easily fabricated; quick delivery
2. Adjacent teeth take pressure from occlusion
3. Inexpensive
4. Prevent tooth movement during healing phase
5. Removable

Disadvantages

1. Possible esthetic issues
2. Tend to wear or fracture in patients who have parafunction
3. Possible speech impairment

BOX 18-10 Laboratory Steps for Fabrication of In-Office Bonded Prosthesis

1. After fabrication of the study cast and articulated setup, fit a denture tooth of appropriate size and shade into the edentulous area. Trim the lingual of the denture tooth and fixate it to the cast with light-cured acrylic (Figure 18-45, *A* to *C*).
2. Cut a small piece of ribbon to extend to the lingual aspect of the adjacent teeth. Secure it to the lingual of the denture tooth with light-cured acrylic (Figure 18-45, *D*).
3. Using self-curing methyl methacrylate, fabricate lingual wings on the adjacent teeth for cement retention (Figure 18-45, *E* and *F*).
4. Polish with acrylic finishing burs (Figure 18-45, *G*)
5. Final prosthesis (Figure 18-45, *H*).

Snap-On Smile (DenMat)

The DenMat is a noninvasive, cosmetic partial or full-arch removable prosthesis that "snaps" over the patient's existing dentition. This prosthesis does not impinge on any gingival tissue including the palate, which makes it an appropriate solution for provisionalization of implant and bone grafting sites. Retention is excellent with no adhesives usually required. A polyvinyl siloxane impression is made of the teeth and surrounding soft tissues (Figure 18-50 and Box 18-12).

Advantages

1. Esthetic
2. Excellent retention
3. No pressure on surgical site
4. Adjacent teeth absorb pressure from occlusion
5. Removable

Disadvantages

1. Possible esthetic issues for patients with a high smile line
2. Possible fracture with parafunction patients

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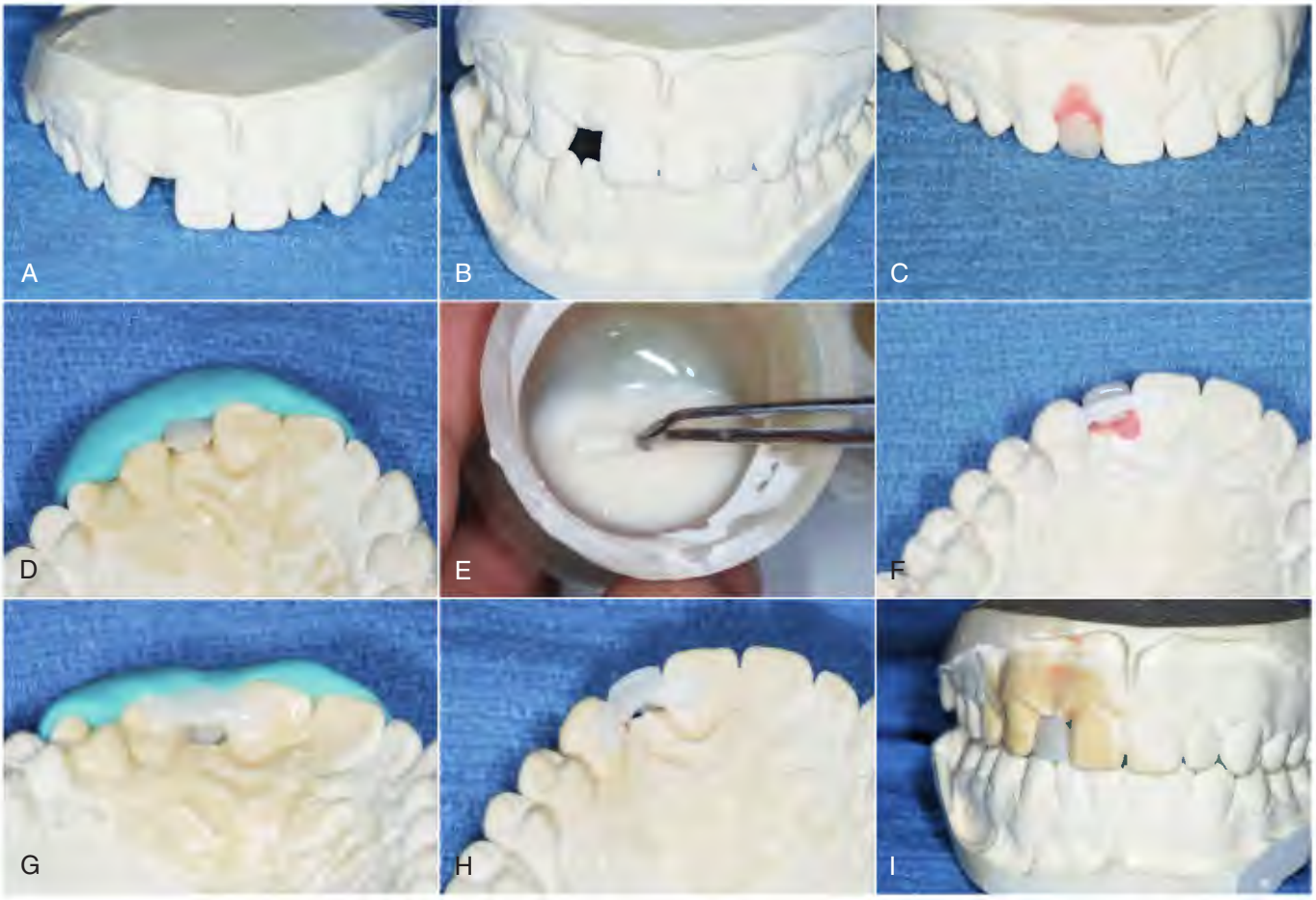


FIGURE 18-45. **A** to **I,** Laboratory steps in fabrication of in-office resin-bonded bridge.

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FIGURE 18-46. Examples of removable provisional prostheses.

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3. Laboratory fee (expensive)
4. Possible demineralization of enamel

Fully Edentulous Sites

Complete Denture

The most challenging provisional prosthesis for implant dentists is for fully edentulous patients. It is very technique sensitive to maintain a complete denture as an interim prosthesis that does not place any pressure on the surgical site. Fundamental complete denture principles such as the primary stress-bearing area should be adhered to. By maintaining strong support on the primary stress-bearing areas, there will be less chance that pressure will be placed on the site.

Advantages

1. Easily fabricated or can modify existing prostheses
2. Removable

Disadvantages

1. Difficult to wear after surgery
2. Possible retention problems
3. Must be relined on a continuous basis

Relining of Prostheses

Most patients are reluctant to be without their dentures after surgery and during the healing period. In today's society, patients are more active than in previous years in both professional and recreational activities. Patients may be more amenable to having a series of appointments using a tissue-treatment material than going about daily activities without their removable prostheses (i.e., maxillary and mandibular complete dentures).

Implant dentists are faced with many options in the relining of provisional prostheses. A vast array of products are available today, but implant dentists must understand the differences in the materials to select and use the product best suited for the clinical situation.

Ideal Material

- Resilience
- Dimensional stability
- Tear resistance
- Low solubility and absorption in saliva
- Ease of cleaning

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FIGURE 18-47. Partially edentulous provisional restoration errors. **A,** Reline material that is not periodically changed will cause fungal growth and hardness. **B,** Reline material protruding into the surgical site. **C,** An excessively large flange leading to pressure on the surgical site.



FIGURE 18-48. **A** to **C,** Laboratory-fabricated Essix appliance. **D,** Essix appliance inserted after implant placement.

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BOX 18-11 Laboratory Steps for Fabrication of an Essix Appliance

1. After fabrication of the study cast, fit a denture tooth of appropriate size and shade into the edentulous area. Trim the base of the pontic to approximate the ridge, allowing a space between the tissue (Figure 18-49, *A* and *B*)
2. Cut a mesiodistal undercut into the lingual surface of the denture tooth with a #4 round bur or #34 inverted cone lab bur. This mechanical retention will secure the denture tooth into the Essix appliance (Figure 18-49, *C* and *D*).
3. Using a Ministar machine (Great Lakes Orthodontics), a thermoform Isofolan sheet (0.10 mm) material is vacuformed over the cast. This will act as a separator and as an undercut insulator.
4. Secure the pontic to the edentulous area with light-cured Triad Gel. Do not use wax because it will melt during the thermoforming process (Figure 18-49, *D*).
5. With the denture tooth cured in place, position the cast back in the Ministar.
6. Machine and vacuform a 0.75 endure invisible retainer material (Figure 18-49, *E*).
7. Remove cast from Ministar and using a hot knife tray trimmer, cut the appliance just below the mucogingival junction on the facial and extend on the lingual several mm beyond the gingival margin. Carefully separate the appliance from the cast. If needed, trim excess material with scissors and smooth edges (Figure 18-49, *F*).

Note: Advise patients about demineralization. When acidic foods are retained within the appliance for an extended period of time, the enamel becomes susceptible to demineralization. Hygiene reinforcement must be stressed to prevent this. Commercially available daily fluoride remineralization rinses are recommended to prevent the decalcification process.

BOX 18-12 Snap-On Smile Technique

1. Obtain maxillary and mandibular study casts.
2. Take polyvinyl siloxane impressions of the maxillary and mandibular arches.
3. Centric bite registration.
4. Shade.
5. Send to the laboratory (DenMat).

BOX 18-13 Reline Technique

1. Prosthesis preparation: Remove sufficient acrylic from the tissue surface overlying the surgical site. A minimum of 1 to 2 mm is required for bulk of material and the ability for the material to flow. If a flange exists that may impinge on the surgical site, the flange should be removed.
2. Mix the tissue conditioner: Follow the manufacturer's recommendation for proper powder-to-liquid ratio. Additional powder may be added to thicken the mixture, thus reducing the flow of the material when the prosthesis is inserted. Water-soluble petroleum jelly is applied to facilitate easy removal of the excess material.
3. Seat the prosthesis in the mouth. Have the patient occlude in centric occlusion.
4. Trim the excess material: After sufficient setting time (~10 minutes), the prosthesis is removed from the patient's mouth, and excess material is removed with a sharp knife or scalpel.

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Classification[2]

Hard Reline Material

Generally, hard denture reline materials are made of modified poly(methyl methacrylate) (PMMA) acrylic, which because of their inherent hardness, should never be used postsurgically for relines.[36]

Soft Reline Material

Soft relines have been classified as either acrylic or silicone. Silicone soft liners include heat cured liners similar to Molloplast-B. This is a gamma-methacryloxypropyltrimethoxysilane heat-polymerized silicone[36] (Box 18-13).

Tissue Conditioner

Tissue conditioners are soft elastomers that are classified as plasticized acrylics, which are composed of a poly (ethylmethacrylate) mixture of phthalate plasticizer and up to 25% ethanol. The enclosed plasticizer lowers the glass-transition temperature so the rigid acrylic resin becomes rubbery and resilient.

Tissue-conditioning material, when mixed properly, results in a gel of the polymer and monomer with a resilient consistency. The resilient gel provides an excellent cushion for traumatized tissue adjacent to the intaglio surface of the hard, processed denture-base material. When the tissue-treatment liner is replaced frequently, the damaged intraoral supporting tissues can return to a state of health. Effective use of any tissue-treatment material may require replacement every 3 days for up to 30 days depending on the material. Eventually, these materials will become hard and rough and will harbor bacteria and fungus.

Before a tissue conditioner is applied, the intraoral tissues must be clean and dry. Although most dental materials should be mixed according to the manufacturer's instructions, the mixing instructions of some tissue-treatment materials can be altered depending on the desired viscosity and flow needed clinically. After the material is placed on the surface of a prosthesis and seated intraorally, the material is allowed to flow as the patient closes the bite into maximum intercuspation or appropriate interocclusal relation. After the material sets, excess amounts are trimmed using a sharp, heated knife or scalpel.

Placing a tissue conditioner in a prosthesis for frequent liner replacement is a relatively simple procedure, but a soft liner material that is not changed frequently, as per the manufacturer's recommendations, can cause excess pressure and tissue damage to the surgical site. Plasticizers can leach out of the material, which will result in a hardened material. Thus, the selection of tissue-conditioning material used is paramount to minimize loading of the implant or bone graft site (Figure 18-51).

Some of the most common tissue conditioners are Coe-Comfort (G-C America), Lynal (Dentsply/Caulk), and Visco-Gel (Dentsply). When there exists greater tissue mobility and inflammation (postimplant placement or bone grafting), the

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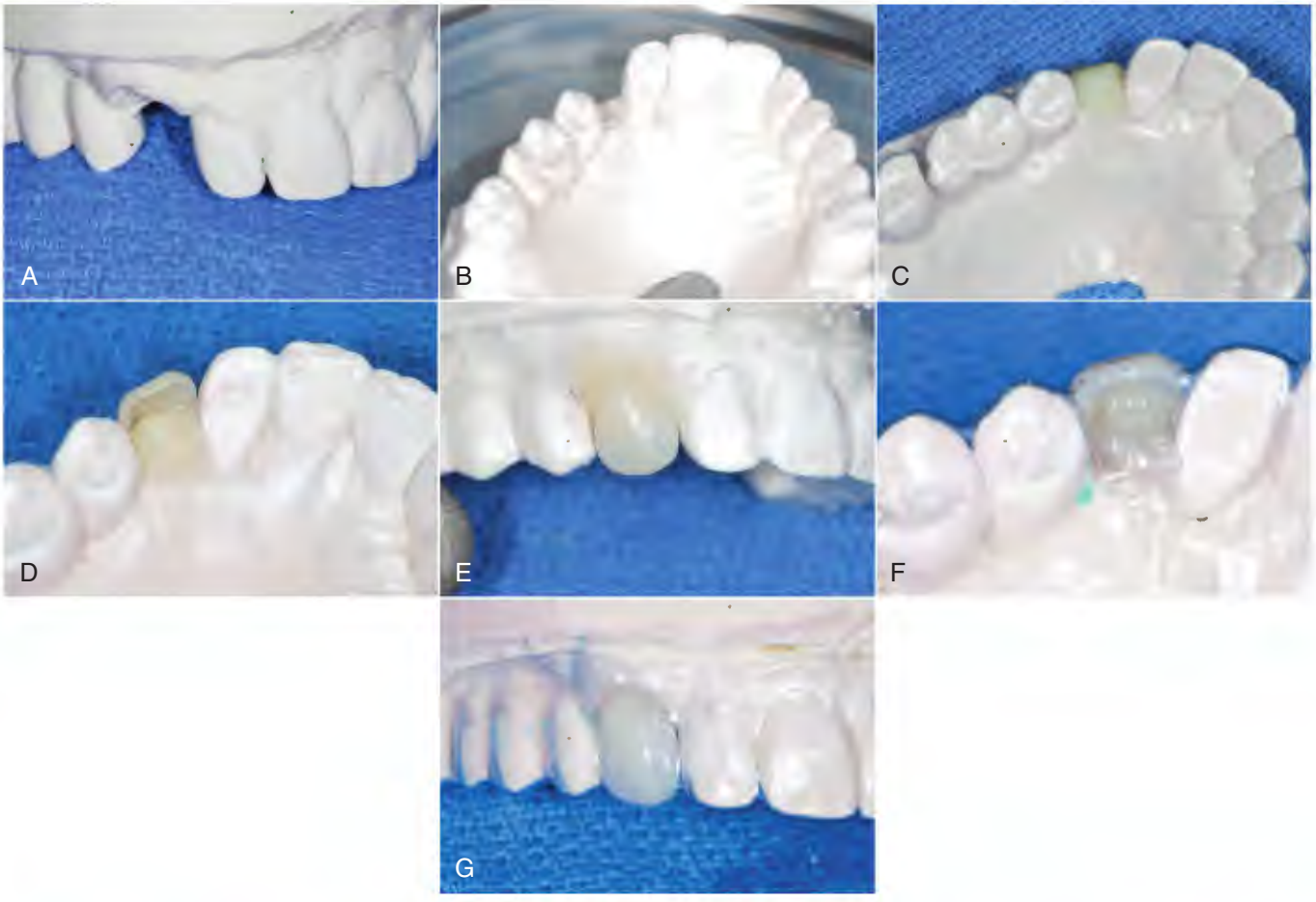


FIGURE 18-49. **A** to **G,** Laboratory steps in fabrication of an Essix appliance.



FIGURE 18-50. Partially edentulous provisional restorations: postsurgery (**A**), Snap-On Smile (**B**), and Snap-On Smile inserted (**C**).

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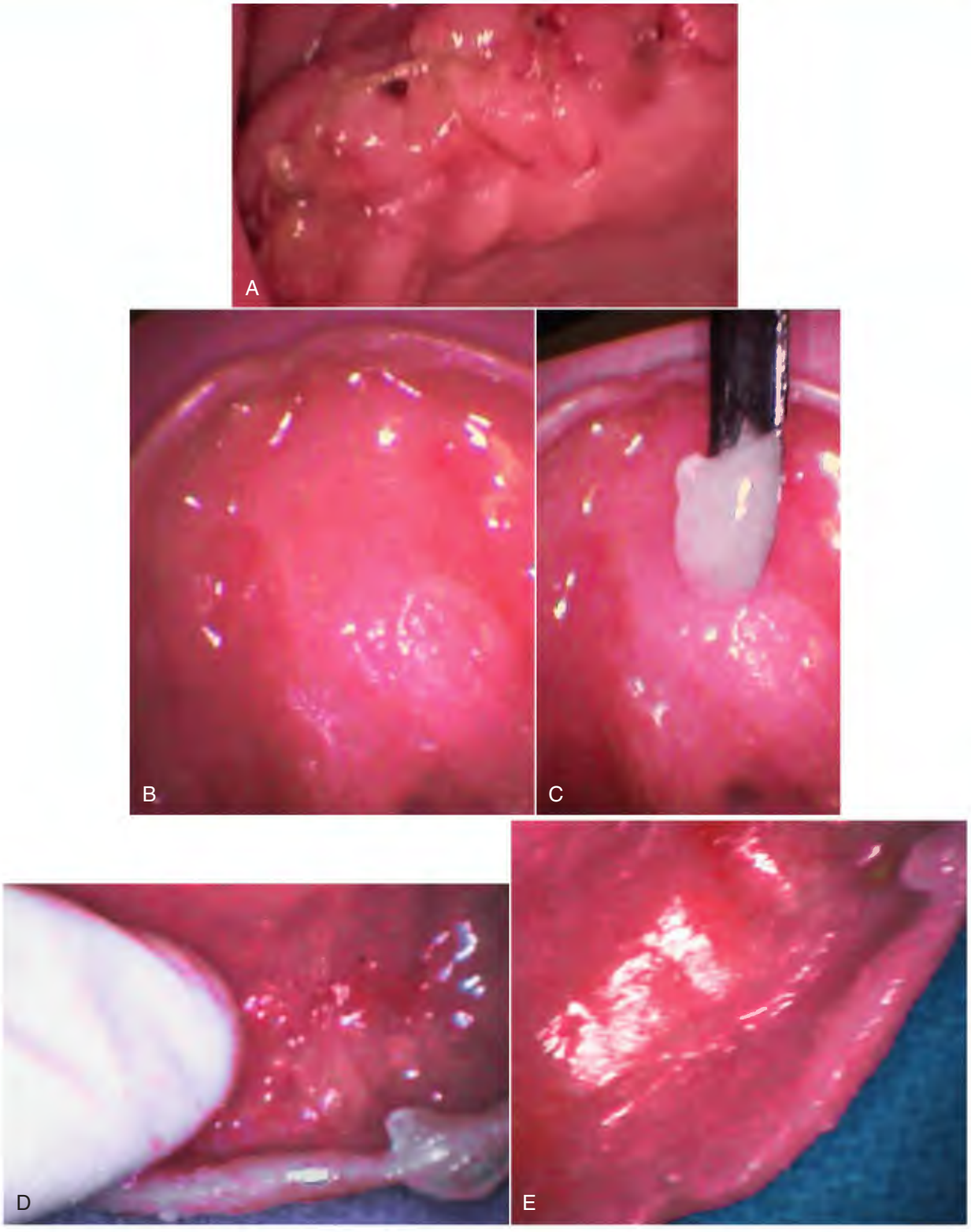


FIGURE 18-51. **A,** Postsurgery site. **B,** Ideal viscosity (nonrunny). **C,** Placement in interim prosthesis. **D,** After the initial set, tissue may be manipulated and "leveled off" with intention of no impingement on the surgical site. **E,** Final prosthesis showing no protrusion into the surgical site.

use of a less viscous material (more flowable) is indicated. Thus, Visco-Gel is usually the tissue conditioner of choice because it has favorable flow characteristics, resists bacterial invasion, and is usually replaced every 30 days compared with other tissue conditioners, which need to be replaced every 2 to 3 days.

Summary

Dental implant prosthetics have revolutionized the dental profession in allowing a wide range of treatment options for dental patients. Because more patients are inquiring and receiving

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treatment with complex implant treatment plans, implant dentists are posed with considerable challenges in the treatment planning phase. Because of the resorption pattern of the maxilla and mandible after tooth loss, many changes result such as changes in vertical dimension, lack of sufficient change of bone volume, and occlusal disharmonies. These alterations in the patient's anatomy must be accounted for before initiation of treatment.

The diagnostic phase of implant dentistry is very important to the long-term success of implant treatment. Proper mounting and evaluation of the study casts are crucial in the fabrication of radiographic templates and surgical templates. Evaluation of the edentulous sites and maxilla–mandibular relationships is an invaluable diagnostic tool in determining ideal implant positioning. Implants ideally should be placed with strict guidelines in relation to adjacent teeth, implants, and vital structures and according to various planes with respect to the edentulous site. With the use of radiographic and surgical templates, precision has been improved, and uncertainty and surgical time have been reduced, thus addressing complex rehabilitation with greater confidence. In addition, predictable positioning allows for better prosthetic outcome by simplifying abutment selection and avoiding complex laboratory fabrication when misalignment must be corrected. Future technical improvements likely will allow dentists to access these technologies while controlling costs, reducing surgical time, and minimizing restorative steps.

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CHAPTER 19

Treatment Plans for Partially and Completely Edentulous Arches in Implant Dentistry

Carl E. Misch

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Partially Edentulous Arches

To organize treatment plans in a consistent approach, a classification of patient conditions is necessary. There are more than 65,000 possible combinations of teeth and edentulous spaces; as a result, no universal agreement exists regarding the use of any one classification system. Numerous classifications have been proposed for partially edentulous arches. Their use allows the profession to visualize and communicate the relationship of hard and soft structures. This chapter reviews a classification for diagnosis and treatment planning for patients who are partially or completely edentulous and require implant prostheses. By using this classification, which the author first presented in 1985, the doctor is able to convey the dimensions of the bone available in the edentulous area and indicate the strategic position of the segment to be restored.[1,2]

History

Cummer,[3] Kennedy,[4] and Bailyn[5] originally proposed the classifications of partially edentulous arches that are most familiar to the profession. These classifications were developed to organize removable partial denture (RPD) designs and concepts. Other classifications have also been proposed[6-16] (including one by the American College of Prosthodontists), none of which has been universally accepted. The Kennedy classification, however, has been taught in most American dental schools.

The Kennedy classification divides partially edentulous arches into four classes.[4] Class I has bilateral posterior edentulous spaces, class II has a unilateral posterior edentulous space, class III has an intradental edentulous area, and class IV has an anterior edentulous area that crosses the midline.

The Kennedy classification is difficult to use in many situations without certain qualifying rules. The eight Applegate rules are used to help clarify the system.[13] They may be summarized in three general principles. The first principle is that the classification should include only natural teeth involved in the final prosthesis and follow rather than precede any extractions of teeth that might alter the original classification. This concept, for example, considers whether second or third molars are to be replaced in the final restoration. The second rule is that the most posterior edentulous area always determines the classification. The third principle is that edentulous areas, other than those determining the classification, are referred to as *modifications* and are designated only by their number. The extent of the modification is not considered.

Classification of Partially Edentulous Arches

The implant dentistry bone volume classification developed by Misch and Judy in 1985 may be used to build on the four classes of partial edentulism described in the Kennedy–Applegate system.[1,2] This facilitates communication of teeth positions and the primary edentulous sites among the large segment of practitioners already familiar with this classification, and it enables the use of common treatment methods and principles established for each class. The implant dentistry classification for partially edentulous patients by Misch and Judy also includes the same six available bone volume divisions (A, B, VB–w, C–w, C–h, and D) previously presented for edentulous areas. Other intradental edentulous regions that are not responsible for the Kennedy–Applegate class determination are not specified within the available bone section if implants are not considered in the modification region. However, if the modification segment is also included in the treatment plan, then it is listed followed by the available bone division it characterizes.

Treatment Planning: Class I

In class I patients, distal edentulous segments are bilateral and natural anterior teeth are present (Figure 19-1). The majority of these arches are only missing molars, and almost all have retained at least the anterior incisors and canines.[17] Therefore, after restored to proper occlusal vertical dimension, the natural anterior teeth contribute to the distribution of forces throughout the mouth in centric relation occlusion. More importantly, when opposing natural teeth or in fixed implant prosthesis, they also permit excursions during mandibular movement to disclude the posterior implant–supported prostheses and protect them from lateral forces. However, many of these mandibular class I patients oppose a maxillary denture, in which case bilateral balance is more appropriate.

Class I patients are more likely to wear a RPD than class II or III patients because mastication and support of an opposing removable prosthesis is more difficult when not wearing the bilateral mandibular prosthesis. The posterior soft tissue–supported class I partial dentures are designed to either primarily load the edentulous regions or the natural anterior teeth. The clasp design, which places less force on the tooth

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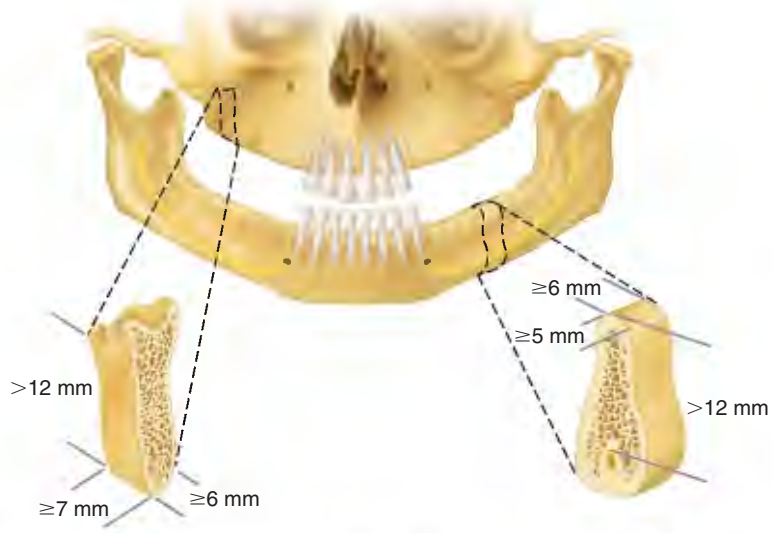


FIGURE 19-1. A class I, division A dental arch has bilateral posterior missing teeth and abundant bone volume in the edentulous sites.



FIGURE 19-2. A mandible with a class I, division A classification. The key implant positions are determined, and the implant sizes are ideal (4 mm × 12 mm in premolars and 5 mm × 12 mm in the molars).

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(e.g., bar clasp including t, y rpi), places more force on the bone. The RPDs, which place more force on the abutment teeth (e.g., precision partial dentures), place less force on the bone. In either case, the removable prosthesis often accelerates the posterior bone loss. In addition, a partial denture that is not well designed or maintained distributes additional loads to abutment teeth and may even contribute to poor periodontal health. The combinations of these conditions lead to bone loss in the edentulous regions and poorer adjacent natural abutments.[18-20] As a result, it is this author's observation that long-term class I patients who have been wearing a RPD often exhibit division C ridges and mobile abutment teeth.

Class I patients often have mobile anterior teeth because long-term lack of bilateral posterior support caused by the wearing of a poorly fitting RPD, or none at all, has resulted in an overload to the remaining dentition. Therefore, these patients often require a posterior implant prosthesis to be independent from the mobile natural teeth. In addition, the occlusal scheme must accommodate the specific conditions of mobile anterior teeth. This requires increased implant support in the posterior segments compared with most class II or III patients, as well as greater attention and frequency for occlusal adjustments.

The treatment plan must consider the factors of force previously identified and relate them to the existing bilateral edentulous condition. Osteoplasty cannot be as aggressive in a class I patient to increase bone width compared with a class IV or fully edentulous patient with implants primarily in the anterior regions because of the opposing anatomical landmarks (maxillary sinus or mandibular canal). Augmentation procedures are often required to improve posterior bone volume, increase the implant surface area, and permit the fabrication of an independent implant restoration.

Financial concerns may require the staging of treatment over years. The posterior region with the greatest volume of bone usually is restored first if no bone grafting is required. In this manner, implants of greater size and surface area can resist the unilateral posterior forces while the patient awaits future treatment. If many years pass before implants are to be inserted in the lesser available bone, then continued resorption may require augmentation before reconstruction.

If both posterior segments require bone grafting, the patient is encouraged to have both posterior segments augmented at the same time. In this way, the autologous portion of the graft may be harvested and distributed to both posterior regions, decreasing the number of surgical episodes for the patient.

Division A Treatment Plans

When patients are placed in a class I, division A category, an independent implant–supported fixed prosthesis is usually indicated. Two or more endosteal root form implants are required to replace molars with independent prostheses (Figure 19-2). The greater the number of teeth missing, the larger the

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size or number of implants required. Posterior available bone is limited in height by the mandibular canal in the mandible or the maxillary sinus in the maxilla. The first premolar positioned implants must avoid encroachment on the apex of the canine root and yet avoid the maxillary sinus in the maxilla. In the mandible, the first premolar implant is placed most often anterior the mental foramen and the anterior loop when present (Figure 19-3).

Division B Treatment Plans

Class I, division B patients have narrow bone in posterior edentulous spaces and anterior natural teeth (Figure 19-4). A fixed prosthesis is also indicated in these categories. Available bone height is restricted by the mandibular canal or maxillary sinus. Therefore, osteoplasty to increase bone width has limited applications. Endosteal small-diameter root form implants may be placed in the mandibular posterior division B edentulous ridge. If narrow-diameter root forms are used, then a greater number is usually required than for the division A root form size. The use of one implant for every missing tooth root with no cantilever is recommended.

A patient missing molars and both premolars in the mandible requires at least three division B root forms (distal of the first molar, first premolar, and mesial of first molar [the second molar is not replaced]), and this may be the foundation of an independent fixed partial denture (FPD) in the mandible, depending on the other stress factors. In the maxilla, the second molar is usually replaced, and four division B root form implants are required (first premolar, second molar, first molar, second premolar). If stress factors are too great (as a result of parafunction) or bone density is poor (as in the maxilla), then the division B bone should be augmented to division A before larger-diameter implant insertion. The anterior teeth in class I patients should provide disclusion of the posterior implants during all excursions when opposing natural teeth or a fixed prosthesis.

Molar endosteal implants should not be rigidly cross-splinted to each other in a mandibular class I patient. Flexure of the mandible during opening and torsion during clenching may cause a rigid splint to exert lateral forces on the posterior implants. Therefore, independent restorations are indicated.

Another option in selected patients for division B bone may be a narrow plate form implant. These implants are usually used to replace a missing molar or molar and second premolar (when opposing a maxillary denture or low for factors). The plate form implant is often splinted to one or two nonmobile premolars in the final prosthesis. No lateral loads should be applied to the implant prosthesis when opposing natural teeth.

Division C Treatment Plans

When inadequate bone exists in height, width, length, or angulation or if crown height space (CHS) is equal to or greater than 15 mm, the practitioner must consider several options. The first

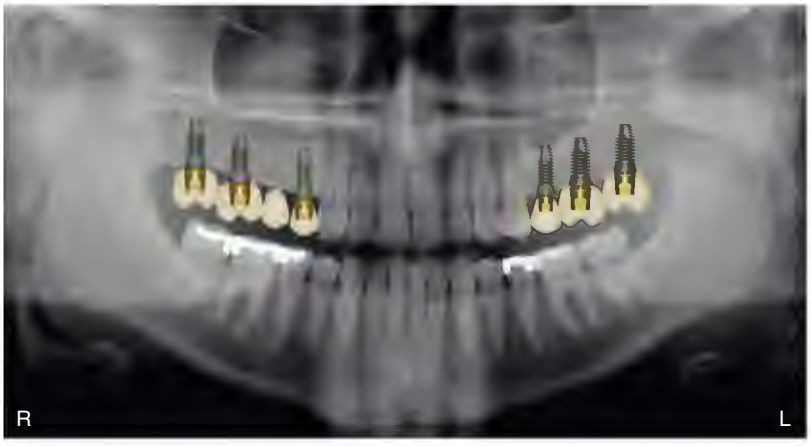


FIGURE 19-3. A maxilla with class I, division A bone. The key implant positions and implant sizes are positioned without limitation.

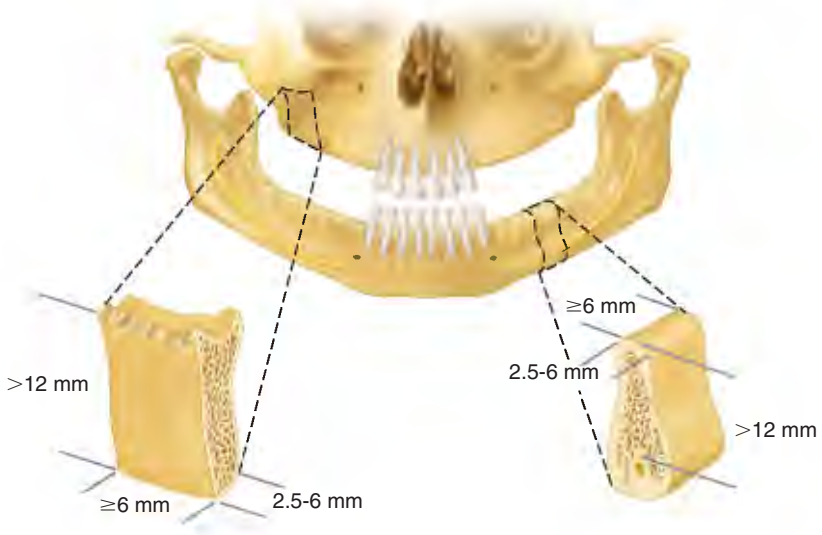


FIGURE 19-4. A class I, division B dental arch has adequate height of bone but is barely sufficient in width.

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treatment option is to not use implant support but rather to orient the patient toward a conventional removable partial prosthesis. However, although this condition is easiest to treat with a traditional soft tissue–borne restoration, bone loss will continue and can eventually compromise any restorative modality.

The second option is to use bone augmentation procedures. If the intent of the bone graft is to change a division C to a division A or B for endosteal implants, then at least some autogenous bone is indicated. Augmentation is used most often in the class I maxilla, where sinus grafts with a combination of allografts and autogenous bone are a predictable modality. Implants may be placed after the graft has created a division A ridge, and the treatment plan follows the options previously addressed.

In the mandible, the third option for the class I, division C patient is to place unilateral subperiosteal implants or disc implants above the canal (Figure 19-5). The disc or subperiosteal implant may support independent posterior fixed prostheses bilaterally or may be splinted to one or two premolars. As with the plate form implant, no lateral loads should be applied to the implant restoration when opposing natural teeth.

A division A root form implant may usually be inserted in the first premolar position even when the rest of the posterior ridge is division C–h. A fourth treatment option in the mandible is nerve repositioning and endosteal implants in class I patients who are poor candidates for bone augmentation or subperiosteal implants. Risks of long-term paresthesia exist that may include hyperesthesia and pain. Reports in the literature also concern dysesthesia and fracture of the severely atrophic mandible.[21,22]

The placement of disc implants or nerve repositioning in the division C mandible still must compensate for the increased crown height and resultant unfavorable forces to any cantilever or angled force. Therefore, it is important that only long axis forces are placed on the prosthesis and anterior guidance distributes bilateral forces away from the posterior restorations.

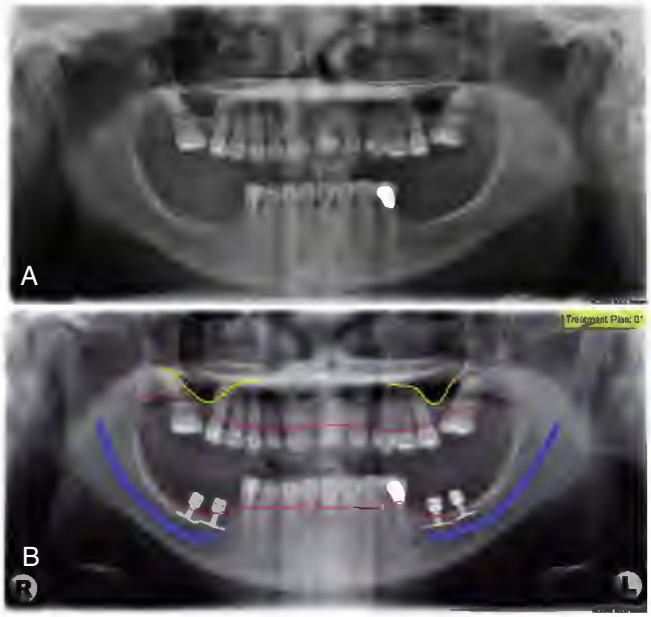


FIGURE 19-5. **A,** In class I, division C, options include small-dimension implants such as disc implants, which can be placed in minimal heights of bone above the mandibular canal. **B,** Two independent fixed prostheses are supported by the posterior implants or, on occasion, may be splinted to a posterior tooth.

Division D Treatment Plans

Class I, division D usually occurs most often in the long-term edentulous maxilla (Figure 19-6). The ridge is division D because the sinus expands more than the crest of the ridge resorbs. A sinus graft is usually performed before implant placement. These augmentation procedures are very predictable. Class I, division D ridges are rarely found in a mandibular partially edentulous patient. When observed, the most common causes are from trauma or surgical excision of neoplasms. These patients often need autogenous bone onlay grafts to improve implant success and prevent pathologic fracture before prosthodontic reconstruction. After the graft is mature and the available bone improved, the patient is evaluated and treated in a manner similar to other patients with favorable bone volume.

Another option in a class I, division D mandible is to extract the anterior teeth, place five or six implants in the anterior region between the mental foramen, and cantilever a fixed prosthesis to restore the complete dentition. This option is more often used when the anterior teeth are periodontally compromised, the patient desires a fixed restoration, and the anterior mandible has an ovoid to tapering residual ridge form.

Treatment Planning: Class II

Kennedy–Applegate class II partially edentulous patients are missing teeth in one posterior segment (Figure 19-7). These patients are often able to function without a removable restoration and are less likely to tolerate or overcome the minor complications of wearing the prosthesis. As a result, they are not as likely to wear a removable restoration. The available bone is therefore often adequate for endosteal implants even when long-term edentulism has been present. Endosteal implants with minimum osteoplasty in the mandible are a common modality in these patients, who are class II, division A or B types.[23,24] However, in the maxilla, the sinus usually expands and the local bone density may be decreased.

Because the patient is less likely to wear the RPD, the opposing natural teeth have often extruded into the posterior edentulous region. The occlusal plane and tipped or extruded teeth should be closely evaluated and restored as indicated to provide a favorable environment in terms of occlusion and forces distribution. It is not unusual to require extraction of the second molar, endodontics, crown lengthening and a crown of the first molar, and enameloplasty for the second premolar.



FIGURE 19-6. A class I, division D patient is usually seen in the maxilla when the maxillary sinus has expanded and less than 7 mm of bone is present.

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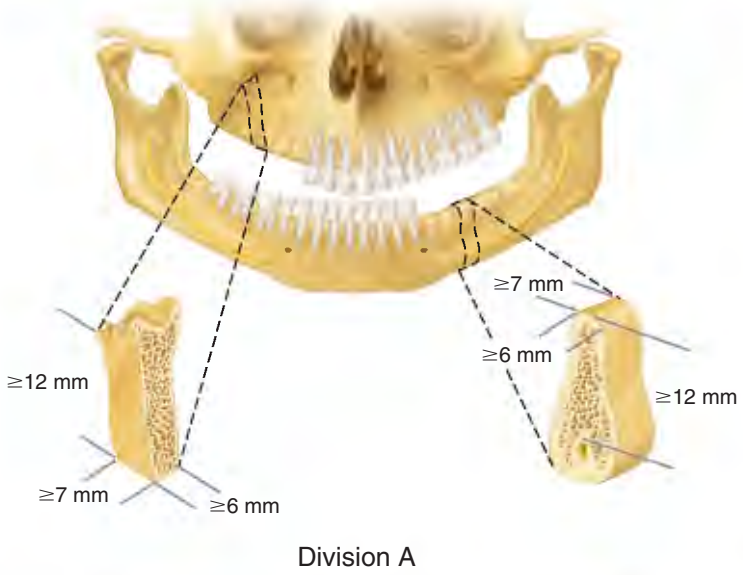


FIGURE 19-7. A class II patient has posterior missing teeth in one quadrant. When the available bone is abundant, it is division A.



FIGURE 19-8. A maxillary arch that is class II, division A may have implants placed in the key implant positions and are of ideal sizes.

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Division A Treatment Plans

When patients are placed in a class II, division A category, an independent implant–supported fixed prosthesis is usually indicated. Two or more endosteal root form implants are required to replace molars with independent prostheses. The greater the number of teeth missing, the larger the size or number of implants required. Posterior available bone is limited in height by the mandibular canal in the mandible or the maxillary sinus in the maxilla. The first premolar-positioned implants must not encroach on the apex of the canine root while still avoiding the anterior loop of the mandibular canal or maxillary sinus (Figure 19-8). When parafunction is present, one implant for each tooth missing should be considered (Figure 19-9).

Division B Treatment Plans

Class II, division B patients have narrow bone in one posterior edentulous space and anterior natural teeth. A fixed prosthesis is also indicated in these categories. Available bone height is restricted by the mandibular canal or maxillary sinus. Therefore, osteoplasty to increase bone width has limited applications. Endosteal small-diameter root form implants may be placed in the mandibular posterior division B edentulous ridge. If narrow-diameter root forms are used, then a greater number than for the division A ridge is indicated, and the use of one implant for every missing tooth root with no cantilever is recommended when stress factors are greater than use (e.g., parafunction, opposing an implant prosthesis). Remember, in the mandible, the second molar is rarely replaced. In the division B maxillary ridge, bone spreading or augmentation is more usual because the density of bone is more often poor.

When force factors are low (i.e., older female patient, opposing a denture, limited parafunction), a plate form implant may be used to replace a molar or second premolar and molar in the mandible. This implant is usually splinted to a nonmobile posterior tooth.

A patient missing molars and both premolars requires additional implant support. Three division B root forms may be the foundation of an independent FPD in the mandible, depending on the other stress factors. If stress factors are too great (as a result of parafunction) or bone density is poor (as in the maxilla), then the division B bone should be augmented to division A before larger-diameter implant insertion (Figure 19-10). The anterior teeth in class II patients should provide disclusion of the posterior implants during all excursions.

Division C Treatment Plans

When inadequate bone exists in height, width, length, or angulation or if CHS is equal to or greater than 15 mm, the

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edentulous site is division C (Figure 19-11). This category has several options. In the mandible, the first treatment option is to not use implant support but to consider a posterior cantilevered FPD replacing one premolar-sized crown using two or three anterior teeth as abutment support. This is the easiest option and is strongly recommended when only molars are missing.

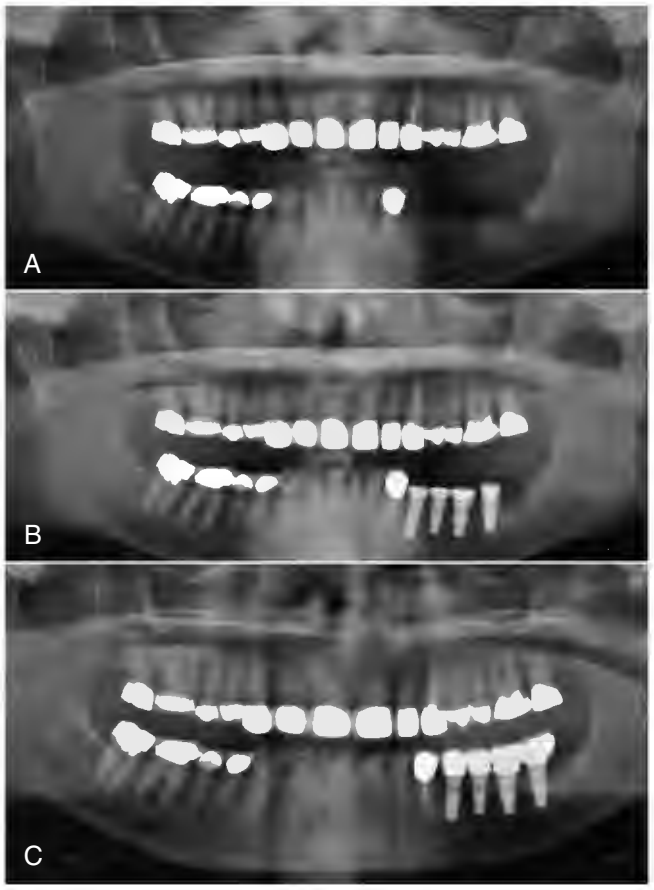


FIGURE 19-9. **A,** A class I, division A mandible. **B,** The key implant positions and implant sizes are placed in the first premolar, second molar (no cantilever), and first molar (first molar rule). An additional implant is positioned because of a moderate clenching, young male patient, and opposing natural dentition. **C,** The final fixed restoration in position.

The second option is to use bone augmentation procedures. If the intent of the bone graft is to change a division C to a division A or B for endosteal implants in the mandible, then autogenous bone is indicated as part of the graft. Augmentation is used most often in the class II maxilla as the first choice, where sinus grafts with a combination of allografts and autogenous bone are a predictable modality. Implants may be placed after the graft has created a division A ridge, and the treatment plan follows the options previously addressed (Figure 19-12).

The third option for a division C mandibular patient is to place a class II unilateral subperiosteal implant or a disc implant above the canal. An independent prosthesis with no lateral forces in excursions is then fabricated. These implants may be splinted to a nonmobile posterior tooth or root form implant anterior to the mental foramen.

The fourth treatment option in the mandible is nerve repositioning and endosteal implants in class II patients who are poor candidates for bone augmentation. Risks of long-term paresthesia exist that may include hyperesthesia and pain. Reports in the literature concern dysesthesia and fracture of the severely atrophic mandible.[21,22] In addition, the CHS is still greater than 15 mm, and the implant support should not have lateral forces or cantilevers.

Division D Treatment Plans

Class II, division D usually occurs most often in a long-term edentulous maxilla. A sinus graft is usually performed before implant placement converts the ridge to division A often with a greater crown height than ideal. Class II, division D ridges are rarely found in a mandibular partially edentulous patient. When observed, the most common causes are from trauma or surgical excision of neoplasms. These patients often need autogenous bone onlay grafts to improve implant success and prevent pathologic fracture before prosthodontic reconstruction. After the graft is mature and the available bone improved, the patient is evaluated and treated in a manner similar to other patients with favorable bone volume.

Treatment Planning: Class III

Typically, the two most common class III patients consulting for implants are either missing a single tooth (between adjacent teeth) or have a long posterior edentulous span (with a second or third molar present) (Figure 19-13). A multiple-tooth posterior edentulous region most often can be restored as an independent restoration, but it may on occasion need to be joined

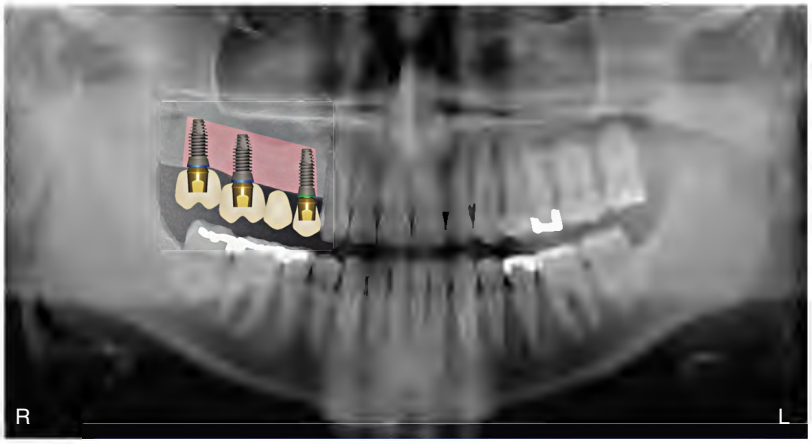


FIGURE 19-10. A maxillary class II, division B patient often has a membrane bone augmentation to increase width *(pink)* followed by implants in the key implant positions and of ideal sizes.

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to a posterior natural abutment. The posterior tooth usually exhibits less mobility compared with the anterior teeth, and disclusion of the posterior segments can be more readily achieved.

A review of the literature demonstrates joining implants to posterior teeth in the same prosthesis under specific conditions is predictable. On the other hand, an anterior tooth abutment exhibits greater mobility and sustains greater lateral forces during excursions and should not be joined to an implant unless it is a "living pontic" (implants on each side of the tooth) or a part of a restoration using a splinted arch concept to distribute lateral forces.

A single-tooth implant is the treatment of choice when the bone and soft tissues are within normal range before or during implant treatment. Fixed prostheses on natural teeth increase the risk of decay, pulpal involvement, and periodontal disease.[25] As a consequence, both the traditional prosthesis and the abutment teeth have a poorer survival rate compared with implant prostheses. As a result, implant abutments and independent prostheses are often the treatment of choice for most class III patients.[26,27]



FIGURE 19-11. A class I, division C-h arch has 7 to 9 mm of bone in height in the edentulous site.

Division A Treatment Plans

Class III, division A patients are good candidates for endosteal root form implant placement in the edentulous space. This allows the restoration of natural teeth to be independent and allows the fabrication of shorter-span restorations. It is easier to obtain maximum available height of bone for implant placement anterior to the mandibular foramen or maxillary sinus (Figure 19-14).



FIGURE 19-12. A maxillary arch with class II, division C–h most often has a sinus bone graft *(white)* and then implants in the key implant positions and of the ideal implant sizes.

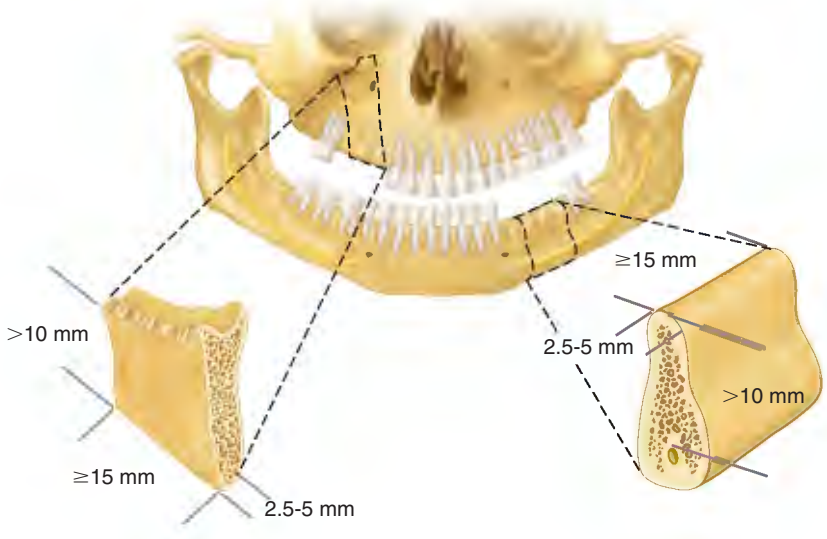


FIGURE 19-13. A class III patient has an intratooth edentulous space. When it is adequate in height but barely sufficient in width, it is division B bone.

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As a general rule, the final prosthesis should be completely implant supported, and two implants should support each section of three missing tooth roots (not three missing crowns). Mobile natural teeth adjacent to the edentulous span cause greater loads on the implants; therefore, one implant for each missing root may be indicated. If the adjacent teeth are mobile, then the implant must support both the missing teeth and mobile teeth during occlusion.

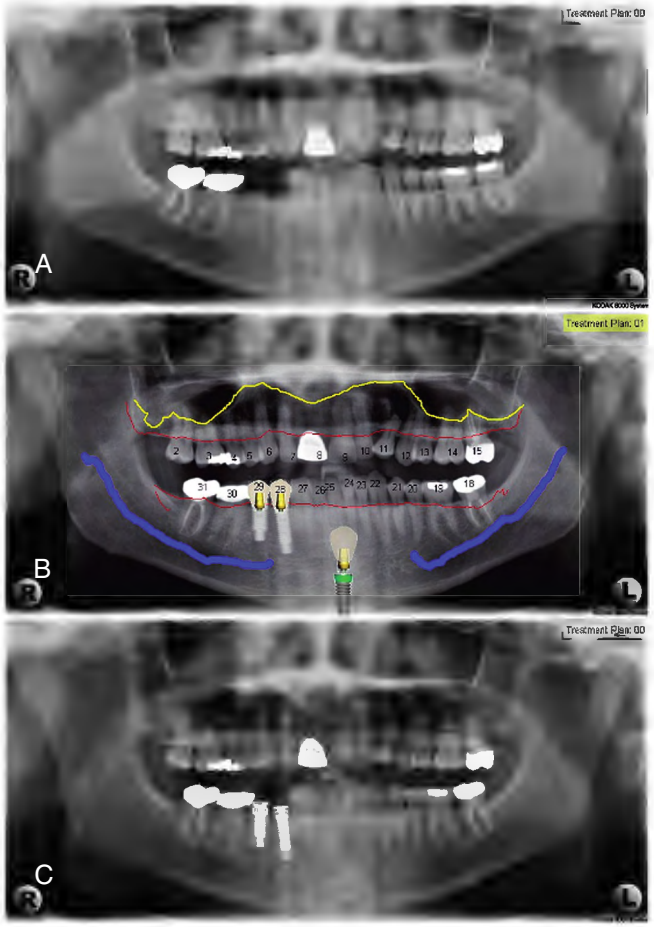


FIGURE 19-14. **A,** Typically, patients with class III edentulous segments are missing a single tooth or a posterior space. **B,** The ideal treatment plan can be studied with computer-assisted programs that help visualize proper positioning and the contours of the final restoration (XCPT, Naples, FL). **C,** The implant surgical phase replicates the computer-assisted programmed surgery. (Courtesy of N. Levine, Chicago, IL.)

Division B Treatment Plans

In class III, division B patients, narrow-diameter endosteal implants may be placed in the mandibular long-span edentulous space. When narrow-diameter implants are used, one implant for each missing tooth and two implants to replace a molar should be considered when patient force factors are greater than normal. This treatment plan is primarily used for a fixed prosthesis when the span is too long or occlusal forces are too great for the natural abutments to act as sole support for the final prosthesis. The final implant prosthesis should be independent of these teeth (Figure 19-15).

The division B long edentulous span between posterior teeth may also be treated with a plate form implant. These narrow implants are usually splinted to an adjacent nonmobile tooth with no lateral forces applied to the restoration.

Bone augmentation for width is a common treatment plan for a class III division B patient. Membrane bone grafts are very predictable between existing teeth for division B bone volume. The key implant positions may then be applied along with ideal implant width and length (Figure 19-16).

Division C or Division D Treatment Plans

When division C or D is found in class III patients, the most common treatment plan in the maxilla is bone augmentation (sinus grafts) before implant insertion and an independent implant prosthesis (Figure 19-17). Sinus grafting in the posterior division C and D ridge is very predictable.

In the mandible, division C bone volume for class III patients may often consider a traditional fixed prosthesis because bone grafting for height is less predictable than in the maxilla. When the posterior span of missing teeth is three or more teeth, a fixed prosthesis is not indicated. Therefore, a disc implant may be considered in the mandible. These implants are often splinted to a nonmobile natural tooth. When the available bone is 9 mm and the implant length is 7 mm in the posterior mandible, the crown height is usually greater than 12 mm. Incisal guidance on the anterior teeth is necessary under these conditions to eliminate any lateral loads on the prosthesis (Figure 19-18).

Treatment Planning: Class IV

In a class IV patient, the anterior edentulous space crosses the midline (Figure 19-19). In the past, traditional FPDs were often

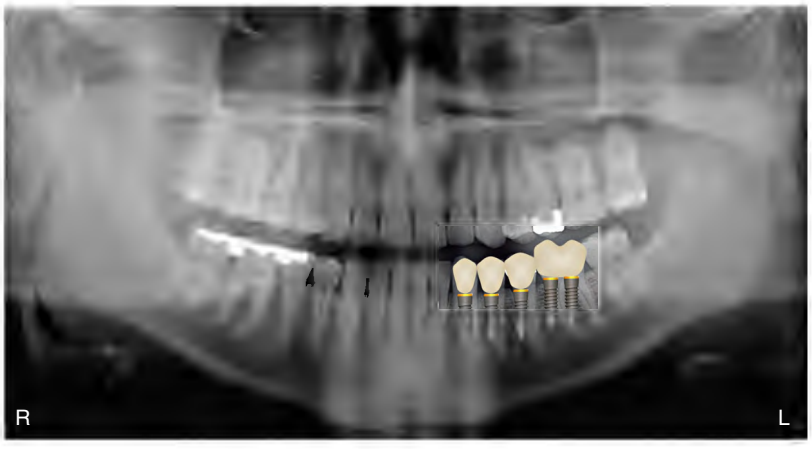


FIGURE 19-15. A class III, division B mandible may use smaller diameter implants. When this option is used, one implant for each tooth root missing is often indicated.

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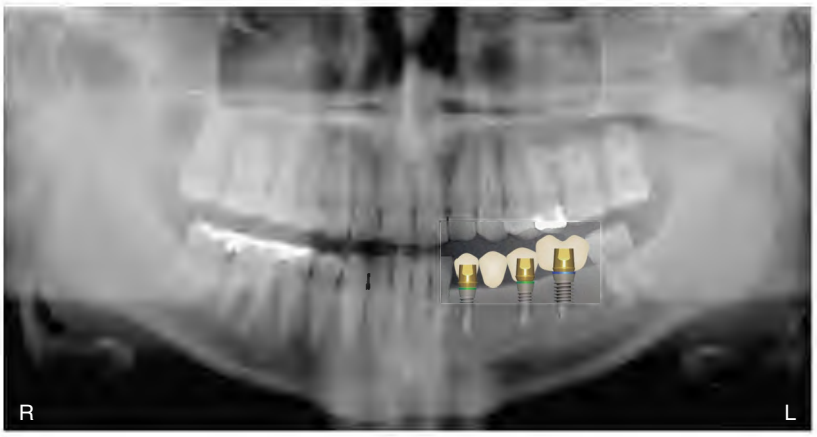
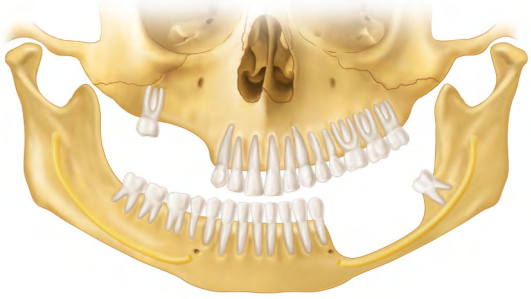


FIGURE 19-16. A class III, division B mandible may have a membrane bone graft to gain abutment width *(grey)* followed by ideal implant sizes in the key implant positions.



Division D

FIGURE 19-17. A class III, division D patient is more often observed in the maxillary arch.

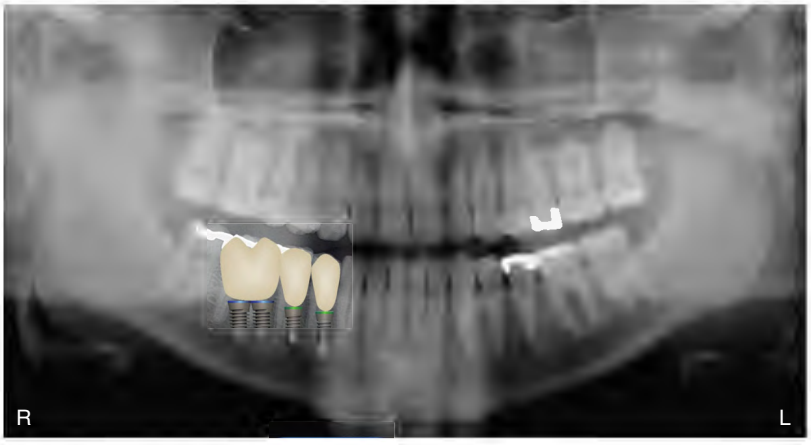


FIGURE 19-18. A class III, division C–h patient may use 7- to 9-mm root form implants to support a fixed prosthesis. Incisal guidance on the anterior teeth during all mandibular excursions is indicated to eliminate greater forces on the extended crown heights.

the treatment of choice when the canines were present. Today, an independent implant prosthesis is often warranted. However, a lack of anterior bone volume in the maxilla is common, and bone grafts before implant placement are typically necessary to prevent the implants from being placed palatally in relation to the natural roots. An anterior offset load is often created off the implant bodies to place the maxillary incisor edge in proper position for esthetics and speech. The moment force generated is greater than when found in the mandibular counterpart. This, added to other factors, makes the premaxilla one of the more difficult regions of the mouth to successfully treat. As a general rule, three implants are considered to replace the six anterior teeth in the premaxilla and three division B root form implants for the four incisors. In the mandible, two implants can often be used to replace the four anterior incisors and three implants for the anterior six teeth.

Division A Treatment Plans

Class IV, division A patients are good candidates for endosteal root form implant placement in the edentulous space. This allows an independent restoration from the adjacent teeth and allows the fabrication of shorter-span restorations. This situation is also indicated when occlusal forces are too great for the natural abutment teeth to act as support for a fixed prosthesis but are not mobile (Figure 19-20).

In division A bone, the key implant positions are able to be placed without compromise. An exception to the key implant position may be made in the class IV, division A mandible

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missing eight anterior teeth. The terminal abutments (no cantilever rule) and canine position (canine rule) are used. However, the no three adjacent pontics rule may be violated for the anterior incisors when the patient force factors are low and the bone density good (Figure 19-21).

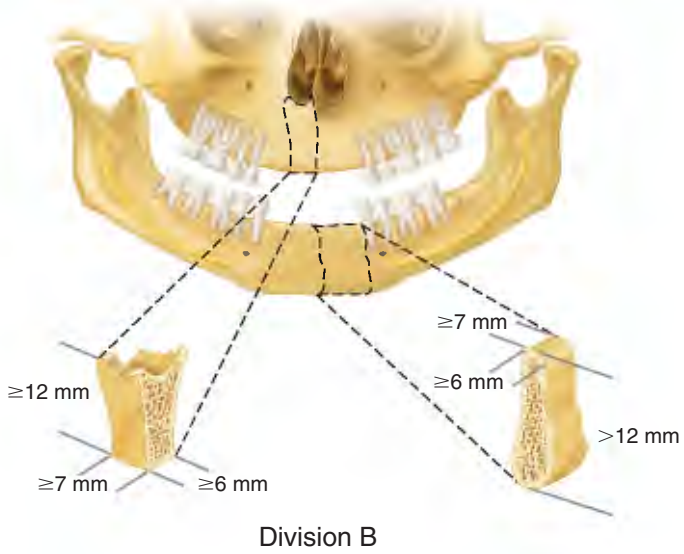


FIGURE 19-19. A class IV patient has missing teeth that cross the midline. When the bone is adequate in height but barely sufficient in width, it is division B.

If the adjacent teeth are mobile, then the implant must support both the missing teeth and the mobile teeth during occlusion. As a general rule, the final prosthesis should be completely implant supported, and two implants should support each section of three missing teeth. Mobile natural teeth adjacent to the edentulous span cause greater loads on the implants. Therefore, one implant for each missing tooth may be indicated under these conditions.

Division B Treatment Plans

A maxillary class IV, division B patient is most often treated with augmentation before implant placement. If the ridge is division B and inadequate in width for division A root form implants, then the narrow-diameter root forms compromise esthetics and oral hygiene procedures. Bone augmentation is more often used in anterior edentulous regions with narrow bone (Figure 19-22). Division A implants for the maxillary central incisors are indicated to improve the final crown contour, esthetic appearance, and daily maintenance. Implant and tooth replacement should remain independent.

In a class IV, division B mandible, narrow-diameter implants (3.0–3.5 mm) may often be used to support an independent implant prosthesis without compromises of esthetics or function (Figure 19-23). The bone density is usually good, and the direction of force in centric occlusion is in the long axis of the implant.

The canine is an important natural abutment. When the canine and two adjacent teeth are missing, a fixed prosthesis is contraindicated. An implant should replace a canine whenever multiple teeth are missing, which includes the canine.[28] A



FIGURE 19-20. A class IV, division A patient has implants positioned in the key implant positions of ideal width and length.



FIGURE 19-21. A class IV, division A mandible has implants positioned in the key implant positions. When force factors are low to moderate and bone density good, the implant between the canine positions may be eliminated when posterior implants are connected to the canine implants.

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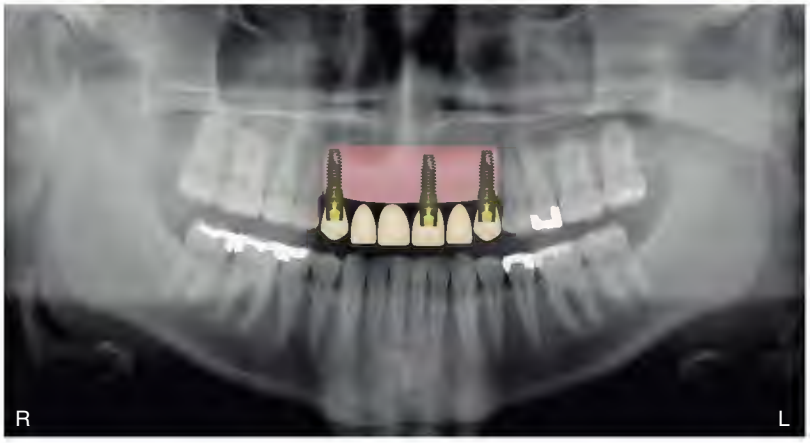


FIGURE 19-22. A maxillary class IV, division B patient usually has bone augmentation *(pink)* to increase the bone volume width. After augmentation, the key implant positions and ideal implant sizes may be used to support a fixed prosthesis.



FIGURE 19-23. A mandibular class IV, division B patient may use a narrower diameter implant (3.0–3.5 mm) of ideal implant length (12 mm or more). The key implant positions should be selected including an implant between the canine positions.



Division C

FIGURE 19-24. A class IV, division C–h dental arch has compromised bone in height. If the bone is compromised in width, it is C–w.

hydroxyapatite (HA) or a cellular dermal matrix graft is often placed on the labial aspect of the division B edentulous ridge for enhanced soft tissue contour, proper emergence profile, and improved lip support for esthetics when pontics are used in the region.

Division C and D Treatment Plans

The first option for a maxillary class IV patient is to use bone augmentation procedures (Figure 19-24). If the intent of the bone graft is to change a division C or D to a division A or B for endosteal implants, then autogenous bone is usually indicated. Implants may be placed after the graft has created a division A ridge, and the treatment plan follows the options previously addressed (Figure 19-25).

In the anterior mandible, implants may often be inserted in division C bone for fixed prostheses with limited compromises (Figure 19-26). The bone density and direction of force permit fixed prostheses even when the CHS is 15 mm. A FP-3 restoration is fabricated when the speaking lower lip position exposes the cervical aspects of the anterior teeth.

Classification of Completely Edentulous Arches

Completely edentulous classifications include the classification of Kent and the Louisiana Dental School.[29] The classification was for ridge augmentation with HA and a conventional denture. This classification treats all regions of an edentulous arch in a similar fashion and does not address regional variation. Likewise, the classification of Lekholm and Zarb only addressed the anterior maxilla and mandible, always resulted in root form implants without regard for bone grafting, and always used a fixed prosthesis regardless of biomechanical considerations.[30] The divisions of bone previously presented by Misch and Judy are the basis of the classification of a completely edentulous patient presented in this chapter.[1,2] Its purpose is to allow communication of not only the volume of bone but also its location. It organizes the most common implant options of prosthodontic support for completely edentulous patients.

The edentulous jaw is divided into three regions and described according to the Misch–Judy classification.[31] In the mandible, the right and left posterior sections extend from the

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FIGURE 19-25. A maxillary class IV, division C–w patient should have block bone graft procedures to increase the width of bone followed by implants in the key implant positions. An additional implant may be necessary if bone density is poor or force factors are greater than normal.



FIGURE 19-26. A mandibular class IV, division C–h mandible often may have implants positioned in key implant positions. Bone density is usually good, and in centric occlusion, the implants may be loaded in their long axis.

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mental foramen to the retromolar pad, and the anterior area is located between the mental foramina. The anterior section usually extends from first premolar to first premolar because of the foramen's most common location (i.e., between the two premolar teeth).

The right and left posterior regions of the edentulous maxilla also start from the second premolar site, where the maxillary sinus most often determines the height of available bone. The anterior section of the maxilla consists of the region between the first premolars and is usually anterior to the maxillary sinus (Figure 19-27).

The division of bone in each section of the edentulous arch determines the classification of the edentulous jaw. The three areas of bone are evaluated independently from each other. Therefore, one, two, or three different divisions of bone may exist. The term *type* is used in the completely edentulous classification rather than *class*, as in the partially edentulous classification.

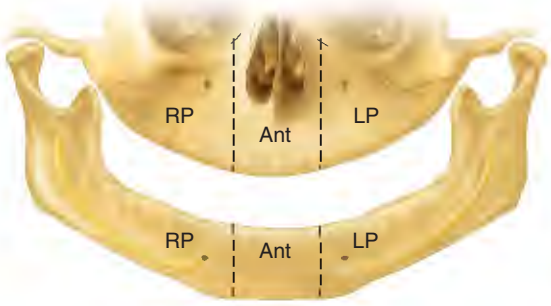


FIGURE 19-27. A completely edentulous jaw is divided into three segments. The anterior component (Ant) is between the mental foramina or in front of the maxillary sinus. Right (RP) and left (LP) posterior segments correspond to the patient's right and left sides.

Type 1

In a type 1 edentulous arch, the division of bone is similar in all three anatomical segments. Therefore, four different categories of type 1 edentulous arches are present. In a type 1, division A ridge, with abundant bone in all three sections, as many root forms as needed may be inserted (and the locations of implants are not limited) to support the final prosthesis. As a general rule, the range of five to nine implants may be used in the mandible and seven to 10 implants in the maxilla for a fixed prosthesis.

The type 1, division B edentulous ridge presents adequate bone in all three sections in which to place narrow-diameter root form implants. It is common practice to modify the anterior section of bone in the mandible by osteoplasty to a division A and to place full-size root form implants in this region.

It is more unusual to have sufficient height in either the posterior maxilla or mandible to permit osteoplasty to improve the division. Therefore, several narrower implants are often indicated in the mandible if posterior implants are inserted without grafting. One implant is used for every tooth root to compensate for the decrease in surface area of implant support.

Augmentation by bone spreading may be indicated in the maxilla if the patient desires a fixed prosthesis, especially when opposing natural teeth. If stress factors are great, then lateral

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augmentation may also be necessary in the posterior regions to increase implant diameter.

Type 1, division C–w edentulous arches present adequate height of available bone but have inadequate width. If the patient desires an implant-supported removable prosthesis, then an osteoplasty may be used to convert the ridge to C–h in the mandible. The treatment plan then follows a type 1, division C–h formula. When a fixed restoration is desired, an autogenous onlay graft in the C–w arch is usually warranted to restore the ridge to division A before implant insertion. In the maxilla, osteoplasty is less effective to increase width and augmentation is more usual to convert the ridge to division A or B.

Type 1, division C–h edentulous arches often do not present all of the essential requirements for predictable long-term implant support for fixed prostheses. An implant-supported RP-4 or RP-5 removable prosthesis is often indicated to reduce occlusal loads. The mandibular arch may be treated with a complete subperiosteal implant or root form implants in the anterior section. The prosthesis should be completely implant supported (RP-4) to halt the continued bone loss in the posterior regions of the mouth. When only division C anterior root form implants are inserted, posterior soft tissue support (RP-5) may be required.

The edentulous maxilla is often treated with a conventional removable prosthesis until the mandible is completely restored. If this denture needs additional retention or stability, then HA can be used to augment the premaxilla. This squares the ridge shape and provides resistance to occlusal excursions during function. The C–h maxilla should often consider subnasal augmentation combined with root form implants in the canine eminence region and sinus graft with root form implants with an RP-4 prosthesis.[32,33] Additional surgical training is required for these last two alternatives, and they have a greater incidence of complication.

Fixed prostheses in either arch may need autogenous iliac crest grafts to change the anterior division of bone and improve long-term success and esthetics. Sinus grafts are also indicated in the maxilla in these situations (Figure 19-28).

The edentulous arches classified as type 1, division D are the most challenging to traditional and implant dentistry. If an implant fails in a type 1, division D patient, then pathologic fractures or almost unrestorable conditions may result, yet these are the patients who need the most help for support of their prostheses. The benefits versus risks must be weighed carefully for each patient. Endosteal implants may be placed in the anterior mandible. However, the unfavorable crown height of greater than 20 mm and mandibular fracture during implant placement or after implant failure may result in significant complications.[34]

Often the best solution is to change the division with autogenous grafts and then reevaluate the improved conditions and appropriately alter the treatment plan. The type 1, division D ridges most often use autogenous iliac crest grafts. After 6 months, the arch is reevaluated. It may be converted to a C–h or a division A bone volume, depending on a list of patient host factors. A total of five to nine implants may then be placed in the anterior and posterior regions.[35,36]

Type 2

In a type 2 completely edentulous arch, the posterior sections of bone are similar but differ from the anterior segment. The most common arches in this category present less bone in the posterior regions, under the maxillary sinus, or over the mandibular canal than in the anterior segment. These edentulous ridges are described in the completely edentulous classification with two division letters following type 2, with the anterior segment being listed first because it often determines the overall treatment plan. Therefore, a mandible with division A between the foramina and division C distal to the mandibular foramen is a type 2, division A, C arch. This condition is common in the mandible because the posterior regions resorb four times faster than the anterior regions. Because onlay grafts in the posterior mandible are more difficult to perform predictably, the anterior region is often the only segment used for implant support.

In a type 2, division A, B arch, the posterior segments may be treated with narrow-diameter implants, but the anterior section is adequate for larger-diameter root form implants to support the prosthesis (Figure 19-29). When possible, the posterior division B section is changed into division A. Synthetic onlay augmentation is not as predictable or timely as division B endosteal implants, which may be used when stress factors are low. Autogenous grafts are more debilitating and require extended healing periods but may be indicated for the benefit of increased posterior bone width when stress factors and

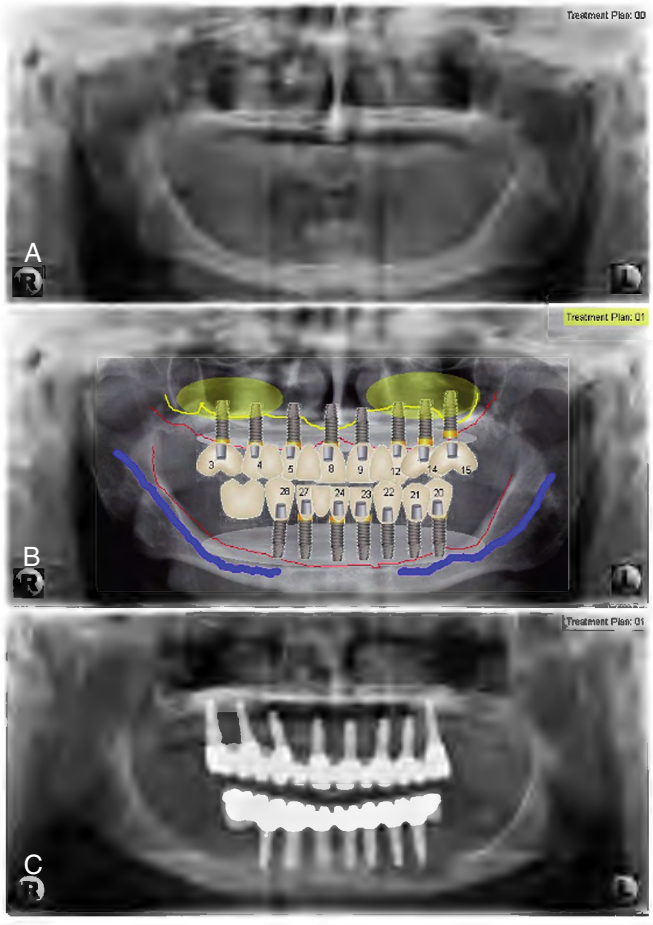


FIGURE 19-28. **A,** A type I, division C–h mandible and maxilla should be restored to division A with autogenous grafts when a fixed prosthesis is desired. **B,** Computer-assisted treatment plans with five to nine implants placed in the grafted bone volumes can be developed before treatment (XCPT, Naples, FL). **C,** Panoramic radiograph of a patient with division C–h maxilla and mandible restored to division A arches with iliac crest grafts, endosteal implants, and fixed maxillary and mandibular prostheses.

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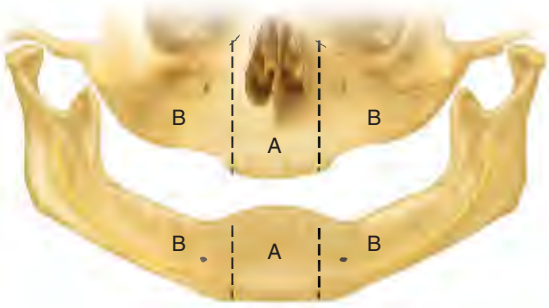


FIGURE 19-29. A type 2, division A, B arch has an anterior section classified as division A *(A)* and posterior sections as division B *(B)*. The anterior region dominates the overall treatment plan in all edentulous arches and usually has a greater volume of bone than the posterior.

patient desires are high. Smaller segments can be augmented with intraorally harvested block grafts. In the posterior maxilla, bone spreading and division A root forms should be considered. The softer the bone is, the easier it is to spread to a division A bone volume.

Two primary modules exist to restore the type 2, division A, C edentulous ridge. In the mandible, the most common option is the use of the anterior section only for implant-supported root form implants (Figure 19-30). The maxillary arch may be treated with a combination of sinus graft and endosteal implants if additional posterior support is required for the prosthesis. Because the bone density of the mandible is usually superior to that of the maxilla and the moment forces remain directed within the arch form, rarely does the mandible require additional posterior support with grafts. However, for a patient with a square arch form or high masticatory dynamics such as opposing natural teeth, posterior support may be required for a RP-4 or fixed prosthesis. A disc implant for 7-mm-long root forms may be used for this added support in the mandible.

An edentulous ridge with severe posterior bone loss and abundant bone in the anterior region is uncommon and occurs more frequently in the maxilla. A type 2, division A, D patient is treated in a similar manner as the patient with a type 2, division A, C arch. Sinus grafts and endosteal implants in the maxilla or only anterior implants with or without an autogenous graft in the mandible are most often the treatment of choice.

A type 2, division B, C edentulous arch can be treated with two main treatment options. The anterior section may be changed to division A by osteoplasty if anatomical conditions permit. These patients are then treated exactly as the previously described type 2, division A, C. When the ridge does not present sufficient height after osteoplasty to upgrade the division, the posterior segments may be improved by sinus grafts, and the whole arch treated in the same manner as type 1, division B or type 2, division B, A. Onlay grafts are less predictable than sinus grafts; therefore, the anterior mandible may be changed to a division C by osteoplasty, and a RP-4 restoration with anterior root forms and RP-5 prosthesis may be selected for type 1, division C mandibular patients.

Patients who have advanced atrophy in the posterior segments and adequate ridge width and height in the anterior may be described as type 2, division B, D. This condition almost never occurs in the mandible, but it can be found on occasion in the maxilla. These patients are treated in a manner similar to

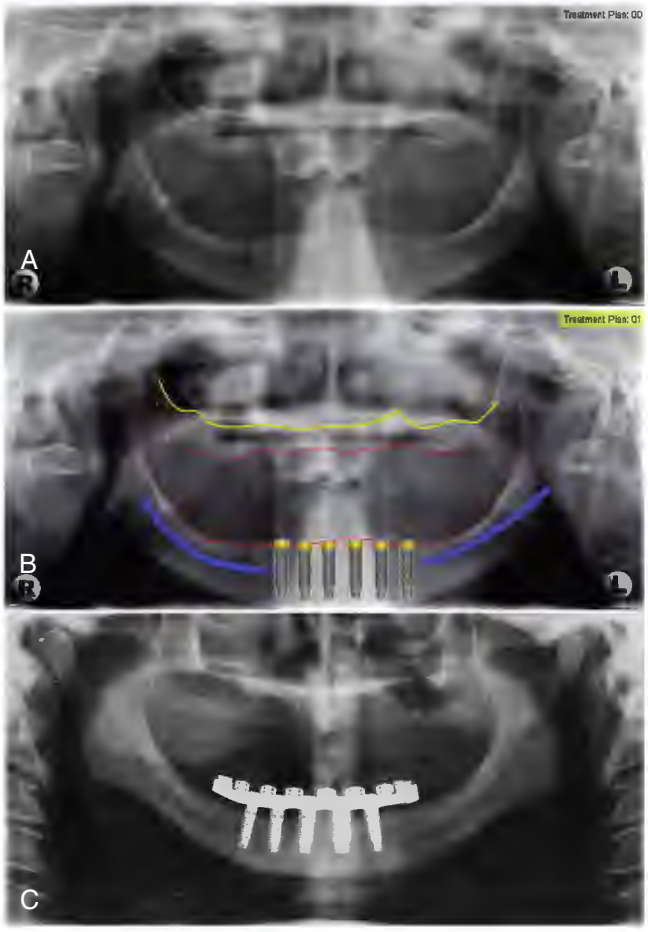


FIGURE 19-30. **A,** A treatment option for type 2, division A, C. **B,** A computer-generated treatment plan with favorable biomechanics places implants in the anterior section of the mandible and restores the arch with cantilevered posterior sections (XCPT, Naples, FL). **C,** In a situation with higher masticatory dynamics or nocturnal parafunction, this type of arch may mandate the fabrication of a RP-4 prosthesis rather than a fixed restoration.

patients with type 2, division B, C, as previously described. The primary difference is that the posterior graft is more extensive and requires additional months for healing before implant insertion and prosthodontic reconstruction. In the mandible, type 2, division C, D patients may be treated similar to a type 1, division D mandible with autogenous bone grafts before implant placement (Figure 19-31).

Type 3

In type 3 edentulous arches, the posterior sections of the maxilla or mandible differ from each other. This condition is less common than the other two types and is found more frequently in the maxilla than the mandible. The anterior bone volume is listed first and then the right posterior followed by the left posterior segment. Therefore, the edentulous maxilla with abundant bone in the anterior section, no bone available for implants in the left posterior section, and adequate bone in the right posterior segment is a type 3, division A, B, D edentulous arch (Figure 19-32).

A patient with a mandible that has adequate bone in the right posterior segment and inadequate bone on the other side but abundant bone in the anterior has a type 3, division A, B,

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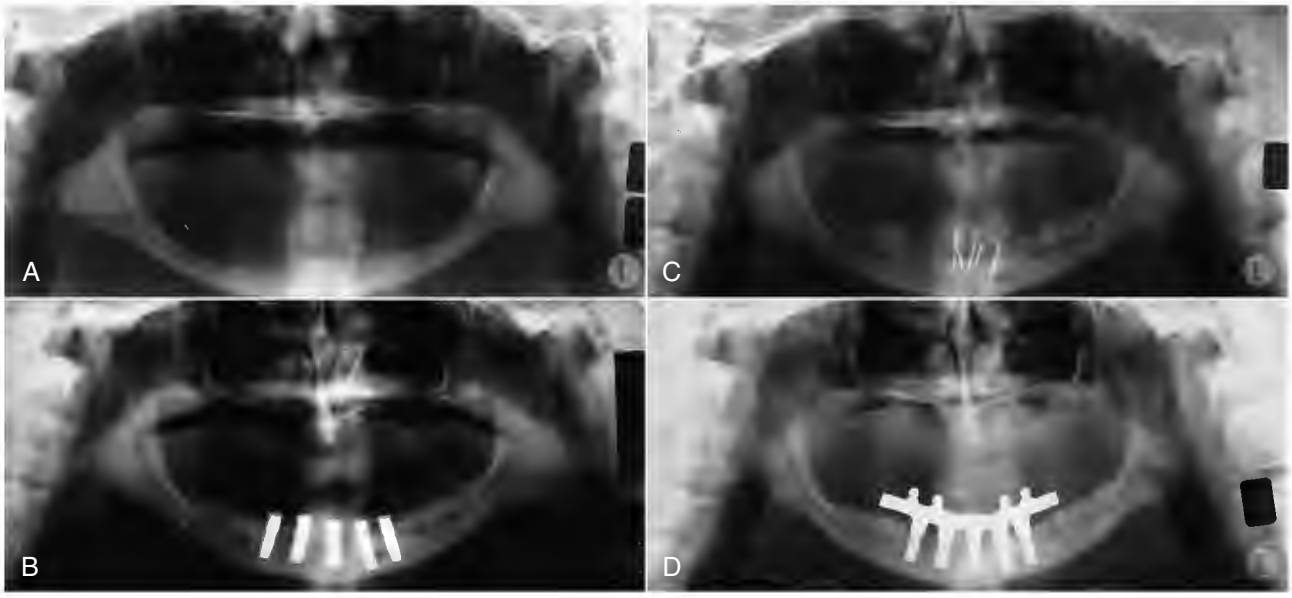


FIGURE 19-31. **A,** Patients with type 2, division C, D mandibles may be treated in a similar fashion as patients with type I, division D arches. Iliac crest bone grafting is necessary to restore proper volume of bone to division A. **B,** Before implant placement (**C**) and final restoration fabrication (**D**).

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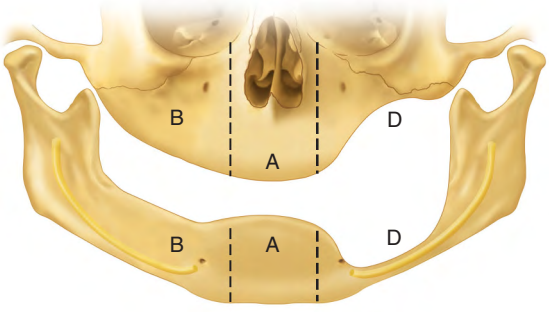


FIGURE 19-32. This type 3, division A, B, D arch has abundant anterior bone *(A)*, moderate atrophy of bone in the posterior right *(B)*, and severe atrophy in the left posterior segment *(D)*. Sinus grafting is a common treatment if posterior implants are required in the maxilla. However, bone augmentation in the posterior mandible for division D is more unusual, and additional anterior implants in the division A with a cantilever are more typical. Another option is to use narrower implants in the right posterior, splinted to the anterior implants.



FIGURE 19-33. The square dentate maxilla with type 3, division C, D, E, may require bilateral sinus grafts and implants in the canine with nasal elevation to support a fixed prosthesis.

C edentulous ridge. A narrow-diameter implant may be placed in the right posterior segment, as well as root forms in the anterior section as indicated by the prosthesis. If additional prosthetic support is needed in the left mandibular region, then in most cases additional anterior root forms are placed and splinted to the posterior implants and the teeth or bar cantilevered without implant support on the left posterior region. A type 3, division A, C, B patient is treated as a mirror image of a type 3, division A, B, C.

A type 3, division A, D, C (or type 3, division A, C, D) patient receives a treatment plan similar to the plans discussed under type 2, division A, C. Endosteal root form implants are placed in the anterior section; if the prosthesis needs additional posterior support, then grafts are considered, especially in the posterior maxilla. Patients with type 3 arches with anterior division B or C are treated similar to the corresponding type 2 patients with an anterior division B or C.

In the maxilla, it is not unusual that the premaxilla presents insufficient bone volume and one posterior quadrant requires a sinus graft (type 3, division C, A, D). In that case and if appropriate bone volume is present in the cuspid area with favorable force factors and a square arch form, then a full-arch fixed prosthesis can be fabricated after sinus graft and implant placement in the cuspid and posterior regions, bypassing the lateral and central implant sites (Figure 19-33).

The arch is type 3 even when the anterior region is similar to one of the posterior sections. For example, the type 3, division C, D, C ridge has division C in the anterior, severe atrophy on the right section, and moderate atrophy in the left section. In a mandibular arch of this type, implant placement in the anterior section only may be sufficient to restore the patient, although a disc implant or 7-mm-long root from may be indicated in the division C posterior section. The maxilla usually requires sinus grafts and subnasal elevation because of the poor biomechanics and bone quality. The anterior section usually determines the treatment plan.

Rarely are posterior implants inserted without any anterior implant support. In traditional prosthetics, Kennedy–Applegate class I, modification I patients with anterior missing teeth are

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often restored with an anterior FPD and posterior RPD. This limits rocking of the prosthesis and decreases the forces transmitted to the abutments. Conventional prosthetics also dictate that a FPD is not indicated when the canine and two adjacent teeth are missing. This applies also when the anterior six teeth are missing and implants cannot be inserted. These time-tested, traditional prosthodontic axioms indicate that posterior implants alone should not be placed without any anterior implant or natural tooth support. However, this concept is often ignored in the maxilla, where practitioners often rely solely on sinus grafts and implants in the posterior segments. If no canine implants are inserted, then the lack of anterior support can cause rotation of the prosthesis and accelerate posterior implant loss.

The two posterior sections are not connected because the span between the first premolars is too great, and the posterior implants are placed almost in a straight line with little biomechanical advantage. Anterior rocking and posterior lateral forces on these straight-line implants increase implant failure. The patient's condition is then often worse than before any implant therapy. It is usually far more prudent to convince the patient to be treated with an anterior onlay graft and anterior implants so that a full-arch restoration (RP-4 or fixed) may be fabricated.

Summary

An implant dentistry classification has been outlined that permits visualization of teeth and bone in partially edentulous arches. The foundation of this classification is the Kennedy–Applegate system, which is the most used classification in prosthodontics. A classification for the completely edentulous arch based on available bone also has been developed. As a result of this merge in classifications, generalized treatment plans may be established to and the dentist in restoring partial and completely edentulous patients.

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CHAPTER 20

Posterior Single-Tooth Replacement: Treatment Options and Indications

Carl E. Misch

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Seventy percent of the dentate population in the United States is missing at least one tooth. The average number of missing teeth above the poverty level in a U.S. survey from 1999 to 2004 was 2.96 teeth and below the poverty level was 4.15 teeth. Hence, income is not a major factor for the average tooth loss in the adult population (Figure 20-1). Single-tooth replacement will most likely comprise a larger percentage of prosthetic dentistry in the future, compared with past generations. In 1960, the average American older than age 55 years had just seven original teeth. Today the average 65-year-old adult has 18 original teeth, and baby boomers (those born between 1946 and 1964) can expect to have at least 24 original teeth when they reach 65 years of age (Figure 20-2).

The first adult teeth lost today are usually between the ages of 35 and 54 years. Almost 30% of the 50- to 59-year–old adults examined in a U.S. national survey exhibited either single or multiple posterior edentulous spaces bordered by natural teeth.[1] This segment of the population has the most disposable income and is the least dependent on insurance companies to pay for dental care. Treatment to replace single teeth in the posterior regions represents nearly 7% of the annual dental care reimbursement from insurance companies and totals more than $3.2 billion each year.[2,3] Because most companies often reimburse less than 50% for tooth replacement, the total costs of single-tooth replacement may approach $7 billion in the United States each year.

Posterior Missing Tooth

The first molars are the first permanent teeth to erupt in the mouth and often play a pivotal role in the maintenance of the arch form and proper occlusal schemes. These teeth are often the first to decay, and adult patients often have had one or more crowns fabricated to restore the integrity of the teeth and replace previous large restorations. Longevity reports of crowns have yielded very disparate results, with the mean life span at failure reported to be 10.3 years. The primary cause of failure of the crown is endodontic therapy, porcelain or tooth fracture (or both), or uncemented restoration. Teeth are at risk for extraction as a result of these complications, and coupled with decay, these complications are a leading cause of single posterior tooth loss in adults[1–9] (Figure 20-3).

Posterior Single-Tooth Replacement Options

Evidence-based medicine is the conscientious, explicit, and judicious use of the best evidence in making decisions about the care of individual patients.[10] Over the years, researchers have observed that external clinical evidence would both invalidate previously accepted treatment and allow replacement with new modalities that are more efficacious and safe.[10] An evidence-

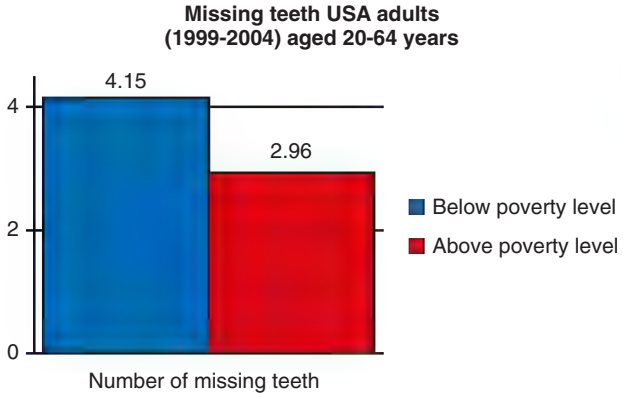


FIGURE 20-1. The average number of missing teeth in a 20- to 64-year-old population is similar, regardless of income.

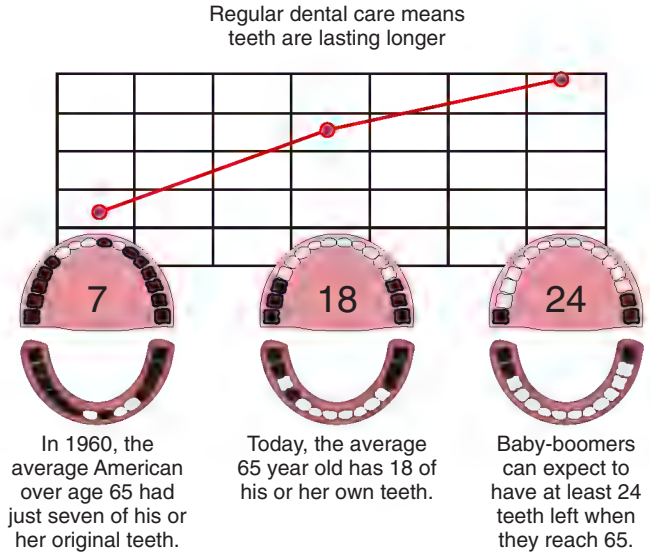


FIGURE 20-2. The number of missing teeth in people older than the age of 65 years old has been decreasing since 1960.

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FIGURE 20-3. A mandibular first molar is often the first tooth lost in a permanent dentition.



FIGURE 20-4. A removable partial denture to replace a missing posterior tooth is rarely a definitive appliance.

BOX 20-1 Alternative Options: Single-Tooth Replacement

1. Removable partial denture (RPD)
2. Resin-bonded fixed prosthesis
3. No restoration (space maintained)
4. Fixed partial denture (FPD)
5. Implant prosthesis

based approach may be applied to the replacement of a posterior single tooth.

Five alternative treatment options exist for the replacement of a posterior single missing tooth (Box 20-1). The interocclusal space must be assessed carefully regardless of the treatment selected. Patients with insufficient vertical space may be contraindicated for any prosthesis without the prior correction of the occlusal plane and maxillomandibular relationships.

Removable Prosthesis

One option to replace a single missing posterior tooth is a removable partial denture (RPD) (Figure 20-4). A common axiom in restorative dentistry is to use a fixed prosthesis whenever possible.[8] RPDs are usually indicated to replace spans of three or more posterior teeth or a missing canine and two or more adjacent teeth. Rarely does a patient consent to a RPD as an acceptable definitive substitute for one posterior single tooth.

BOX 20-2 Advantages of Removable Partial Dentures

1. Hygiene
2. Soft tissue replacement in esthetic areas
3. Maxillary lip support in gross defects
4. Minimum tooth preparation
5. Reduced cost

BOX 20-3 Disadvantages of Single-Tooth Removable Partial Dentures

1. Bulk—often requires cross-arch stabilization
2. Food debris, plaque
3. Movement
   a. Speech affected
   b. Function decreased
4. No clinical studies
5. Bone loss in edentulous site
6. Highest loss of abutment teeth (up to 44% within 10 years)

The advantages of the removable restoration for multiple tooth loss include ease of daily care of the adjacent teeth, the ability to have a soft tissue replacement around the missing tooth in esthetic zones with gross defects, maxillary lip support in gross defects, minimal preparation of the abutment teeth, and reduced cost (Box 20-2). However, no reported advantages exist for a RPD replacing one posterior tooth.

Removable prostheses do not maintain bone. The maxillary posterior teeth are often in the esthetic zone (especially the maxillary premolars), and bone loss may compromise the esthetic result. Function is not improved with a removable prosthesis replacing one or two teeth. Therefore, esthetics and the fear of other teeth shifting in the arch are the two primary reasons for the patient to consent to wearing the restoration. Because of its bulk and usually the need for cross-arch stabilization, a RPD promotes more food debris and plaque accumulation on the adjacent teeth than any other treatment option (Box 20-3). Few clinical reports are available to assess the longevity survival rate, complications, or survival of adjacent teeth for a single-tooth RPD in the posterior regions of the mouth. From an evidence-based approach, this procedure is not indicated.

The plaque accumulation with the RPD increases the risk of decay and periodontal complications. Recently, Shugars et al.[3] and Aquilino et al.[11] have reported on survival rates of teeth adjacent to treated and untreated posterior-bounded edentulous spaces. When RPDs supported by adjacent teeth on each side were used to replace teeth, the survival rate of the posterior teeth adjacent to the edentulous space were poorer than with any other treatment option, with ranges from 17% to 44% abutment tooth loss at 4.2 to 13.5 years.[3,11–14] Patients electing not to wear the RPD had greater survival of the adjacent teeth than those wearing the removable prosthesis.

In conclusion, an evidence-based evaluation for a posterior single-tooth replacement with a RPD as a definitive restoration

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is not indicated and may even accelerate the loss of the adjacent teeth. These devices are most often used as a transitional prosthesis in the esthetic zone.

Resin-Bonded Fixed Partial Denture

A second option to restore a single missing tooth bordered by posterior natural teeth is a resin-bonded fixed partial prosthesis. The primary advantages of this restoration are the minimal preparation of the adjacent teeth and reduced cost compared with a fixed partial denture (FPD) (Box 20-4).

Failure rates reported in the literature are greatly disparate, but the majority of reports indicate a failure rate of at least 30% within 10 years and as high as 54% within 11 months.[6,15–17] It also appears that earlier perforated designs exhibited lower survival rates (Box 20-5).

The majority of resin-bonded FPD failure initially occur from cement failure (which often results in caries when partially retained), with different regions of the mouth exhibiting various retention rates. The highest survival rates occur in the maxillary anterior followed by mandibular anterior, maxillary posterior, and mandibular posterior teeth, respectively.[18] Therefore, posterior tooth replacement is not as successful compared with an anterior resin-bonded restoration.

Debonding most often occurs during function, and because eating is often a social experience, this may cause the patient embarrassment and insecurity. The prosthesis may also become partially debonded and result in decay under the retainer. The selection of this option is usually driven by economics and the desire to maintain as much tooth structure as possible on the abutment teeth. This option is usually more accepted by the patient than the RPD, but it should be considered as a transitional restoration because of its high debonding rate and associated decay.

Maintenance of the Posterior Space

A third treatment option for a missing posterior tooth is to not replace the tooth but instead to maintain the missing space. A common doctrine has been to replace a missing tooth to prevent complications such as tipping, extrusion, increased plaque retention, caries, periodontal disease, and collapse of the integrity of the arch[8,14] (Figure 20-5). It is speculated that these conditions cause the loss of additional teeth and have been cited as the second most common cause of missing teeth after the age of 30 years. Clinical studies evaluating the consequences of adjacent tooth loss indicate the loss of one or two teeth adjacent to a long-term edentulous space may range from 25% to less than 8% at 8 to 12 years.[3,13,14] For example, Aquilino et al.[11] reported an 18% 10-year tooth loss rate of adjacent teeth to a posterior missing tooth.

An indication for not replacing a single missing posterior tooth is a small intratooth space. When the space between the teeth is less than 6 mm, the adjacent teeth are often prevented from migration or extrusion from the existing occlusion. The existing occlusion often has each of the adjacent teeth with occlusal contact with two opposing teeth and as such prevents the tipping of adjacent teeth and the extrusion of the opposing teeth. This condition is most often observed with a missing mandibular second premolar when a third molar is present or after orthodontics when the first premolar was extracted. When the reduced amount of intratooth space should be closed, orthodontics or overcontoured crown(s) on adjacent teeth may correct the condition.

The location of a missing posterior tooth may influence the prosthodontic treatment plan. In general, when third molars are missing, the author suggests not replacing a second mandibular molar[19] (Figure 20-6). The mandibular second molar is not in the esthetic zone of the patient. Ninety percent of the masticatory efficiency is generated anterior to the mesial half of the

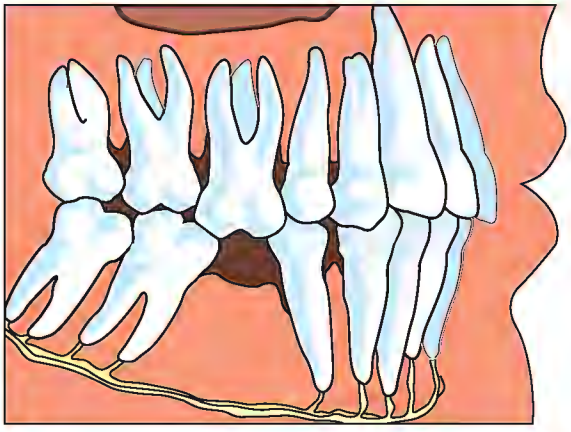


FIGURE 20-5. As many as 82 reasons have been presented in the literature for replacing a first molar after extraction. The most common reasons are tipping of adjacent teeth, extrusion of opposing teeth, and eventual loss of additional teeth.

BOX 20-4 Advantages of Resin-Bonded Fixed Partial Dentures

1. Minimal preparation of teeth
2. Good for young patients (no need to crown, no risk of encroachment on pulp)
3. An alternative when skeletal growth is not complete

BOX 20-5 Disadvantages of Posterior Resin-Bonded Fixed Partial Dentures

1. High debond rates (50% within 3 years)
   a. Inconvenience to patient and doctor
2. Risk of decay on abutment teeth when partially debonded



FIGURE 20-6. When a mandibular second molar is missing, there are few consequences when the tooth is not replaced, and there are advantages.

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mandibular first molar, so function is rarely a primary reason to replace the second molar. A 10% greater occlusal force is measured on the second molar compared with the first. As a result, biomechanical stress–related complications are more of a risk, including abutment screw loosening. This tooth is more likely to exhibit working or nonworking interfaces during mandibular excursions. As a result of the increased forces and occlusal interferences, a greater incidence of porcelain fracture occurs. The crown height space (CHS) decreases as it proceeds posteriorly and represents a limited access for implant placement along with abutment screw and abutment insertion, especially when opposing natural dentition. A reduced CHS results in the abutment height being reduced, so the retention of the crown may be compromised. Cheek biting is more common in this region because of the proximity of the buccinator muscle (Box 20-6).

The course of the mandibular canal anterior to the mid first molar corresponds to the level of the mental foramen. However, in the region of the second molar, its course becomes highly variable with less available bone height and an elevated risk of paresthesia and neurovascular bundle damage during implant surgery and insertion. The bone quality in the second mandibular molar region is often inferior to other regions of the mandible, with an increased risk of bone loss or implant failure as a consequence.[20] The submandibular fossa topography is deeper in the second molar regions compared with the premolar or first molar sites and mandates greater implant body angulation, with associated increased stresses at the crestal region of the implant, thereby increasing the risk of bone loss and abutment screw loosening. In addition, the facial artery is located in the submandibular fossa before it crosses the mandibular notch and crosses over the face. Perforation of the lingual plate in the region of the second molar may violate the facial artery and cause life-threatening bleeding. The mandible exhibits increased flexure and torsion in this area during opening or heavy biting on one side, and masticatory dynamics are less favorable. As a result, the implant may not integrate in a patient with moderate to severe bruxism or clenching. Finally, the cost of an implant or fixed prosthesis to replace the second molar often does not warrant the benefits achieved. As a consequence, the mandibular second molar is often not replaced when the third molar and second molar are the only posterior mandibular teeth missing.

BOX 20-6 Disadvantages of Replacing a Mandibular Second Molar

1. Not in esthetic zone
2. Extruded maxillary second molar not esthetic or occlusal consequence
3. Less than 5% of total chewing efficiency
4. A 10% higher bite force (increased bone loss risk, porcelain fracture risk, and abutment screw–loosening risk)
5. More often exhibits occlusal interferences during excursions
6. Higher and less predictable location of mandibular canal in that site
7. Less dense bone
8. Submandibular fossa depth greater
9. Angulation of bone to occlusal plane greater
10. Limited to unfavorable crown height space for cement retention (increased risk of uncementation)
11. Limited access for occlusal screw placement
12. Limited access for correct implant body placement
13. Crossbite position—implant placed more buccal than maxillary tooth
14. Hygiene access more difficult
15. Cheek biting more common
16. More incision line opening after surgery
17. Greater mandibular flexure during parafunction
18. Greater cost to patient
19. When mandibular third molar (when present) moves forward, intratooth space limited

The primary disadvantage of electing not to replace a mandibular second molar tooth is the potential extrusion and loss of the maxillary second molar or a loss of proper interproximal contact with the adjacent tooth with increased risk of caries, periodontal disease, or both. The extrusion of the maxillary second molar is usually not an esthetic or occlusal concern. When the mandible moves into an excursion, the maxillary second molar is behind the mandibular first molar and does not alter the mandibular pathway of movement even if the maxillary second molar extrudes. If extrusion of the maxillary second molar is a concern for the patient or doctor, then a crown on the mandibular first molar may include an occlusal contact with the mesial marginal ridge of the maxillary second molar, or the maxillary second molar may be bonded to the maxillary first molar.

On the other hand, a missing maxillary second molar opposing a mandibular second molar with extrusion may result in occlusal concern when the mandible moves into an excursion. The extrusion of a mandibular second molar results in an occlusal interference when the mandible moves into protrusive or lateral excursion. Hence, as a general rule, maxillary second molars are usually replaced with an implant when opposing a natural tooth (Figure 20-7).

The mandibular second molar is usually replaced when the third molar is in function and will remain present (Figure 20-8). In addition, some patients desire an intact dentition and wish to have the tooth replaced, whether or not they have a third molar (Figure 20-9). If the bone is abundant and no paresthesia or surgical risk is apparent, then the second molar may be replaced. However, this is usually the exception rather than the rule of treatment and usually replaces only a premolar-sized tooth.

The other indication to replace a mandibular second molar is when the force factors are extreme (e.g., severe parafunction) and the patient is also missing both molars. In these cases, two or three implants may be indicated to replace the missing teeth (Figure 20-10).

Fixed Partial Denture

The treatment most commonly used for the replacement of a posterior single tooth is the three-unit fixed restoration (Figure 20-11). In 1990, more than 4 million FPDs were placed in the United States.[21] This type of restoration can be fabricated within 1 to 2 weeks and satisfies the criteria of normal contour, comfort, function, esthetics, speech, and health. Because of these benefits, the FPD has been the treatment of choice for the past 6 decades.[22,23] Few bone and soft tissue considerations exist in the missing tooth site. Every dentist is familiar with the procedure, and it is widely accepted by the profession, patients, and dental insurance companies (Box 20-7).

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FIGURE 20-7. **A,** When a maxillary second molar is lost, there are more consequences when the tooth is not replaced. **B,** As a result, the opposing plane of occlusion is corrected, and an implant is used to replace the maxillary second molar.



FIGURE 20-8. The second mandibular molar is usually replaced when the third molar is present and will remain in function.



FIGURE 20-9. Some patients desire a second molar replacement despite the lack of need. When existing conditions are favorable, little disadvantage exists to placing an implant in this region. Most often a bicuspid-sized tooth and one implant are used in this region for the restoration.

BOX 20-7 Advantages of Fixed Partial Dentures

1. Most common treatment (doctor friendly)
2. Reduced time (two appointments, 1 to 2 weeks apart)
3. Restores function, esthetics, and intraarch health
4. Few bone and soft tissue considerations
5. Proven long-term survival
6. Reduced cost—dental insurance covers procedure (reduced patient cost)
7. Less than 6-mm mesiodistal space
8. Potential abutments have clinical mobility; will benefit from being splinted
9. Increases patient compliance and reduces fear
10. Few consequences if failure

A three-unit FPD presents survival limitations to the restoration and to the abutment teeth.[7] In an evaluation of 42 reports since 1970, Creugers et al.[23] calculated a 74% survival rate for FPDs for 15 years. Walton et al.[24] and Schwartz et al.[25] reported mean life spans (50%) of 9.6 and 10.3 years, respectively. Scurria et al.[26] performed a meta-analysis of several reports at 10 to 15 years and found 30% to 50% failure within these time frames. However, reports are very inconsistent with as little as 3% loss over 23 years to 20% loss over 3 years.[4,5,23–26]

Caries and endodontic failure of the abutment teeth are the most common causes of prosthesis failure.[22,24,26] Caries occurs more than 20% of the time and endodontic complications to

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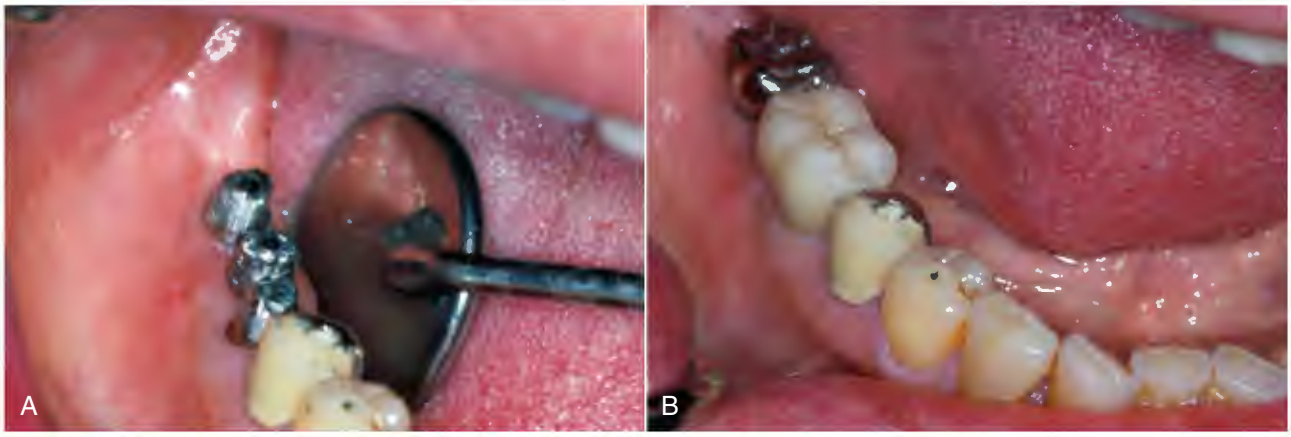


FIGURE 20-10. **A,** The mandibular second molar is often replaced when the first molar is also missing. **B,** Greater force factors than usual may indicate three implants to replace the two molars.



FIGURE 20-11. A three-unit fixed partial denture is the most common method taught in dental schools to replace a posterior missing tooth.

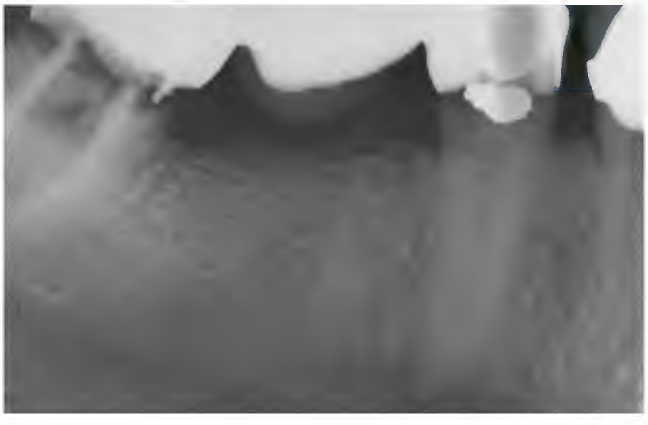


FIGURE 20-12. The most common reason for fixed partial denture failure is caries on an abutment tooth resulting from increased plaque retention next to the pontic. Caries, endodontic failure, fracture, and uncemented restorations often lead to abutment tooth loss.

the abutments of a FPD 15% of the time. Caries on the abutment crown primarily occurs on the margin next to the pontic (Figure 20-12). Fewer than 10% of patients floss on a regular basis, and those using a floss threader are even fewer.[27] As a result, the pontic acts as a large overhang next to the crown and a reservoir for plaque. The long-term periodontal health of the abutment teeth may also be at greater risk as a result of the plaque increase, including bone loss.

When a vital tooth is prepared for a crown, a 3% to 6% risk of irreversible pulpal injury and subsequent need for endodontic treatment exists.[28] Not only does tooth preparation present a risk for endodontics on each of the vital abutment teeth, but the crown margin next to the pontic is also more at risk of decay and the need for endodontics as a result. Up to 15% of abutment teeth for a fixed restoration require endodontic therapy compared with 3% to 6% of nonabutment teeth with crown preparations[29] (Box 20-8).

Unfavorable outcomes of FPD failure include not only the need to replace the failed prosthesis but also the loss of an abutment tooth and the need for additional pontics and abutment teeth in the replacement bridge. Root canal therapy is not guaranteed, and a meta-analysis reports a 90% success at the 8-year mark. Because 15% of FPD abutment teeth require endodontics, many abutment teeth may be lost. In addition, an endodontic posterior tooth abutment is at a greater risk of fracture. Reports indicate that abutment teeth for a FPD fail from endodontic complications (e.g., fracture) four times more often than those with vital pulps[27,30,31] (Figure 20-13). The fracture of the tooth may result in failure of the prosthesis and abutment tooth.

The abutment teeth of a FPD may be lost from caries, endodontic complications, or root fracture at rates up to 30% for 8 to 14 years.[3,13,14] Recent reports indicate 8% to 18% of the abutment teeth holding a FPD are lost within 10 years

BOX 20-8 Disadvantages of Fixed Partial Dentures

1. Mean life span often 10 to 15 years
2. Caries and endodontic failure of abutment teeth most common complication
3. Increased plaque retention of pontic increases caries and periodontal disease risk
4. Damage to healthy teeth
5. Failure of prosthesis related to loss of abutment teeth (8% to 18% within 10 years)
6. Fracture complications (porcelain, tooth)
7. Esthetics complications (crowns less esthetic than natural teeth)
8. Uncemented restoration

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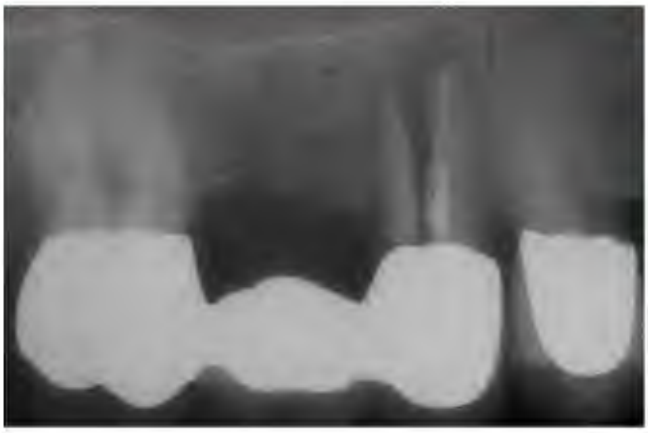


FIGURE 20-13. Fracture of an abutment occurs four times more often when the tooth has endodontic therapy.

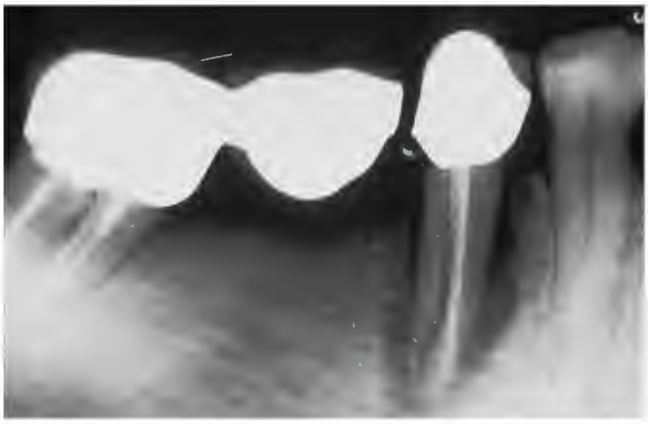


FIGURE 20-14. Several consequences of fixed partial denture complications result in abutment tooth or teeth loss.

(Figure 20-14). This is most disturbing because 80% of abutments have no previous decay or are minimally restored before the fabrication of the FPD.[6,32]

Contraindications for a posterior fixed partial prosthesis primarily are related to the abutment teeth. When the abutment teeth have bone loss or short roots, the additional support required for the missing tooth with a FPD may place them at risk. A FP-3 prosthesis is more difficult to fabricate when the teeth and pontic areas have inadequate hard and soft tissue in the esthetic zone. A partial denture may be more esthetic under these conditions. On occasion, the patient does not want the natural teeth to be prepared for crowns because they are adequate in contour, health, and esthetics. The FPD cannot be fabricated without their preparation. In addition, young patients with abutment teeth that have not erupted into final position may be contraindicated for a FPD, especially when the large pulp horns in the clinical crowns are still present (Box 20-9).

Indications for a FPD include time, patient fear of surgery, adjacent tooth mobility, and unfavorable missing tooth size. A final prosthesis may be delivered within 2 weeks with a traditional FPD. An implant option most often requires several months. Rarely, is this the determining factor but on rare occasion may be significant. The patient may have a psychologic fear of implant surgery. This most often can be handled with conscious sedation. But if general anesthesia is required, a FPD may be more prudent.

BOX 20-9 Contraindications for Fixed Partial Dentures

1. Poor abutment teeth support
2. Inadequate hard or soft tissue (or both) in esthetic regions (pontic contour)
3. Patient will not allow preparation of adjacent teeth (patient desire)
4. Young patients with large pulp horns in clinical crowns



FIGURE 20-15. A single-tooth implant is usually the best treatment option to replace a posterior missing tooth.

When the teeth adjacent to a missing space have class II mobility and all other periodontal indexes are normal, a FPD may be the treatment of choice. A posterior space requirement for an implant option is most often greater than 6.5 mm in width and 9 mm in height. If a mandibular canal or maxillary sinus may not be modified by augmentation or the mesiodistal space is too narrow, a FPD is often the treatment of choice (see Box 20-7).

Single-Tooth Implants

The fifth treatment option to replace a posterior single missing tooth is a single-tooth implant (Figure 20-15). For years patients were advised to set their desires aside and accept the limitations of a FPD. The primary reasons for suggesting the FPD were its clinical ease and reduced treatment time. However, a RPD is faster, easier, and less expensive. If this concept of faster, easier, and cheaper was expanded, then extractions would replace endodontics, and dentures could even replace orthodontics (the teeth are straight and white). The primary reason to suggest or perform a treatment should not only be related to treatment time, cost, or difficulty to perform the procedure but also should reflect the best possible long-term solution for each individual.

Before 1990, few long-term studies focusing on single-tooth implant replacement with osseointegrated implants in any region of the mouth had been published. Early reports indicated that single-tooth implant results were less predictable than they have become in the past 10 years. For example, in 1990, Jemt et al.[33] reported a 9% implant failure within 3 years of prosthesis completion on 23 implants (21 in the maxilla, two in the mandible). In 1992, Andersson et al.[34] published a preliminary report of a prospective study of 37 implants restored with single-tooth crowns in 34 patients. A 3-year follow-up

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included this "developmental group" and an additional 23 patients with 28 crowns. The cumulative success rate recorded was 93.7%, with 89% of the developmental group in function 3 to 4 years.[24]

From 1993 to the present time, single-tooth implants have become the most predictable method of tooth replacement. Almost all 5- and 10-year reports demonstrate a higher survival rate than for any other method of tooth replacement. For example, in 1993, Schmitt and Zarb[35] reported no failures for 40 implants placed in 32 patients (28 in the maxilla, 12 in the mandible, with 27 in the anterior region and 13 in the posterior). After a period of up to 6.6 years, all implants were in function. In 1994, Ekfeldt et al.[36] reported a 4- to 7-year retrospective study of 77 patients who received 93 implants. Two implants were lost, both within the first year of function. In 1995, Haas et al.[37] reported on 76 single-tooth implants observed for 6 years with a 2.6% implant loss. Simon[38] observed 70 molar implants over a period ranging from 6 months to 10 years, with a 97.1% success rate. Levin et al.[39] reported in 2006 on single-molar replacement with implants over a 10-year period with a 93.6% success rate.

A multicenter prospective clinical study by general dentists was initiated in 1996.[40] Thirty-eight implants were placed in the posterior regions of the jaws: 15 in the maxilla and 23 in the mandible. The implant survival rate was 100% at the 5-year follow-up. The mean bone loss from implant insertion to uncovering was 0.4 mm from the original crest of the ridge, the additional mean bone loss over the first 1 year of loading averaged less than 0.3 mm, and no bone loss over the following year was observed. No incidence of abutment screw loosening or fracture of any components was observed in this study. In 2000, Misch et al. reported on 30 single-tooth implants in the posterior maxilla, with a 100% survival rate over a 5-year period. In 2006, Misch et al. followed 1377 single-tooth implants in a multicenter study for 10 years and found a 98.9% survival rate for single-tooth implants.[40,41] A 10-year report by Priest indicated that the posterior single-tooth implant was more than 97% successful.[6]

Perhaps of more significance, the Misch et al. and Priest reports evaluated the teeth next to the implant crowns more than 10 years.[6,32] In both reports, no adjacent teeth were lost from endodontic failure or caries. Only one tooth required endodontic therapy after implant insertion, and fewer than 10% of the teeth required a restoration. These reports clearly identify that the adjacent teeth are least at risk when the missing tooth is replaced with an implant.

Although posterior single-tooth replacement is a relatively new treatment alternative, more articles have been published on this treatment option than for any other alternative. If early reports are excluded, then survival rates reported range from a low of 94.6% to a high of 100% for up to 10 years. A review of the literature by Goodacre et al.[42] from 1981 to 2003 found single-tooth replacement with an implant had the highest implant prosthesis survival rate and averaged 97% survival. The most common complications reported have been abutment screw loosening or porcelain fracture, which do not cause the implant or adjacent teeth to fail.

Cost comparison studies conclude that the implant restoration demonstrates a more favorable cost-effectiveness ratio.[6,42,43] Even when the adjacent teeth are not lost, the conventional FPD often needs to be replaced every 10 to 20 years because of decay, endodontic complications, porcelain fracture, or unretained restoration (which then decays and may need endodontics). Implants do not decay or need endodontics. Hence, the restorations have an extended lifetime. Unlike a FPD or resin-bonded restoration, an implant may replace a posterior tooth without a distal abutment. Hence, a second molar in the maxilla may be replaced and prevent the extrusion of the mandibular second molar.

Despite some limitations and obvious clinical challenges, the posterior single-tooth implant represents a highly desirable and justified treatment option. When the adjacent teeth next to the implant are not prepared for crowns, many advantages are incurred. These advantages include the decreased risk of caries and endodontic treatment on the abutment teeth, the improved ability to clean the proximal surfaces of the adjacent teeth (which decreases the risk of decay and periodontal disease), a decreased risk of cold or root contact sensitivity with a brush or scaler on the abutment teeth, improved esthetics (the unrestored adjacent teeth look more natural than a crown), psychological advantages (especially with congenitally missing teeth or the loss of a tooth after endodontics and crown restoration), and the decreased risk of abutment tooth loss from endodontic failure or caries (Box 20-10). These advantages are so significant to the health and periodontal condition of the adjacent teeth and maintenance of the arch form that the single-tooth implant has become the treatment of choice in most situations.

In conclusion, the single-tooth implant exhibits the highest survival rates of the five treatment options presented for single-tooth replacement. In addition, the adjacent teeth have the highest survival rate and the lowest complication rate, which is a considerable advantage (Figure 20-16). On the other hand, the longevity of the implant crown has not been adequately determined because these reports do not extend as long as those of other treatment options and often do not report on prosthetic complications. However, 10-year data clearly indicate an implant and its associated crown have greater survival than a FPD, and the adjacent teeth are less at risk.

BOX 20-10 Advantages of Single-Tooth Implants

1. Adjacent teeth do not require splinted restorations
   a. Less risk of caries
   b. Less risk of endodontics
   c. Less risk of porcelain fracture
   d. Less risk of uncemented restoration
   e. Less fracture of tooth
2. Psychological need of patient addressed: patient does not desire two adjacent teeth (often virgin) prepared and splinted to restore missing tooth
3. Improved hygiene conditions
   a. Less decay risk
   b. Floss versus floss threader
   c. Less pontic "plaque trap overhang"
4. Decreased cold or contact sensitivity
   a. Prepared teeth more temperature sensitive
   b. Cementum of tooth removed by tooth preparation; toothbrush or scaler sensitive
5. Improved esthetics: natural tooth versus crown esthetics
6. Maintains bone in site: 30% decreasing bone width within 3 years after extraction
7. Decreases adjacent tooth loss: 30% versus 0.05% risk at 10 years

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FIGURE 20-16. Because a single-tooth implant has the highest success rate of all the treatment options to replace a single tooth, it is the treatment of choice, especially when the adjacent tooth has endodontics or when the adjacent teeth need crowns (Note: A tooth with a crown has a 3% incidence of endodontic treatment vs. a 15% risk for a tooth serving as an abutment of a fixed prosthesis.)

Contraindications and Limitations of Posterior Single-Tooth Implants

Local contraindications that are unique to posterior single tooth implants and favor a FPD include inadequate bone volume, inadequate intratooth space, observable mobility of the adjacent teeth, the time required for treatment, and psychologic fear of surgery. Grafting may modify inadequate bone volume, either in height or width. Bone grafting for additional height when the adjacent teeth have lost bone is not as predictable as implant insertion and healing regardless of the technique used. Therefore, a FPD may still be the treatment of choice in some clinical conditions.

The consequences of early failure may be greater for a single-tooth implant compared with a three-unit fixed prosthesis. Although surgical success is very high, the implant failure almost always results in bone loss. As a result, if the patient elects to repeat the procedure, then bone grafting may be required. This most often is at the expense of the doctor because most patients believe early implant failure, at least in part, is the doctor's responsibility. Bone grafting is not as predictable as implant surgery; therefore, if a graft is required (especially in height), then the procedure may not be successful. However, contrary to failure of a fixed prosthesis, implant failure usually does not compromise the adjacent teeth and does not increase the risk of their loss.

The most common conditions that render posterior implant surgery contraindicated in height is found in the mandible. On occasion, the posterior roots of the teeth are short, and the mandibular canal runs higher than usual in the body of the mandible. The ideal available bone height for an implant is 12 mm or greater. An implant that is 9 mm long is usually the shortest length, which ideally should have 11 mm of bone height to have a 2-mm safety zone above the mandibular canal. When less than 10 mm of bone is present in height, the dentist may elect to not place an implant.

The posterior maxilla more often has less than 10 mm of bone in height because the sinus rapidly expands after tooth loss. Sinus grafting is very predictable. However, increased training, increased cost, and a healthy sinus are the requirements to gain additional bone height. Some sinuses have chronic sinusitis, and it is difficult to resolve the pathology for sinus grafting. In these patients, a FPD may be the treatment of choice.

The mesiodistal posterior space should be at least 6.5 mm or larger. Smaller posterior intratooth spaces should be restored with a FPD or two adjacent crowns that are overcontoured (or allow the space to be maintained). Flossing is easier between two adjacent, unsplinted, overcontoured crowns than for a fixed prosthesis, and the cost is reduced. If the space is out of the esthetic zone, then the clinician may consider not replacing the tooth if the adjacent teeth are not at risk of tipping or extrusion because of the occlusal relationship of the opposing teeth.

When the adjacent teeth have observable primary mobility but all other periodontal indices are within normal limits, a three-unit fixed restoration is superior to the other treatment options. When the adjacent teeth have moderate to severe mobility, the occlusal adjustment of an implant crown may be difficult to perform because it is the only rigid component in a span of three to five teeth.

Posterior healthy teeth move vertically 28 microns and exhibit lateral movement of less than 75 microns during primary tooth movement. A heavy bite force occlusal adjustment allows the teeth to move within their physiologic range before the implant crown contacts in occlusion. However, when the surrounding teeth are excessively mobile, an equilibration of force is not possible because the implant crown will come into contact before the conclusion of the adjacent natural tooth primary movement. As a result, the implant bears the load of all the mobile teeth and therefore may be contraindicated when surrounded by teeth with advanced clinical mobility.

On occasion, patients may have a psychologic fear of surgery and require a general anesthetic when these procedures are necessary. If bone grafting or several surgeries are required before implant surgery, it may be necessary to opt for a FPD.

On rare occasions, the length of time needed to replace the missing tooth constitutes the primary deterrent of the treatment. A FPD can be fabricated in less than 1 week and allows for the placement of a fixed transitional prosthesis. An implant may require several months before the final restoration is delivered.

To summarize, the primary indications for the selection of a three-unit FPD correspond to the limitations of single-implant tooth replacements: (1) limited time frame, (2) lack of available bone height with poor prognosis or impossibility to augment, (3) inadequate intratooth space, (4) advanced clinical mobility of adjacent teeth, and (5) psychologic fear of surgery. Under most other clinical conditions, a single-tooth implant is the treatment of choice.

Specific Single-Tooth Implant Indications

Anodontia

The absence of one or more teeth is known as *anodontia* and may be complete (very rare) or partial (also called *hypodontia*). It is many times more common than supernumerary teeth.[44] The primary cause of partial anodontia (third molars excluded) is familial heredity, and the incidence ranges from 1.5% to as high as 10% in the U.S. population.[45] Congenital absence appears to occur less often in Asians and black Americans (2.5%) than in whites (5.15%). The highest average has been reported in Scandinavian countries (10.1% in Norway and 17.5% in Finnish Skolt-Lapps). In addition, a number of

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syndromes exist in the literature that include multiple missing teeth, of which ectodermal dysplasia is the most common.

A high correlation is found between primary tooth absence and a permanent missing tooth; however, a missing tooth occurs more frequently in the permanent dentition. Caprioglio et al.[46] evaluated the records of almost 10,000 patients between the ages of 5 to 15 years of age. Of all the missing single teeth, the mandibular second premolar was most often missing (38.6%), followed by the maxillary lateral incisor (29.3%), the maxillary second premolar (16.5%), and the mandibular central incisor (4.0%). The remaining teeth were absent at a rate of only 0.5% to 1.8%, with the maxillary first molar being the least affected. The missing mandibular second premolar primarily occurred in male patients, and the missing maxillary lateral incisor primarily occurred in female patients (Figure 20-17).

The most common multiple teeth lost (other than third molars) are the maxillary lateral incisors followed by the mandibular second premolars and maxillary second premolars. Congenitally missing teeth are therefore a common scenario in a general practice. Fortunately, fewer than 1% of those missing teeth are missing more than two teeth, and fewer than 0.5% of this group are missing more than five permanent teeth. In the majority of children with more than five teeth missing, it is related to ectodermal dysplasia.

An emotional aspect exists to the replacement of a congenitally missing tooth. Because the cause is often genetic, the parent with the genetic defect often feels a psychological healing when the implant returns his or her son or daughter to "normal." An implant appears to be less traumatic because the adjacent healthy teeth do not require preparation. These conditions make the parent eager for an implant regardless of the time or cost of the procedure. However, if the bone graft, implant, or both should fail, then emotional consequences result. It is especially dangerous to put an adjacent tooth at risk under these conditions. If a young patient loses an adjacent tooth because of improper implant insertion or a consequence of a bone graft, then the patient–doctor relationship is stretched to the limit. As such, the clinician should use highly predictable procedures with care, ensuring that adequate space and bone are present before implant placement.

The dentist should first determine whether space-opening (maintenance) procedures or space closure (orthodontics) is the treatment of choice for the missing tooth. The treatment options are usually different for a mandibular second premolar compared with a maxillary lateral incisor.

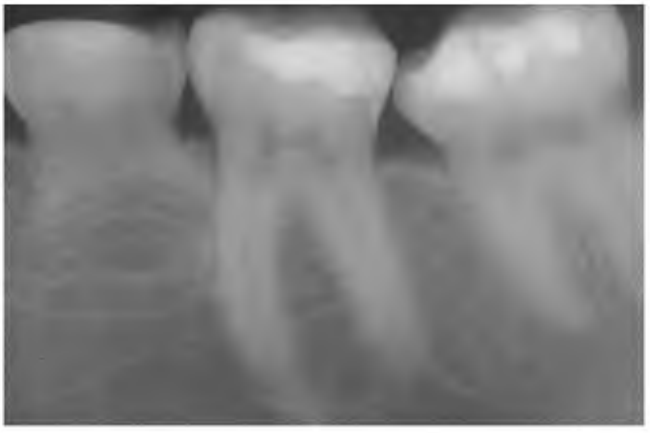


FIGURE 20-17. A periapical radiograph of a deciduous second molar and no permanent second premolar in a male patient.

A congenital missing mandibular second premolar most often has a deciduous second molar. When the patient is 5 to 6 years old, the deciduous second molar may be extracted. The permanent first molar may then erupt in a more mesial position. When the first deciduous molar is lost naturally (around the age of 9 to 11 years), the first permanent premolar and first molar may be orthodontically positioned adjacent to each other. This approach eliminates the need for a second premolar replacement. Because the second premolar space is eliminated with orthodontics, no bone graft, implant surgery, or crown (or combination of these treatments) is required to replace the tooth. Very few disadvantages exist to the use of orthodontics to eliminate this posterior missing tooth space.

A common scenario is to maintain the deciduous second molar for as long as possible. Often, the tooth finally breaks down and needs to be extracted by age 35 to 40 years. When the deciduous second molar is maintained, it may become ankylotic approximately 10% of the time. As a result, the opposing maxillary second premolar extrudes and the adjacent teeth often tip over the deciduous tooth (Figure 20-18). In addition, because the deciduous molar is 1.9 mm larger than a premolar, the mesiodistal space is larger than the usual premolar space after the deciduous molar is lost at a later date in the adult patient's life. An implant is usually the treatment of choice to replace the second premolar. However, the deciduous tooth does not have a buccolingual width of bone that is adequate for a larger-diameter implant. The crown for this larger tooth dimension is supported by a regular-size implant, which increases forces on the abutment screw and increases the risk of screw-loosening complications. However, this is most often the treatment of choice in adult patients rather than preparing the adjacent teeth for a traditional FPD (Figure 20-19). An alternative in an adult implant patient is to augment the site for width and place a larger-diameter implant (5 mm). This improves the emergence profile and decreases the risk of abutment screw loosening.

Another option in an adult patient missing a permanent premolar is orthodontic closure of the space. However, care is taken so the anterior component of teeth do not shift distally and open the centric occlusal bite relationship. To prevent this occurrence, an orthodontic implant (transitional anchorage device) may be inserted distal to the canine root and used as anchorage to pull the molars forward to close the space (Figure 20-20). This approach may also negate the need to extract a third molar in that quadrant when performed on the adolescent patient.

Age Limitations

An ankylosis condition of primary teeth occurs in between 8% to 14% of children and primarily affects the deciduous molars. The tooth does not continue to erupt and appears below the occlusal plane of the adjacent teeth. It appears the root of this tooth has a direct bone–root contact, which prevents an eruption pattern. The same condition exists with an implant in a developing child. The direct bone–implant contact prevents the implant body to shift in conjunction with growth and development. Instead, it captures the bone in three-dimensional space and prevents the implant site from adapting to the changing environment.

A study with implants in developing pigs found the surrounding teeth continued to follow jaw development, and the

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FIGURE 20-18. **A,** A panoramic radiograph of a patient missing bilateral mandibular second premolars and the deciduous molars are ankylosed. **B,** The opposing premolars have extruded and the adjacent teeth have tipped over the deciduous molar.

adjacent teeth were facial and occlusal to mandibular implants and occlusal in the maxillary arch.[47] Tooth bud growth adjacent to the implants were also displaced in their path of eruption. Several clinical reports have found a similar situation in young implanted patients. Therefore, clinical reports and animal studies confirm implants do not accommodate growth and development of the jaws and instead remain in a similar position as initially inserted.

The growth of the jaws may be described in three different planes: transverse (width), anteroposterior (length), and vertical.[48] The order of completion of growth in both jaws is completed in width first followed by length and finally vertical growth. The width growth is completed in the anterior region before the adolescent growth spurt. Both the maxillary and mandibular posterior regions continue to expand until the second and third molars have fully erupted. The posterior maxilla has more growth in width than the anterior maxilla[48] (Figure 20-21).

Because teeth erupt sooner and develop faster in girls than in boys, the width growth usually finishes in girls and young women between 9 to 15 years. Boys have a greater width gain than girls and continue to grow after the growth spurt for a longer period (11–17 years); in comparison, a young woman may be 3 mm wider in the molar areas. As a consequence, an implant inserted in the posterior maxilla prematurely may result in the implant crown in crossbite after growth and development is complete, especially in young men (Figure 20-22). In the maxilla, the maxillary sinus expands as the permanent teeth erupt. Hence, the implant may also have the sinus drape over the end of the implant. It is not clear whether the bone–implant interface is affected by this action. The width growth in the mandible premolar site may be 2 to 3 mm. Hence, an implant crown in the mandible placed before growth and development is complete may appear more lingual.

Growth in the anteroposterior direction continues after the width is completed. In young women, the growth is usually completed by 16 years of age, which is several years after menses begins. In young men, the anteroposterior growth may continue until the early 20s or more than 4 years after sexual maturation.

The vertical growth of the jaws is the last direction to be completed. The vertical growth for young women approximates 17 to 18 years and later for young men. This direction is the dimension most often noted when an implant is inserted before the completion of growth and development. As a result of this three-dimensional growth in the maxilla, from 9 to 25 years, the molars may erupt more than 8 mm downward, 3 mm laterally, and 3 mm mesially, with 1.5-mm changes per year during the growth spurt.

In the mandible, the anteroposterior direction is coupled with the vertical growth because it grows upward and backward. The body, ramus, and condyle growth makes the appearance that the lower jaw is being displaced down and forward. However, there is little actual change in the anterior region of the jaws.

An implant inserted in a premolar position before the completion of growth and development may have the permanent adjacent teeth erupt above the implant crown and change the interproximal contacts (Figure 20-23). The mandibular molar position may even erupt over the implant crown, with the rotational growth of the mandible.

An implant inserted in a missing posterior premolar site may prevent the bone loss in width. However, if growth and development is not completed, the adjacent teeth may be more at risk from the misaligned position, the bone on the implant is more apical than the adjacent root position, the occlusal plane of the opposing arch may extrude or exfoliate, and a soft tissue pocket may develop around the implant.

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FIGURE 20-19. **A,** A single-tooth implant is usually the treatment of choice when a deciduous molar is lost in an adult patient. **B,** The bone volume is often less in width, and the mesiodistal space is greater for the replacement tooth. **C,** A 4-mm-diameter implant is often used to replace the second premolar.

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FIGURE 20-20. A transitional anchorage device may be positioned anterior to the deciduous molar space and help move the molars forward to close the missing tooth space.

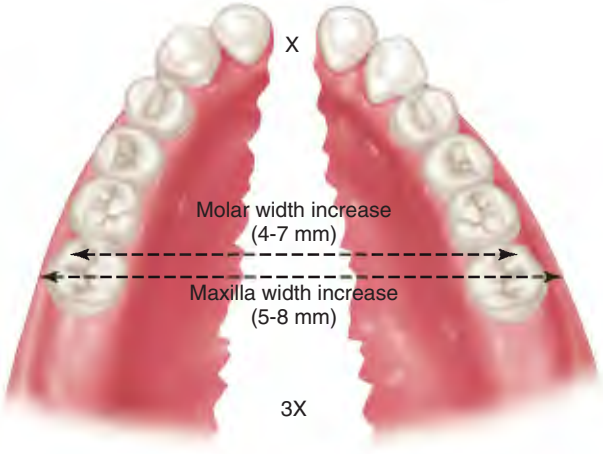


FIGURE 20-21. The posterior maxilla increases in width during growth and development more than the anterior maxilla.

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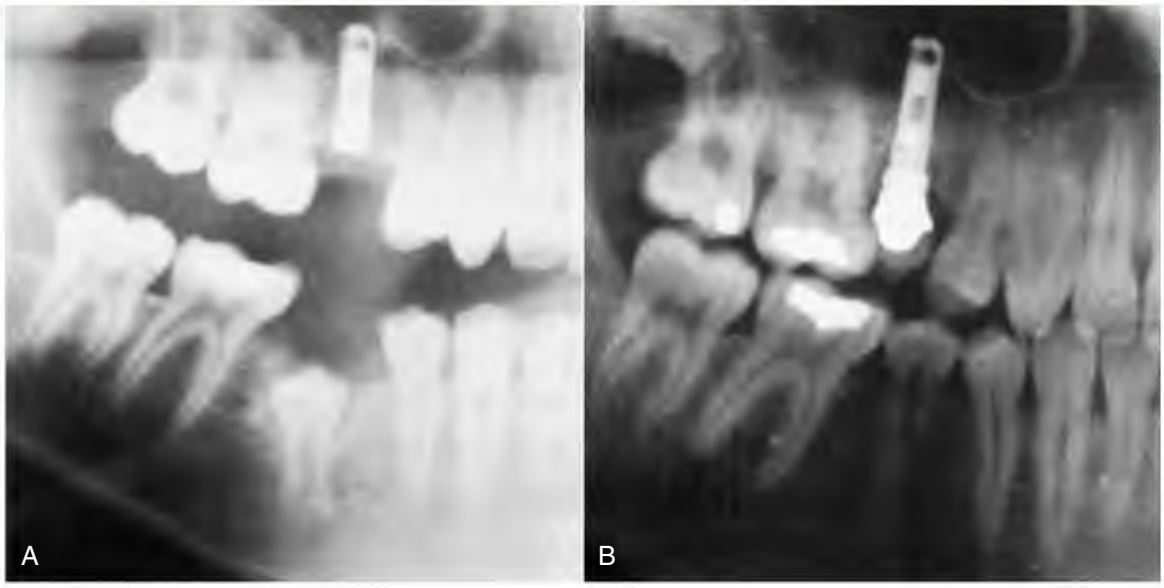


FIGURE 20-22. **A,** An implant placed in a maxillary second premolar site before the finish of growth and development. **B,** After maturity, the implant is in crossbite, the maxillary sinus has draped over the end of the implant, and the implant is in inferior occlusion. (From Oosterle LJ: Implant considerations in the growing child. In Higuchi KW, editor: *Orthodontic applications of osseointegrated implants*, Chicago, 2000, Quintessence.)

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FIGURE 20-23. A second premolar implant placed before growth and development was complete may appear inferior in occlusion, more lingual, and have open interproximal contacts on the distal.

Over the past decade, Misch et al.[49] have created four guidelines for implants placed in younger patients. The first guideline is the chronological age of the patient. The chronological age of vertical growth cessation for girls approximates 17 to 18 years and 18 to 19 years for boys (and is later than the anterior regions of the mouth). It is logical to wait until skeletal and dental growth have been completed. Therefore, as a general rule, implant insertion in the posterior regions is delayed for female patients until at least 17 years and male patients until 18 years of age.[48] However, this guideline is too variable to be used alone. Ideally, age is related to the patient's biological age more than the chronological age.

Other biological factors indicative of completed growth should be assessed before implant insertion. The second criterion for implant insertion relative to children is endocrine changes. The pubertal growth spurt is related to these hormone changes. Female patients should be able to menstruate, and male patients should have body hair, voice changes, and most often need to shave (if his father shaves daily). These criteria are most always met by 17 to 18 years but must at least be included because it is called a "pubertal growth spurt."[50]

The height of the child is also very relevant for implant insertion and is the third criterion. The prospective implant patient should have greater height than their same-sex parent. The size of the patient is more important than the age of the patient when the minimum age is being considered for implant placement.

The fourth criterion for implant insertion is that the patient has not grown in height over the past 6-month period. Thilander et al. have noted that if no statural growth has occurred in the past 6 months, then growth and development of the jaws are at least near completion.[51,52] This criterion is easier to observe than cephalograms or hand–wrist radiographs with a 2-year evaluation period.

Authors have suggested lateral cephalograms of 2 consecutive years of no changes.[44]Although it is difficult to superimpose radiographs taken over several years, this criterion is the best indication that the pubertal growth spurt is finished and the majority of facial growth is finished. However, if any changes have taken place in the past year, another year is necessary with this technique to evaluate if growth has matured enough for implant insertion.

Transitional Restorations

The absence of a transitional posterior tooth replacement is the most frequent situation during bone augmentation and implant healing in a nonesthetic region, such as the mandibular posterior aspect of the mouth. Although the occlusion and adjacent teeth may change during the 4-month healing period, rarely is this a reason for a transitional restoration in nonesthetic regions (Figure 20-24).

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FIGURE 20-24. Rarely do the adjacent teeth shift during the 4-month healing period of an implant. However, the space should be monitored, and if changes begin to occur, a space maintainer may be indicated.

Few indications exist for a removable prosthesis as a definitive treatment when replacing a single posterior tooth. However, it is often used as a transitional restoration in esthetic regions during implant healing. The practitioner should be aware a soft tissue–borne removable transitional restoration (flipper) may load the soft tissue over a bone graft and compromise the end result. Although rare, the RPD may also cause bone loss or perhaps even implant failure from the early loading around the implant during stage I healing. The RPD transitional may also depress the interdental papillae of the adjacent teeth, resulting in an esthetic compromise. As a result, a RPD with rest seats and clasps, a tooth-supported Essix appliance, or a resin-bonded fixed restoration may be fabricated when replacing teeth in the esthetic zone to provide an improved functional transitional prosthesis and protect the region. The resin-bonded restoration is most often the primary option when bone grafting is necessary before or in conjunction with implant placement because of the bone graft's extreme vulnerability to movement and the extended healing time required.

Both a tooth-supported removable and a resin-bonded fixed prosthesis may be fabricated for the transitional restoration. The removable restoration (i.e., Essix appliance) is worn immediately after surgery to protect the suture line during the initial healing.[53] After the sutures are removed, the resin-bonded restoration (without tooth preparation) may be delivered. Because both resin-bonded and removable restorations are fabricated, the patient can insert the removable restoration if the bonded restoration becomes uncemented. This eliminates the esthetic embarrassment until rebonding can be performed. However, this approach increases the overall cost of treatment. The posterior resin-bonded prosthesis may not be indicated in the case of short clinical crowns or unfavorable occlusal relationships.

A second option for a transitional posterior single-tooth replacement is an acrylic cantilevered or a three-unit temporary restoration. This is performed when the adjacent tooth or teeth require a crown. The adjacent tooth or teeth crown is prepared and serves as transitional abutments for the acrylic temporary prosthesis. After the implant is integrated, the crowns and implant crown may be fabricated at the same time as independent units.

Implant Body Selection

The implant body for a posterior single-tooth implant should include specific features to reduce complications. The implant body should be made of titanium alloy to reduce the risk of long-term fracture because it is four times more resistant to fracture than grade 1 titanium and twice as strong as grade 3 titanium. A threaded implant provides greater functional surface area than a cylinder, and a tapered implant provides less surface area than a parallel walled implant body. When implant bodies are internal hex designs, the dimension of the implant in the posterior regions should be at least 4 mm or more in diameter to increase the outer body wall thickness and reduce the risk of long-term body fracture.

The most common problem associated with a single-tooth implant is abutment screw loosening.[42] Crest module and abutment connection designs that decrease forces to the abutment screw are therefore indicated. The implant must have an antirotational feature (i.e., external or internal hex). The greater the height or depth of the antirotational feature, the less force transmitted to the abutment screw. Accuracy of component fit and abutment screw design, as well as the number of threads on the abutment screw, are other critical features.[54–56]

The ideal diameter of a single tooth implant depends on the mesiodistal dimension of the missing tooth and the buccolingual dimension of the implant site. An angular defect may develop around the abutment–body connection measuring 1.0 to 1.4 mm in width. As a result, when the implant is placed closer than this dimension to an adjacent tooth, the vertical, angular defect dimension may be converted to a horizontal defect and cause bone loss on the adjacent tooth. The horizontal bone loss around the implant will cause an increase in probing depths or an increased risk of soft tissue shrinkage. These may affect the bacterial flora or cervical esthetics of the soft tissue drape. When the implant has facial bone thickness less than 1.0 mm of cortical bone or 1.5 mm of trabecular bone, an increased risk of bone loss and implant failures may occur.[57] As a consequence, the ideal implant diameter is 1.5 mm or more from each adjacent tooth and 1.0 mm or more from each of the lateral plates of the ridge. Therefore, the ideal implant diameter in the intratooth posterior region should be at least 3 mm less than the mesiodistal dimension of the missing tooth (from cementoenamel junction [CEJ] to CEJ) and at least 2 mm narrower than the buccolingual dimension of bone. As general rule, the molar implant should be larger in diameter than a premolar implant (Figure 20-25).

Premolar Implant Replacement

The most ideal posterior tooth to replace with an implant is the first premolar in either arch (Figure 20-26). When used as an abutment for a three-unit FPD, the canine is at an increased risk of material fracture or uncementation (because of the lateral forces applied) and is often more difficult to restore to its original appearance than are other anterior or posterior teeth. The vertical available bone is usually greater in the first premolar locations than in any other posterior tooth positions. In the maxilla, it is almost always anterior or below the maxillary sinus, and the mandibular first premolar is almost always anterior to the mental foramen and associated mandibular neurovascular complex. The bone trajectory for implant insertion is more favorable in the mandibular first premolar than for any other tooth in the arch.

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A

Maxillary teeth dimensions					
	M-D Crown	M-D CEJ	M-D CEJ-2 mm	Implant	Implant + 3 mm
1st Bi	7.1	4.8	4.2	3.8	6.8
2nd Bi	6.8	4.7	4.1	3.8	6.8
1st M	10.4	7.9	7.0	5.7	8.6
2nd M	9.8	7.6	7.0	5.7	8.6

B

Mandibular teeth dimensions					
	M-D Crown	M-D CEJ	M-D CEJ-2 mm	Implant	Implant + 3 mm
1st Bi	7.0	4.8	4.5	3.8	6.8
2nd Bi	7.1	5.0	4.7	3.8	6.8
1st M	11.4	9.2	9.0	5.7	8.7
2nd M	10.8	9.1	8.5	5.7	7.7

FIGURE 20-25. **A,** The average mesiodistal (M-D) size of the maxillary posterior teeth ranges from 6.8 mm to 10.4 mm. **B,** The average M-D size of the mandibular posterior teeth ranges from 7.0 mm to 11.4 mm, with the molars slightly larger than those in the maxilla. *CEJ,* Cementoenamel junction.

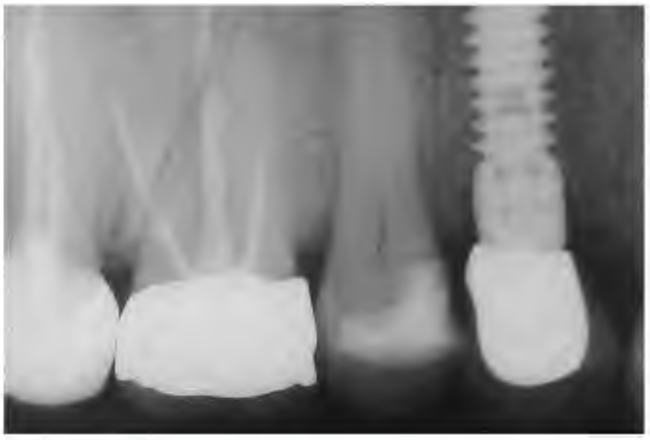


FIGURE 20-26. An implant in the first premolar region is usually anterior to the maxillary sinus or the mental foramen.

The maxillary premolars are often in the esthetic zone of patients with a high smile line. The need for bone grafting before maxillary first premolar implant placement is very common because the extraction process of the thin buccal root often causes facial bone loss during or after the extraction. Implant placement without bone grafting may result with a recessed emergence profile, which in the past was corrected with a facial ridge lap to the crown. However, the crown with a ridge lap contour does not allow proper hygiene or probing of the facial sulcular region of the crown and should be used as a last resort.

To ensure a proper esthetic result and to avoid the need for a crown with a ridge lap, the implant body is often positioned similar to an anterior implant, under the buccal cusp tip (one third buccal, two thirds lingual) rather than midcrest (which is under the central fossa). The slight buccal implant placement improves the cervical emergence profile of the maxillary premolar crown (Figure 20-27).



FIGURE 20-27. The maxillary first premolar implant is usually placed more facial than the mandibular first premolar implant because the cervical region is often in the esthetic zone during smiling.

The natural premolar tooth is 7 mm wide in the mandible and 6.5 to 7 mm in the maxilla. The premolar root is usually 4.2 mm in diameter on average at a distance of 2 mm below the CEJ, which is the ideal position of the bone. As a consequence, the most common implant diameter is about 4 mm at the crest module. This also provides approximately 1.5 mm of bone on the proximal surfaces adjacent to the natural teeth when the mesiodistal space is 7 mm or greater. However, when the mesiodistal dimension is only 6.5 mm, a 3.5-mm implant is suggested.

The maxillary canine root is often angled 11 degrees distally and presents a distal curve 32% of the time, which may extend over the shorter root of the maxillary first premolar. With posterior implant insertion, the implant body is often longer than the natural tooth root. The surgeon may inadvertently place the implant parallel to the second premolar and, consequently, into the natural canine root. This may not only result in endodontic therapy of the canine but also may cause root fracture and loss of the tooth. Therefore, in the maxillary first premolar region, care must be taken to evaluate the canine angulation and vertical height limitation. The first premolar implant may need to be placed parallel to the canine root, and a shorter implant than is considered ideal may be required (Figure 20-28). A tapered implant body at the apical third may also be of benefit to avoid encroachment upon the apical region of the canine.

The second premolar root apices may be located over the mandibular neurovascular canal (or foramen) or maxillary sinus. The foramen is often 2 mm or more above the neurovascular canal. Hence, the second premolar available bone height may be less than the first molar region. This also results in a reduced height of bone compared with the anterior region of the jaws. As a result, a shorter implant than ideal is a common consequence in the second premolar site.

First Molar Implant Replacement

The first molar is one of the teeth most frequently lost in a posterior segment. The natural molars receive twice the load of the premolars and have 200% more root surface area; therefore,

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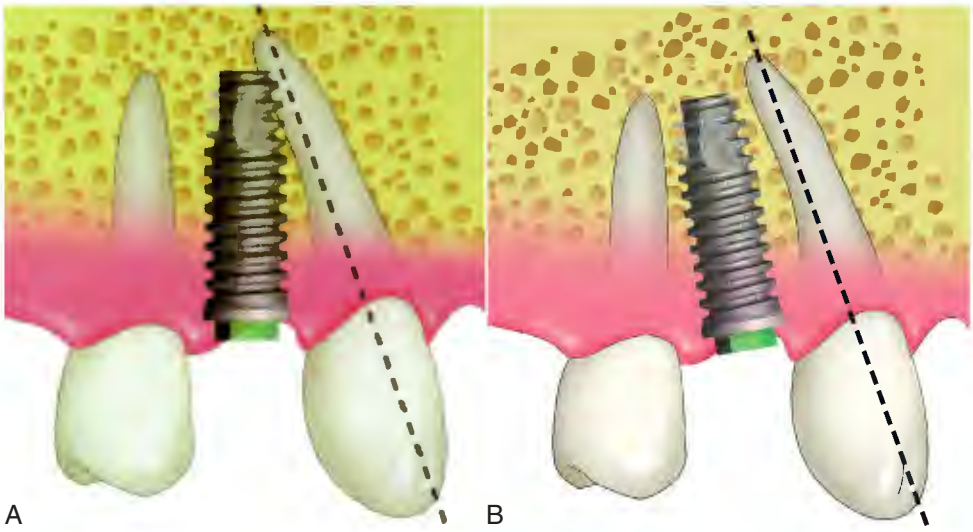


FIGURE 20-28. **A,** The canine root is often angled to the distal 11 degrees and has an apical distal curve 32% of the time. As a consequence, the first premolar implant may contact the canine root. **B,** The first premolar implant may need to be angled so it is parallel to the canine rather than the second premolar.

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it is logical that the implant support in a molar region should be greater than in the premolar position. Its mesiodistal dimension usually ranges from 8 to 12 mm, depending on the original tooth size and the amount of mesial drift of the second molar before implant placement. It should be noted that the ideal size of the implant should be measured by the intratooth distance from the adjacent CEJ of each tooth, not the interproximal distance at the marginal ridges. A tipped adjacent tooth should be recontoured to a more ideal condition, so food impaction does not occur under the interproximal contacts in the enlarged triangular interdental papilla space, which is formed after the implant crown is inserted.

When one 4-mm-diameter implant is placed to support a crown with a mesiodistal dimension of 12 mm, this may create a 4- to 5-mm cantilever on the marginal ridges of the implant crown (Figure 20-29). The magnified occlusal forces (especially important in parafunction) may cause bone loss (which may complicate home care), increase abutment screw loosening, and increase abutment or implant failure because of overload.[58,59] Sullivan[59] reported a 14% implant fracture rate for single molars fabricated on 4.0-mm implants composed of grade 1 titanium and concluded that this is not a viable treatment (Figure 20-30) Rangert et al.[60] reported that overload-induced bone resorption appeared to precede implant fracture in a significant number of 4.0-mm-diameter single-molar implant restorations.[60] Therefore, a larger-diameter implant should be inserted to enhance the mechanical properties of the implant system through increased surface area, stronger resistance to component fracture, increased abutment screw stability, and enhanced emergence profile for the crown[61–64] (Figure 20-31).

When the mesiodistal dimension of the missing tooth is 8 to 12 mm with a buccolingual width greater than 7 mm, a 5- to 6-mm-diameter implant body is suggested (Figure 20-32). Langer et al. also recommended the use of wide-diameter implants in bone of poor quality or for the immediate replacement of failed implants.[61] The larger diameter implant does not require as long an implant body to result in similar loading surface area, which is also a benefit because of the reduced posterior available vertical bone height because of anatomical

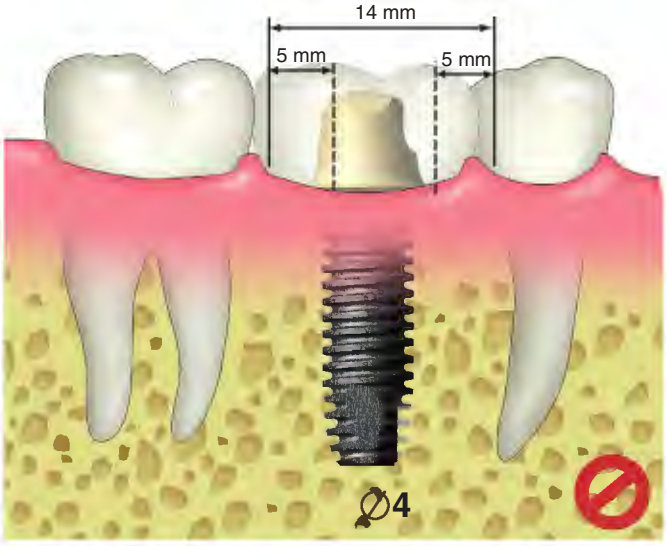


FIGURE 20-29. When a 4-mm-diameter implant replaces a molar, a mesial and distal cantilever is created on the crown.

limitations and landmarks present, such as the maxillary sinus or mandibular canal[65,61,66] (Figure 20-33).

When the mesiodistal dimension of the missing tooth site is 14 to 20 mm, two 4- to 5-mm diameter implants should be considered to restore the region (Figure 20-34). When two implants replace the molar region, the mesiodistal offset loads to the prosthesis can be eliminated because each implant may be placed 1.5 mm from the adjacent tooth. The total surface area of support is greater for the two implants compared with the surface area provided by one larger-diameter implant (two 4-mm-diameter implants >one 5- or 6-mm-diameter implant). In addition, the two regular-size implants provide more stress reduction than just one larger-diameter implant, which in turn reduces the incidence of abutment screw loosening.

In 1996, Bahat et al. reported on the results of various implant numbers and size selection.[65] The overall failure rate

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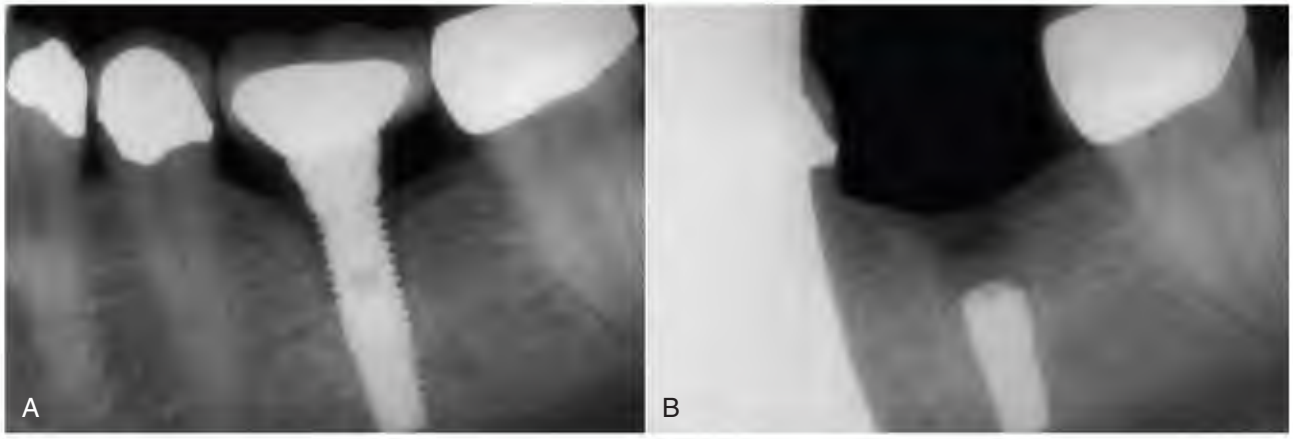


FIGURE 20-30. **A,** A 4-mm-diameter implant was used to replace a first molar. The mesial and distal cantilevers on the crown increased the biomechanical force. **B,** The implant body lost bone and then fractured.

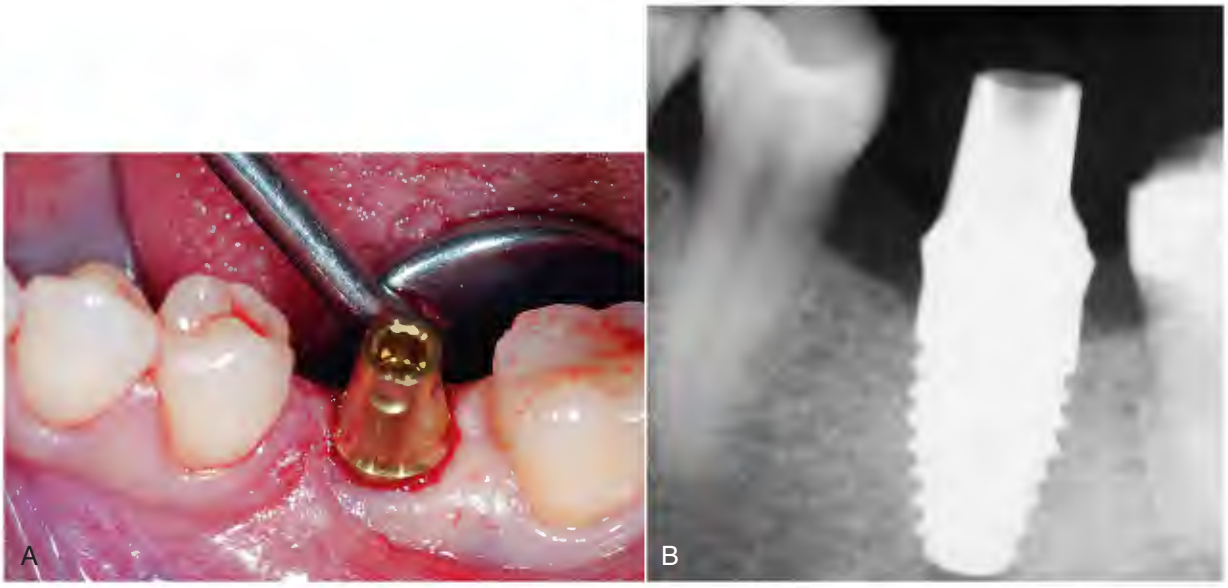


FIGURE 20-31. **A,** When a first molar is missing, a wider-diameter implant is usually indicated. **B,** The wider-diameter implant has less cantilevered forces on the crown and several biomechanical advantages.

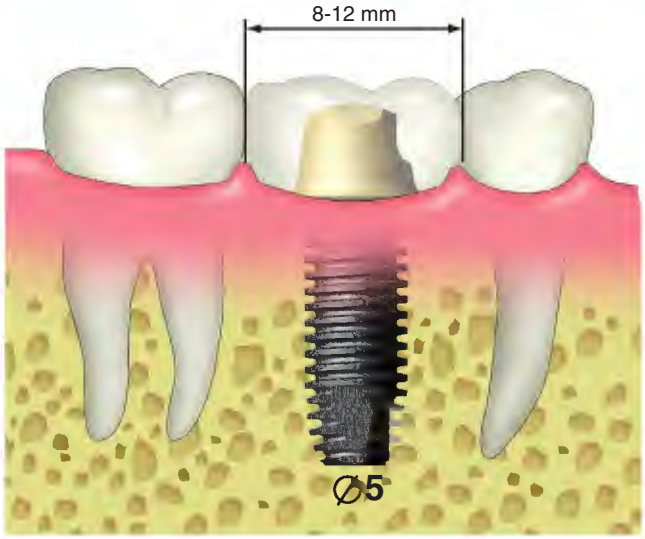


FIGURE 20-32. When the mesiodistal space in the posterior regions is 8 to 12 mm, a 5- to 6-mm-diameter implant is suggested.

was 1.2%, with the two 5-mm implants having 100% success. In the same year, Balshi et al. compared the use of one implant and two implants to replace a single molar.[67,68] The 3-year cumulative success rate was 99%. Prosthesis mobility and screw loosening were the most common complications for the one-implant group (48%); this complication rate was reduced to 8% in the two-implant group. In vitro studies compared screw loosening of one wide-diameter versus two standard-diameter implants and concluded that the one wide-diameter implant had greater screw loosening.[69] In a finite element analysis of three different implant-supported molar crown designs, Geramy and Morgano showed a 50% decrease in mesiodistal and buccolingual stress between a 5-mm and standard-diameter implants.[70] The double-implant design had the least stress of all. Therefore, whenever possible, two implants should be used to replace a larger single-molar space to reduce cantilever loads and abutment screw loosening (Figure 20-35).

When the posterior space is 14 to 20 mm, the largest implant diameter for the two implants may be calculated by subtracting 6 mm (1.5 mm from each tooth for soft tissue and surgical risk

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FIGURE 20-33. A 6-mm-diameter implant has more surface area than a 4-mm-diameter implant and may be used when the vertical bone height is limited by the mandibular canal.

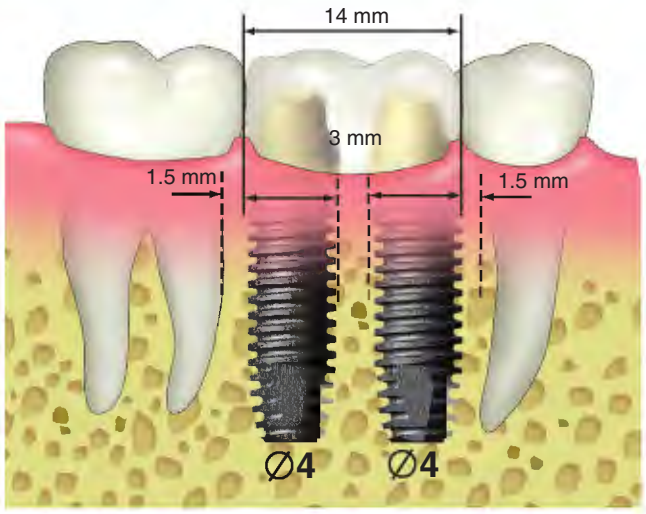


FIGURE 20-34. When the mesiodistal space is 14 to 20 mm, two implants should be used to support the crowns.



FIGURE 20-35. **A,** When the mesiodistal space is 14 to 20 mm, two implants should be used to support the missing teeth. **B,** The two implant crowns are often shaped as two premolar-size crowns.

and 3 mm between the implants) from the intratooth distance and dividing by 2 to determine the size of each implant (16 mm – 6 mm = 10 mm ÷ 2 = 5 mm implants). Remember, when two adjacent molars are missing, it is advantageous to place each implant 1.5 to 2 mm from the adjacent teeth (or under the mesial of the first molar and distal of the second molar crown) and splint the implants together rather than placing the implant in the center of each tooth. This eliminates the cantilever to the mesial and distal from the implants (Figure 20-36).

The desired diameter of the implant is the crest module dimension (not the implant body), which is often 0.2 to 0.35 mm greater than the implant body dimension (i.e., Bio-Horizons, Nobel Biocare, 3i, Lifecore) (Figure 20-37). Ideally, the two implants should be 3 mm apart because crestal bone loss around each implant may occur. The width of the crestal defect is usually less than 1.5 mm. Therefore, the two adjacent implants 3 mm or more apart will not convert an angular defect next to an implant to be a horizontal defect that may increase sulcus depths and cause a loss of papilla height.[71] Although this region is often out of the esthetic zone, the loss of papilla height increases food impaction.

When the mesiodistal space is 12 to 14 mm from adjacent CEJs, the treatment plan of choice is less obvious. A 5-mm-diameter implant may result in cantilevers up to 5 mm on each marginal ridge of the crown. However, two implants present a greater surgical, prosthetic, and hygiene risk. Unfortunately, the 12- to 14-mm space is not unusual. The primary goal is to obtain at least 14 mm of space instead of 12 to 14 mm (Figure 20-38). Additional space may be gained in several ways.

Orthodontics may be the treatment of choice to upright a tilted second molar or increase the intratooth space. One anterior implant may be placed and an orthodontic spring incorporated in the transitional crown; the spring pushes and uprights the distal tooth and moves it more distal. After orthodontic movement, the second implant may be inserted with less risk and improved hygiene between each implant. Another option is to use orthodontics to reduce the space and place only one implant and crown.

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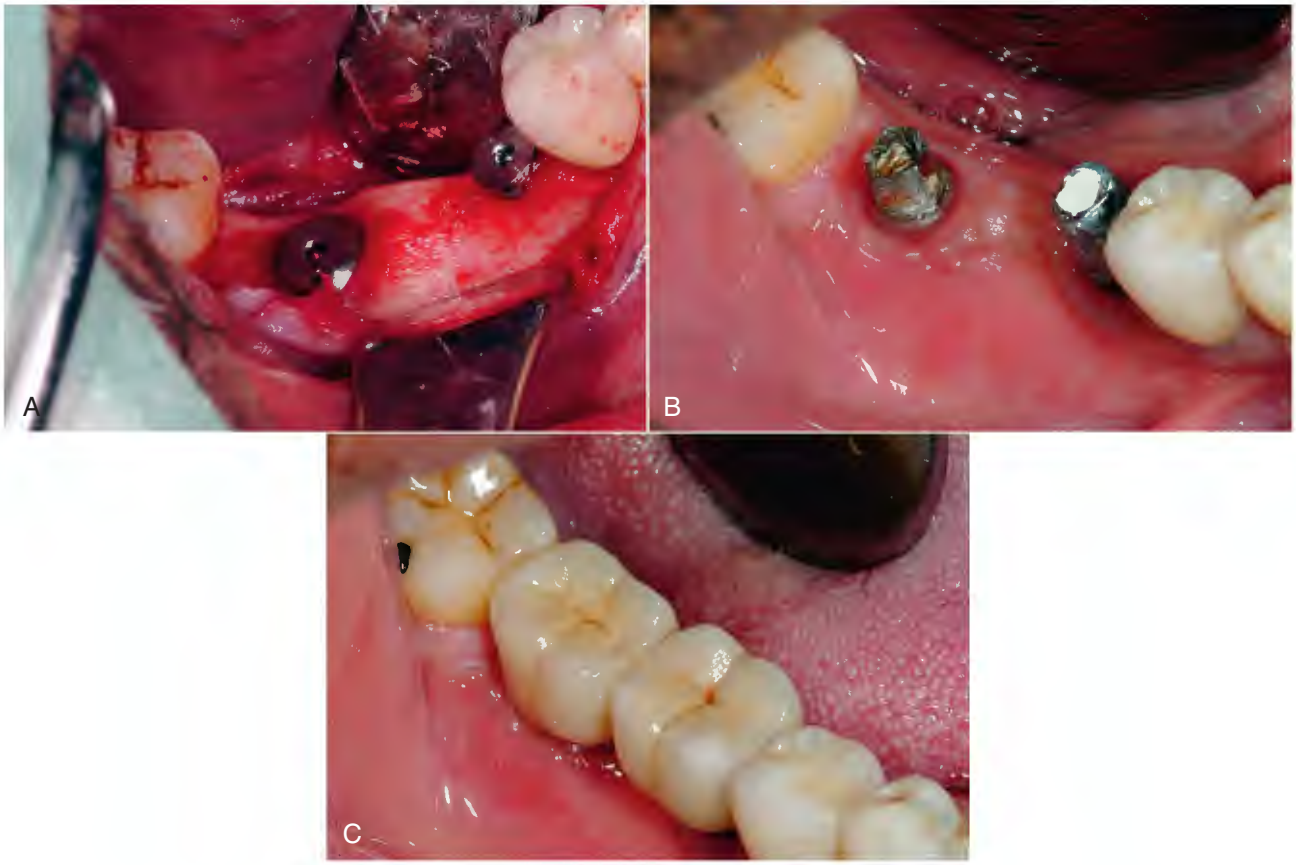


FIGURE 20-36. **A,** When the mesiodistal space is 14 to 20 mm, the two implants are positioned near the adjacent teeth rather than the center of the missing tooth. **B,** The two implants are always splinted together. **C,** The two crowns do not have mesial or distal cantilevers on the prosthesis.

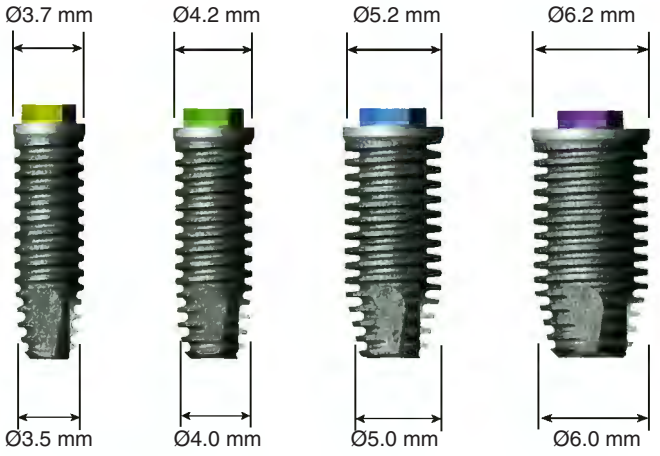


FIGURE 20-37. The crest module of an implant is often wider than the implant body dimension. (BioHorizons Dental Implants, External Hex, Birmingham, AL.)

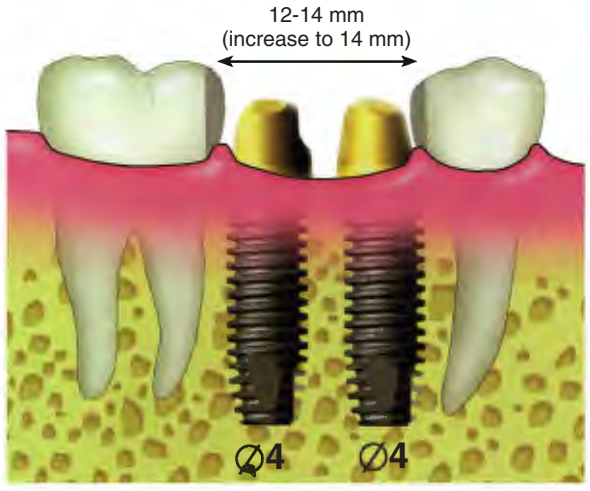


FIGURE 20-38. When the space between natural teeth is 12 to 14 mm, the choice of implant size and number is less obvious.

The implants may not be centered in the crestal width of bone. Instead, one implant is placed buccal and the other on a diagonal toward the lingual (Figure 20-39). The diagonal dimension increases the mesiodistal space by 0.5 to 1.0 mm. When implants are placed in such a way, consideration is given to oral hygiene and occlusion. In the mandible, the most anterior implant is placed to the lingual aspect of the midcrest, and the more distal implant is placed to the facial aspect to facilitate access of a floss threader from the vestibule into the intraimplant space. The occlusal contacts are also slightly modified on the buccal aspect of the mesial implant to occlude over the central fossa (Figure 20-40). In the maxilla, the anterior implant is placed to the buccal aspect and the distal implant to the palatal region to improve the esthetics of the more visible half

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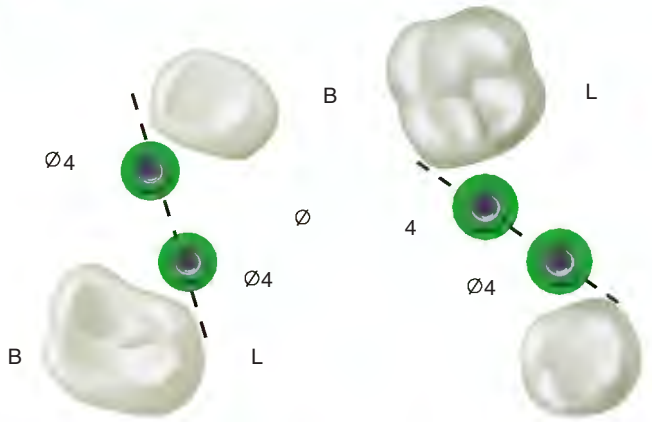


FIGURE 20-39. On the *left* (in the maxilla), the mesial implant is positioned more facial and the distal implant more palatal. On the *right* (mandible), the mesial implant is placed more lingual and the distal implant more buccal.

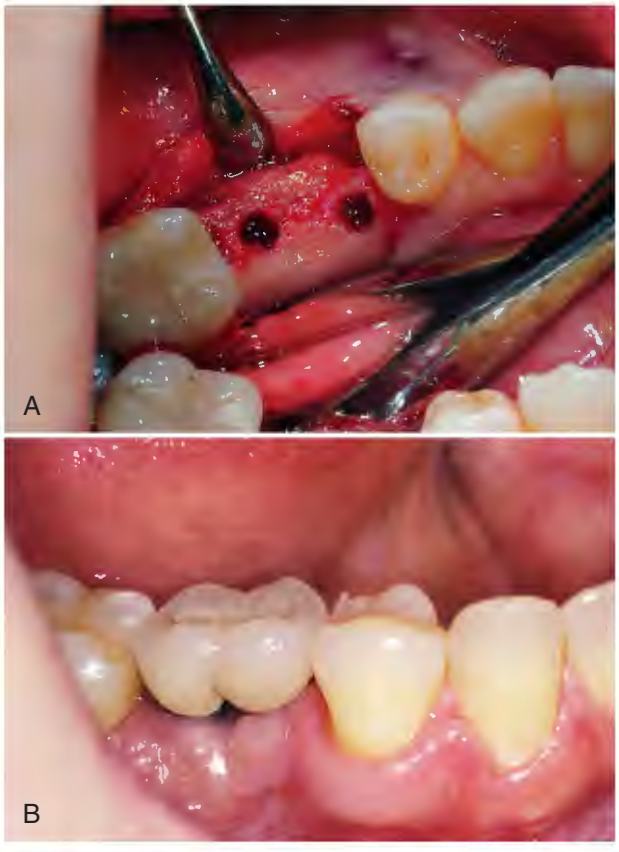


FIGURE 20-40. **A,** The mandibular molar mesiodistal space was 13 mm. The anterior implant is positioned more lingual and the distal implant more buccal (a mirror shot). **B,** The molar crown has a cervical region similar to two premolars to improve oral hygiene.

of the tooth. The distal occlusal contact is placed over the lingual cusp, and the mesial occlusal contact is located in the central fossa position. The cervical esthetics of the maxillary molar is compromised on the distal half of the tooth to the benefit of greater intratooth distance and easier access for home care. This maxillary implant placement requires the intraimplant furcation to be approached from the palate rather than the buccal approach as in the mandible (Table 20-1).

TABLE 20-1
Single-Molar Replacement Options

Mesiodistal	Implant Diameter
7–8 mm	4 mm
8–12 mm	5–6 mm
12–14 mm	Gain additional space; then place two 4-mm implants
14–20 mm	Two implants, one under mesial marginal ridge and one under distal marginal ridge and splint together

Summary

A missing single tooth is a common scenario in restorative dentistry. The options for single-tooth replacement usually are a FPD or a single-tooth implant. Rarely are FPDs the primary treatment option in the posterior regions of the mouth. Abutment teeth caries and endodontic procedures place these teeth at increased risk of loss. On occasion, the posterior tooth may not be replaced (e.g., a mandibular second molar or a small space in which the surrounding teeth are interdigitated to prevent extrusion or tipping).

The primary method to replace a single tooth should be a single-tooth implant of adequate size, design, and material. When the intratooth space is adequate and bone is present or can be created, the implant restoration is the treatment of choice. The single-tooth implant in the posterior regions of the mouth is the treatment of choice in the vast majority of patients.

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CHAPTER 21

Single-Tooth Implant Restoration: Maxillary Anterior and Posterior Regions

Carl E. Misch

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From 1990 to 2000, a 10-fold increase occurred in the number of implants placed by the profession, as well as an increase in the overall implant market.[1] Single-tooth implants are now one of the most common implant procedures performed around the world. In 2010, one of three teeth replaced in several countries was with an implant. In the nonesthetic posterior region, the single-tooth implant is one of the simplest procedures in implant surgery and prosthetics. However, it should be noted that the maxillary central incisor single-tooth replacement is often the most difficult procedure to perform in all of implant dentistry.

Maxillary Anterior Implant Crowns

Implants to replace a maxillary anterior single tooth have been used in the profession for many decades. For example, Strock reported on a replacement of a maxillary lateral incisor with a cylinder implant in 1942.[2] Forty years later, this implant was still in function (Figure 21-1). Before 1989, the most common maxillary anterior single-tooth implant used the existing bone volume. When the bone was not ideal in width, narrow-blade form or pin implants were used to support the crown (Figure 21-2). When root form implants became the primary implant type used by the profession, osteoplasty to increase bone width followed by implant placement was the treatment of choice (Figure 21-3). By 1995, bone augmentation procedures permitted implants in the esthetic zone to be less compromised related to esthetics. However, the soft tissue drape around the implant crown was often deficient and not addressed (Figure 21-4).

Since 2000, the exponential growth of the field of implant dentistry has been paralleled by an exciting growth of esthetic dentistry and soft tissue plastic regenerative surgery. The profession now realizes that the restoration of the periimplant soft and hard tissue to an optimal architecture is the key to a successful implant restoration. It is no longer sufficient to only achieve osseointegration with an implant. The anterior implant and restoration is completely successful only if the final restoration it supports is fully integrated within the adjacent dentition (Figure 21-5).

Contrary to missing posterior teeth, nearly all patients have an emotional response regarding a maxillary anterior missing tooth. No question exists regarding the need to replace the tooth, and financial considerations are less important. When posterior teeth are extracted, little resistance to the preparation of adjacent teeth may be given to the dentist. However, when anterior, normal-looking teeth must be prepared to serve as fixed partial denture (FPD) abutments, the patient is more anxious and often looks for an alternative. In the patient's perspective, anterior FPD restorations are never as esthetic as natural teeth. In part, this is because patients are able to distinguish between good and poor esthetic results. Because patients are only able to notice the restorations that are not natural in appearance, they think anterior FPDs are not esthetic. As a consequence, the anterior single-tooth implant is conceived as the logical and most favorable treatment option.

The highly esthetic zone of the premaxilla often requires both hard (bone and teeth) and soft tissue restoration before or in conjunction with the anterior single-tooth replacement with an implant. The soft tissue drape (interdental papillae and



FIGURE 21-1. Al Strock of Boston, Massachusetts, placed this implant on September 14, 1948, and this radiograph is from November 22, 1986 (38 years later). (Courtesy Al Strock.)

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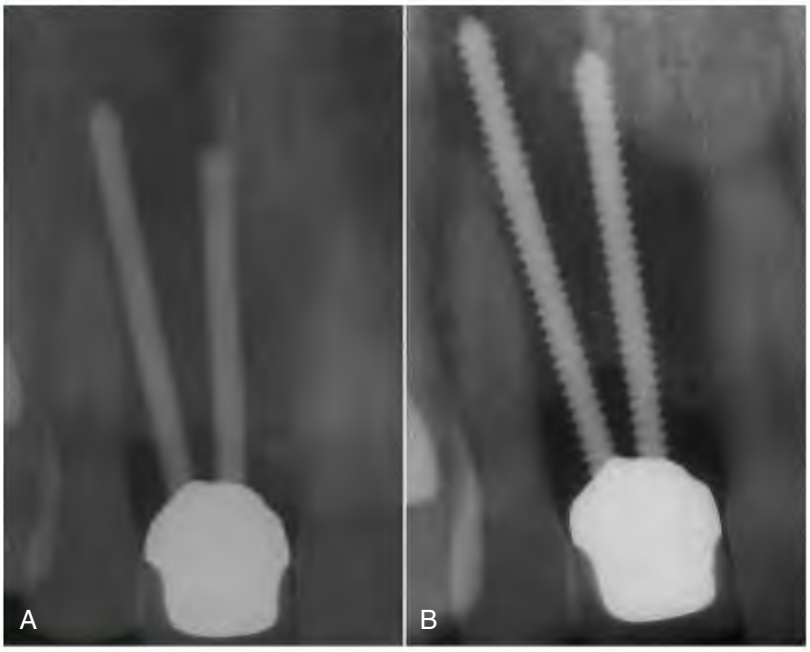


FIGURE 21-2. **A,** A periapical radiograph from 1979 of a single-tooth implant with pin implants. **B,** A radiograph 9 years later with crestal bone loss of the implants and adjacent teeth.

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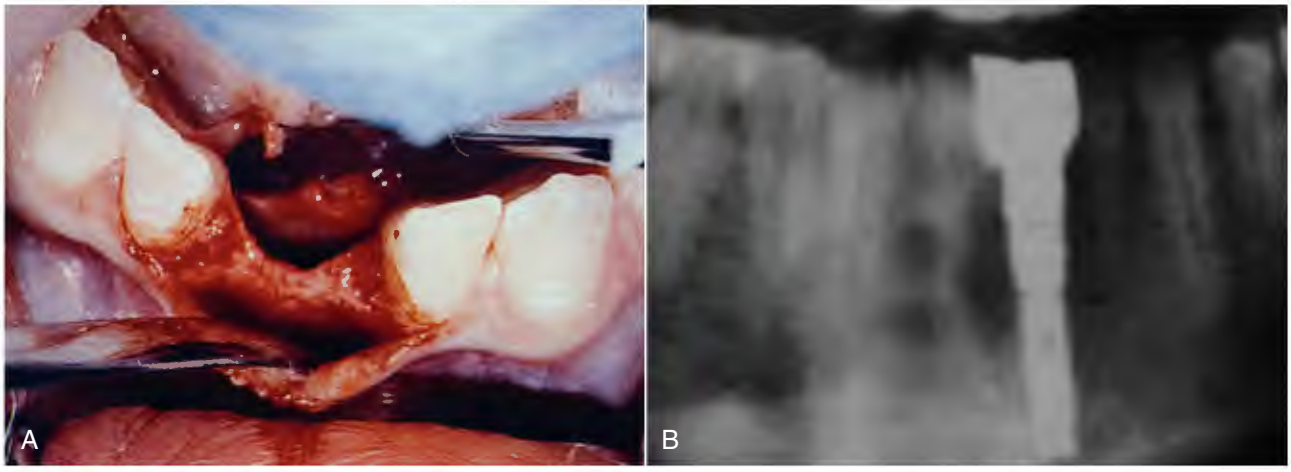


FIGURE 21-3. **A,** Missing mandibular central incisors with inadequate bone width. **B,** An osteoplasty to increase bone width followed by an implant inserted at the apex level of the adjacent teeth.



FIGURE 21-4. The patient's left central incisor is an implant and crown. The crown shade, hue, and contour are acceptable. However, the soft tissue drape is compromised, especially in the regions of the interdental papillae.

cervical emergence zone) is often the most difficult aspect of treatment. The shape of the implant crown below the tissue and its emergence profile is unique, not only compared with a crown on a tooth but also unique for each restoration. As a consequence, maxillary anterior single-tooth replacement is often a challenge regardless of the experience and skill of the laboratory technician and dentist.

Alternate Treatment Options for Anterior Single-Tooth Replacement

The alternatives to restore a single, maxillary anterior missing tooth include a traditional FPD; a cantilever FPD (for a missing lateral incisor); a removable partial denture (RPD); an acid-etched, resin-bonded prosthesis; or a single implant–supported restoration. Maxillary anterior single-tooth replacement is one of the most challenging restorations in dentistry. However, in light of all the advantages of single-implant longevity, bone maintenance, reduced abutment teeth complications, and increased survival of adjacent teeth, single-tooth implants have become the treatment of choice.

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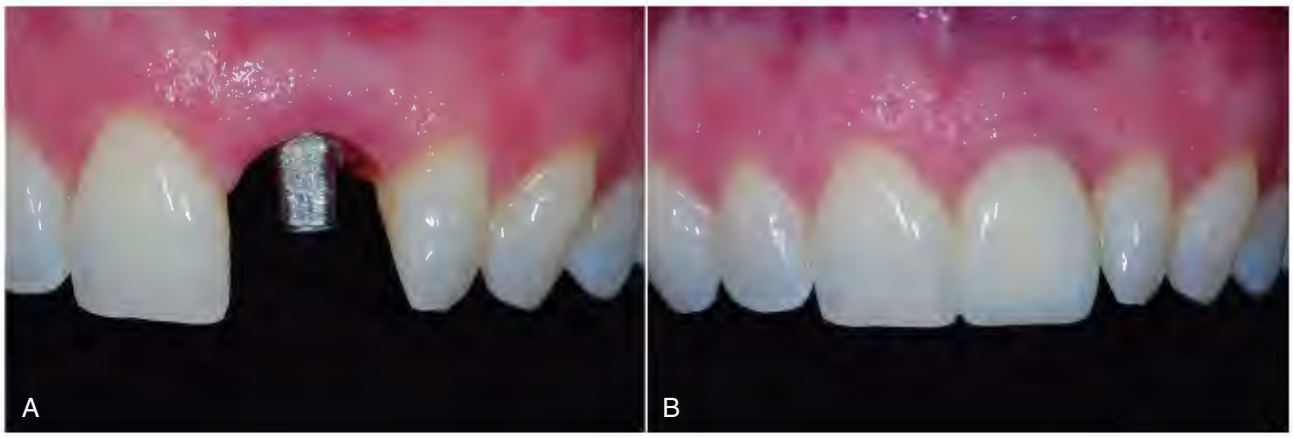


FIGURE 21-5. **A,** An implant inserted into the maxillary left central incisor region. **B,** The implant crown and soft tissue drape are integrated well within the adjacent dentition.

The single-tooth implant has the highest survival rate compared with any other treatment option to replace missing teeth (e.g., overdentures, short-span FPD, full-arch FPD, and single-tooth implant).[3] In 2005, Misch et al. reported on 276 anterior maxillary single implants used to restore missing teeth from agenesis.[4] In 255 adolescent patients, the implants were monitored for a range of 2 to 16 years, with a 98.6% implant and crown survival rate. In the same year, Wennstrom et al. reported on a 5-year prospective study with 45 single-tooth implants, with a 97.7% implant survival rate with minimal bone loss.[5] In 2006, Zarone et al. reported on lateral maxillary agenesis replacement with 34 implants with a 97% survival rate at 39 months.[6] A review of the literature by Goodacre et al. found single-tooth implant studies had the highest survival rate of any prosthesis type, averaging 97%.[3]

More recently, a trend toward single-stage implants has emerged, appearing especially attractive in the maxillary anterior region when preferably the soft tissue drape is ideal. Kemppainen et al., in a prospective study of 102 single-tooth implants in the anterior maxilla, reported a 99% survival rate using either one- or two-stage implants.[7] Several studies have also recommended immediate implant insertion and immediate restoration after extraction of an anterior single tooth with success in specific situations.[8–10]

Challenging Esthetics

The esthetics of a maxillary anterior single crown on a natural tooth is often one of the most difficult challenges in restorative dentistry. It is even more difficult on an implant abutment. The implant is often 5 mm or less in diameter and round in cross-section. A natural maxillary anterior crown cervix region is 4.5 to 7 mm in mesiodistal cross-section and is never completely round (Figure 21-6). In fact, the natural central incisor and canine teeth are often larger in their faciopalatal dimension at the cementoenamel junction (CEJ) than in the mesiodistal dimension.[11,12]

The bone is lost first in the faciopalatal width, so the greater width of implants in this dimension to copy a tooth root would require even more augmentation than presently advocated. As a result, a smaller-diameter, round implant is suggested, and the cervical esthetics of a single implant crown must accommodate a round-diameter implant and balance hygiene and esthetic parameters. Additional prosthetic steps and components with varied emergence profiles or customized tooth colored abutments are often required to render the illusion of a crown on a natural abutment.

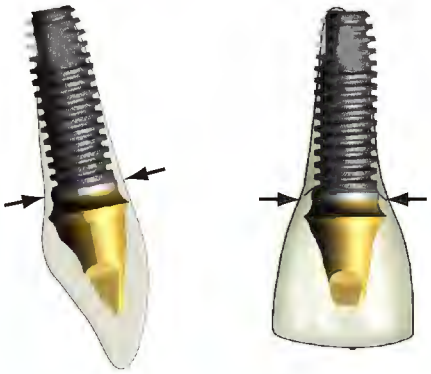


FIGURE 21-6. The maxillary anterior implant is round and smaller in diameter than the root of the tooth it replaces.

The mesiodistal space requirements, the bone height and its relationship to the soft tissue drape, the faciopalatal width, the soft tissue drape, and the remaining maxillary anterior teeth relative to size and position are all presented. In addition, the tissue biotype, the implant crest module design, the ideal implant size, and the transitional restoration during healing are discussed in detail.

The primary purpose of this portion of the chapter is to address the restoration of the maxillary anterior single-tooth implant. A key for ideal anterior esthetic implant restorations is the soft tissue drape. There are six different times the implant dentist may address the complexities of the soft tissue. These include before a bone augmentation in the edentulous site, during a bone graft of the implant site, during the implant insertion surgery, during the implant uncover procedure, during the prosthetic phase of treatment, and during long-term follow-up and care (Box 21-1). The emphasis in this chapter is on the methods during prosthetic reconstruction, although other important surgical elements are also presented.

To ideally restore an esthetic maxillary anterior tooth, the implant should be positioned in three dimensions within the prosthetic contour requirements of the final restoration. Hence, the ideal implant body position is first identified. This is followed by the prosthetic aspects of developing the soft tissue contour after integration. The prosthetic aspects specific to this

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type of restoration are then presented. Treatment options and complications are also discussed.

Implant Body Position

Mesiodistal Position

The maxillary anterior single-tooth implant should be located precisely in three planes. From a mesiodistal aspect, the implant most often is placed in the middle of the space, with an equal amount of interproximal bone toward each adjacent tooth. The goal is to remain 1.5 mm or more from the adjacent CEJ of each tooth. The defect width around an implant with bone loss is usually less than 1.5 mm wide. Hence, if bone loss around the implant occurs, the defect will remain a vertical defect and not cause bone loss on the adjacent natural tooth. The bone on the adjacent tooth will maintain the interdental papilla height.

The incisive foramen is variable in size and position. When a central incisor implant is planned and the foramen between the existing central incisor root and implant site is larger than usual, the remaining bone in this dimension may be inadequate. The foramen may also expand off to one side of the midline within the bony canal. When the central incisor implant is placed in a patient with these foramen variances, the implant may encroach on the canal and result in a lack of bone on the mesiopalatal surface of the implant.

As a precaution, the surgeon should reflect the palatal tissue when placing a maxillary central incisor implant; probe the foramen; and if necessary, place the implant in a more distal position. This may also require a smaller-diameter implant than usual to remain 1.5 mm from the CEJ of the lateral incisor. On these occasions, the central incisor implant is positioned slightly to the distal of the intratooth space (Figure 21-7). On occasion, the contents of the foramen must be removed and a bone graft inserted to decrease the size of the incisive canal (Figure 21-8).

BOX 21-1 Treatment Times to Address the Soft Tissue Drape

1. Before a bone graft
2. During a bone graft
3. During implant insertion
4. During implant uncovery
5. Prosthetic methods
   a. Lower the interproximal contact
   b. Modify the subgingival contour
6. Long-term follow-up

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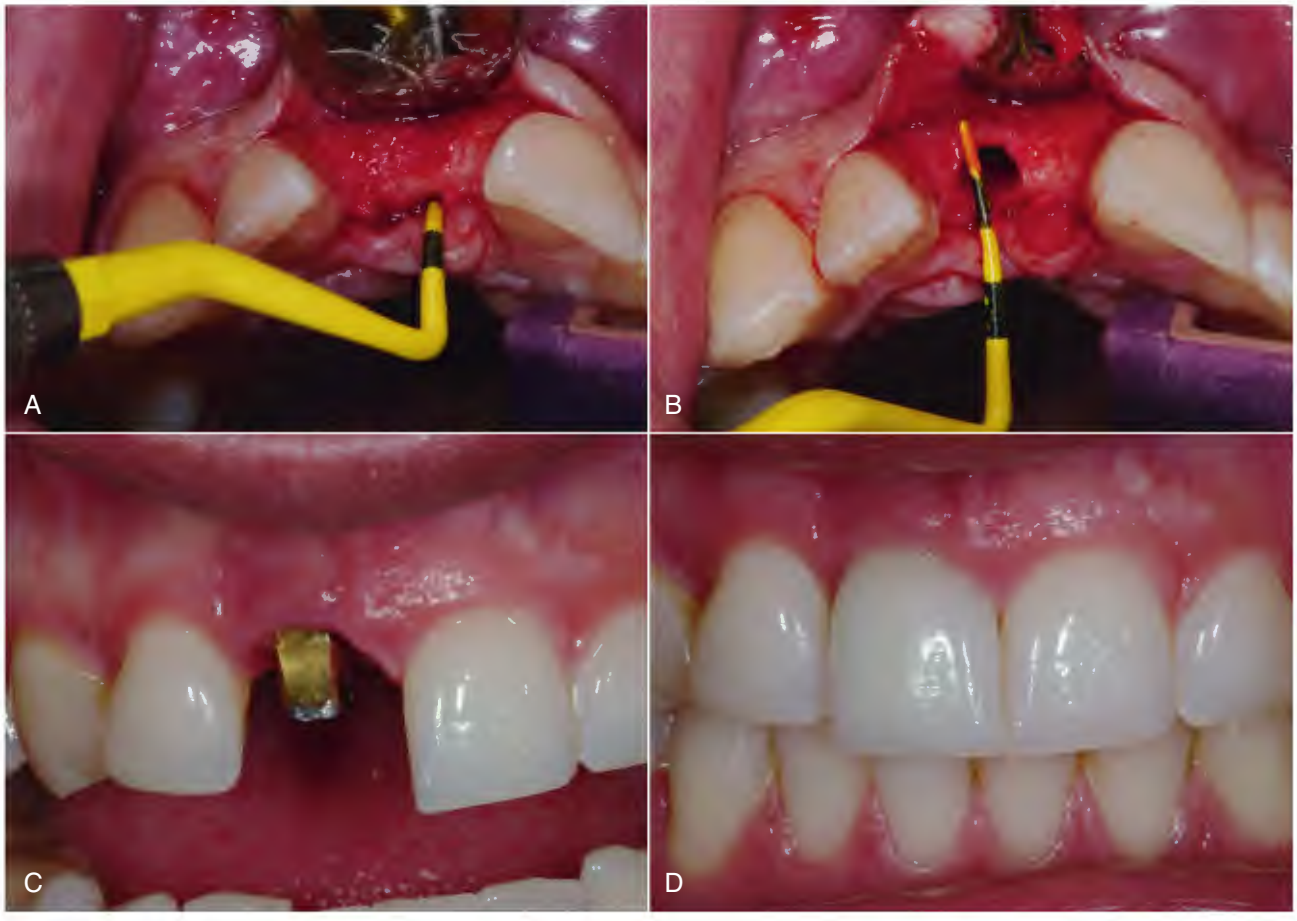


FIGURE 21-7. **A,** The incisive foramen is probed on the palate and invades the region of the patient's right central incisor. **B,** The implant osteotomy is more distal and smaller in diameter than usual. **C,** The integrated implant after healing. **D,** The final crown emergence profile is modified for the smaller-diameter implant.

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Faciopalatal Position

The faciopalatal position of the implant in adequate bone width is in the middle to slightly palatal of the edentulous ridge. This approach permits the use of the greatest-diameter implant. The crestal bone ideally should be at least 1.5 mm wide on the facial aspect of the implant and 0.5 mm or more on the palatal aspect. In this scenario, if bone loss occurs on the implant, the facial plate will remain intact and not cause recession on the facial of the implant crown. Therefore, for a 4-mm-diameter implant, a minimum 6-mm faciopalatal width of bone is required for the central or canine position, and 5.5 mm of bone width is required for a lateral incisor with a 3.5-mm implant. Bone spreading in conjunction with implant placement or bone grafting on the facial aspect of the edentulous site may be used when the ridge is less wide than is desirable.

The thickness of bone on the facial aspect of a natural root is usually 0.5 mm thick. The implant is 1 mm more palatal than the facial emergence of the adjacent crowns at the crest of the bone. The final restoration will compensate for the emergence from the free gingival margin (FGM) to be similar as the adjacent teeth.

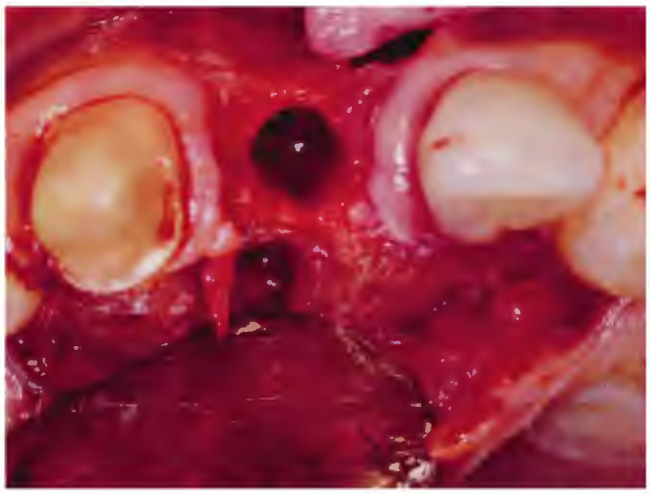


FIGURE 21-8. The incisive foramen is off-center and large, the contents are removed, and a bone graft inserted in order to insert the central incisor implant.

Implant Body Angulation

The implant center at the crest has been addressed relative to the faciopalatal and the mesiodistal positions of the edentulous ridge. The implant body angulation from this point is considered next. In the literature, three faciopalatal angulations of the implant body are suggested: (1) similar to the facial position of the adjacent natural teeth, (2) under the incisal edge of the final restoration, and (3) within the cingulum position of the implant crown (Figure 21-9).

Facial Implant Body Angulation

In theory, a maxillary anterior implant body angulation should be positioned at the facial emergence of the final crown, and this position should be in the same position as a natural tooth. At first, this makes some sense. However, the facial crown contour of a natural tooth has two planes, and its incisal edge is palatal to the facial emergence of the natural tooth by 12 to 15 degrees (Figure 21-10). This is why anterior crown preparations are in two or three planes (Figure 21-11). In addition, because the implant is narrower in diameter than the faciopalatal root dimension, when the implant body is oriented as a natural tooth and has a facial emergence, a straight abutment is not wide enough to permit the two- or three-plane reduction to bring the incisal edge of the preparation more palatal. As a result, the incisal edge of the preparation remains too facial. Therefore, when the implant is angled to the facial emergence of a tooth, an angled abutment of 15 degrees must be used to position the incisal edge more palatal (Figure 21-12).

Most two-piece angled abutments have a design flaw that compromises facial cervical esthetics. The access hole to the abutment screw is toward the facial of the abutment. The metal flange facial to the abutment screw is thinner than a straight abutment and may result in fracture (especially because angled loads are placed on the facial-positioned implant). The implant manufacturers increase the profile of the abutment on the facial aspect to reduce the risk of fracture. However, this design flaw brings the cervical facial margin more facial and wider than the implant body, which is already as facial as the adjacent tooth (Figures 21-13 and 21-14). As a result, the implant crown margin is facially overcontoured. The restoring doctor then has to prepare the facial aspect of the abutment metal flange for esthetics and on occasion eliminate the metal on the facial of the abutment screw hole, and the angled abutment must be replaced. Even when the facial aspect of the angled abutment is

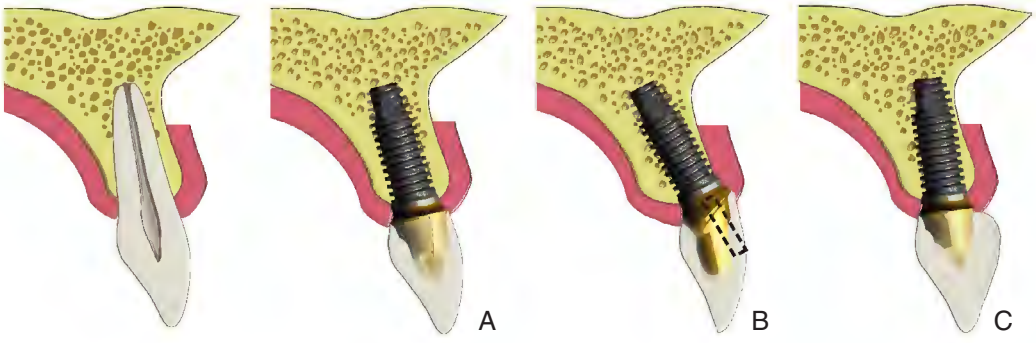


FIGURE 21-9. Three implant angulation positions are suggested in the literature for a maxillary anterior single-tooth implant: under the incisal edge (**A**), similar to the facial position of the adjacent teeth (**B**), and under the cingulum position of the implant crown (**C**).

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FIGURE 21-10. The maxillary anterior teeth have an incisal edge 12 to 15 degrees more palatal than the facial emergence position of the crown.

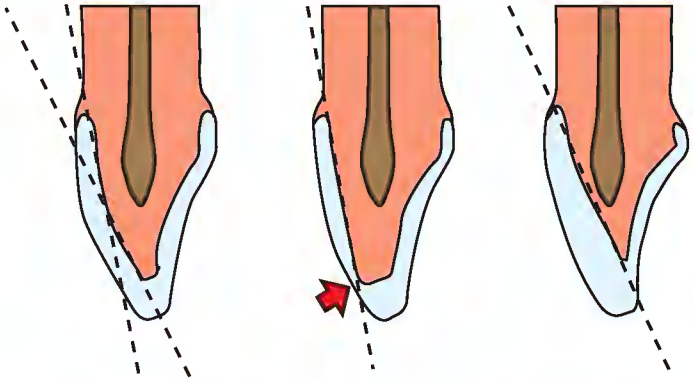


FIGURE 21-11. Maxillary anterior crown preparations are made in two or more planes (**A**). When the plane of the emergence profile is only used (**B**), the incisal edge of the preparation is too facial.



FIGURE 21-12. The implant is positioned similar to the adjacent teeth. An angled abutment must be used to bring the incisal edge of the preparation more palatal to restore the tooth.

reduced without a compromise in integrity, the reduced contour weakens the abutment and makes it more prone to fracture (Figure 21-15). Because the doctor modified the abutment, the implant company is held harmless, but nonetheless, the patient and doctor are at an increased risk.

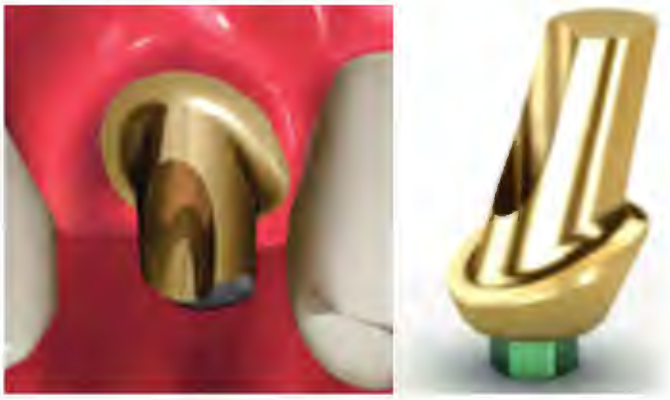


FIGURE 21-13. An angled abutment has an access hole for the fixation screw, which exits the facial of the abutment. As a result, less metal is on the facial. The manufacturer usually increases the metal thickness to improve the strength *(left)*. As a result of the facial flare of metal on an angled abutment, the abutment is more facial than the implant body *(right)*.



FIGURE 21-14. The angled abutment is usually wider on the facial than the implant to increase the metal thickness on the facial of the abutment.

The implant body should be more palatal than a natural root, so 1.5 mm of bone exists on the facial. Remember that there is only 0.5 mm of bone on the facial of the natural tooth roots. When the surgeon attempts to align the implant body with the facial aspect of adjacent teeth, the implant may inadvertently be inserted too facial. No predictable method exists to restore proper esthetics when the implant abutment is located facial and above the FGM of the adjacent teeth. At best, the final crown appears too long. This problem is compounded when the implant is also inserted too shallow. Soft tissue grafts and bone augmentation rarely improve the condition after the implant is already inserted in this position (Figure 21-16).

The natural maxillary anterior teeth are loaded at a 12- to 15-degree angle because of their natural angulation in comparison with the mandibular anterior teeth. This is one reason the

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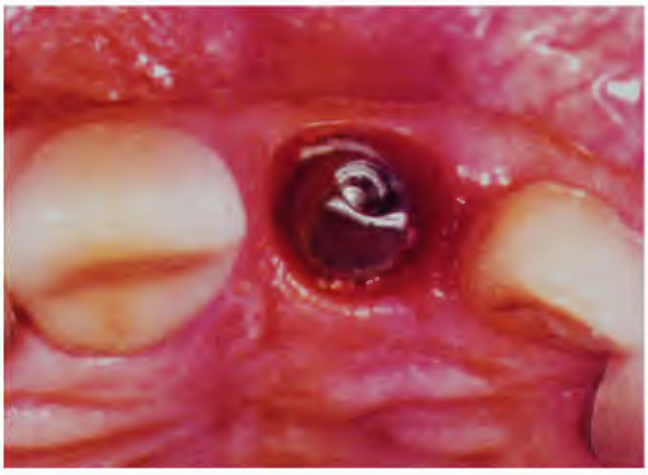


FIGURE 21-15. An angled abutment is used to restore the implant because the implant body is positioned similar to the adjacent teeth. The abutment is reduced on the facial of the abutment screw to make room for the restorative material of the crown.

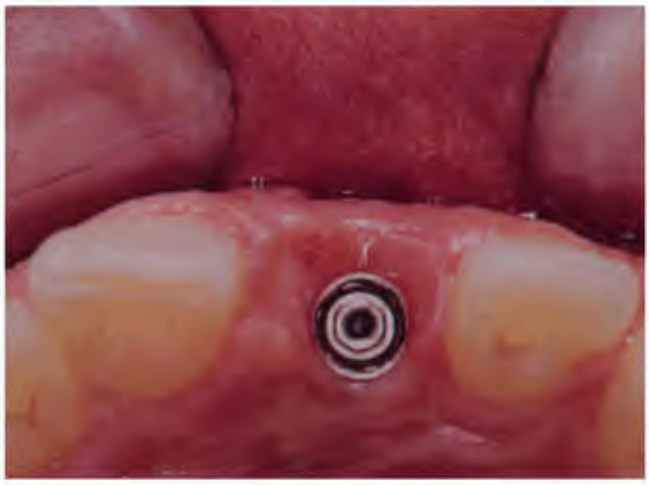


FIGURE 21-18. The implant is inserted under the cingulum position of the final crown. This is a position suggested when the bone is width deficient, a prosthetic screw is desired to retain the crown, or more bone is desired on the facial of the implant.



FIGURE 21-16. An implant positioned too facial and too shallow. The angled abutment must be prepared to make room for restorative materials and to allow a more apical position of the crown margin.



FIGURE 21-17. An implant placed too facial and the thin tissue receded after crestal bone loss.

maxillary anterior teeth are wider in diameter than mandibular anterior teeth (which are loaded in their long axis). The facial angulation position of the implant body often corresponds to an implant body angulation, with 15 degrees off-axial loads. This angled load increases the force to the abutment screw–implant–bone complex by 25.9% compared with a long-axis load.[13] These offset loads increase the risks of abutment screw loosening, crestal bone loss, and cervical soft tissue marginal shrinkage.[14] As a result, implants angled facially may compromise the esthetics and increase the risk of complications (Figure 21-17).

Cingulum Implant Body Angulation

A second angulation suggested in the literature is more palatal, with an emergence under the cingulum of the crown. This may also be the result of an implant insertion in a width-deficient ridge (division B) because the bone is lost primarily from the facial. This position is also often the goal when a screw-retained crown is used in the final restoration. The prosthesis fixation screw (to retain a maxillary anterior crown) cannot be located in the incisal or facial region of the crown for obvious reasons. This position also is suggested to increase the bone thickness on the facial of the implant body (Figure 21-18).

The cingulum implant position may cause a considerable hygiene compromise.[15] The implant body in the anterior maxilla is round and usually 3.5 to 5.5 mm in diameter. The labial cervical contour of the implant crown must be similar to the adjacent teeth for the ultimate esthetic effect. Because the long axis of the implant for a screw-retained crown must emerge from the cingulum position, this requires a facial projection of the crown or "buccal correction" facing away from the implant body. The facial ridge lap must extend 2 to 4 mm and is often similar in contour to the modified ridge lap pontic of a three-unit fixed prosthesis (Figure 21-19). The term *modified ridge lap crown* is appropriate.

The modified ridge lap crown has become a common solution to correct the esthetics of the restoration when the implant is placed in narrow bone or follows a palatal angulation position.[16,17] However, plaque control on the facial of the implant is almost impossible. Unlike a pontic for a FPD, the ridge lap crown has a gingival sulcus that requires sulcular hygiene. Even if the toothbrush (or probe) could reach under the facial ridge lap to the gingival sulcus, no hygiene or measuring device could be manipulated to a right angle to proceed into the facial gingival sulcus. As a result, although an acceptable esthetic restoration may be developed, especially with the additional cervical

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FIGURE 21-19. A screw-retained implant crown with the implant positioned under the cingulum *(left)*. The crown has a facial ridge lap of several millimeters of porcelain so the emergence profile will be similar to the adjacent teeth *(right)*.

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FIGURE 21-20. An implant crown with a "modified ridge lap." The tissue periodically becomes inflamed because hygiene aids (or a dental probe) cannot enter the sulcus of the implant but can only slide along the facial ridge lap to the free gingival margin.

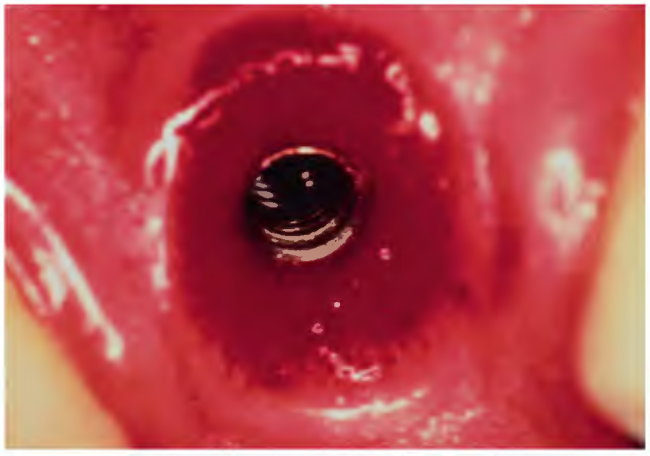


FIGURE 21-21. An implant with a "subgingival ridge lap crown" and an inflamed gingival sulcus.

porcelain, the hygiene requirements render this approach less acceptable (Figure 21-20).

Some authors argue that an improved contour may be developed subgingivally rather than supragingivally with a palatal implant position. To create this contour, the implant body must be positioned more apical than desired. This position may prevent food from accumulating on the cervical "table" of the crown. However, the "subgingival ridge lap" does not permit access to the facial sulcus of the implant body for the elimination of plaque, as well as to evaluate the bleeding index or facial bone loss (Figure 21-21). Therefore, the maintenance requirement for the implant facial sulcular region suggests this modality is not a primary option.

Greater interarch clearance is often needed with an implant palatal position because the permucosal post exits the tissue in a more palatal position. Inadequate interarch space may especially hinder the restoration of Angle's class II, division 2 patients with the implant in this position.

The bony ridge should be augmented if too narrow for the ideal implant diameter and position, or an alternate treatment option should be selected. Most often, the anterior single-tooth implant should use a cement-retained crown, so the cingulum implant angulation is not necessary. However, after the implant is integrated and in this position, the best treatment option is usually to restore the implant with a "ridge lap crown" rather than remove the implant, do a bone graft (and maybe soft tissue graft), and replace the implant.

Ideal Implant Angulation

The third implant angulation in the literature describes the most desirable implant angulation. A straight line is determined by connecting two points. The clinician determines the line for the best angulation by the point of the incisal edge position of the implant crown and the midfaciopalatal position on the crest of the bone. The center of the implant is located directly under the incisal edge of the crown so that a straight abutment for

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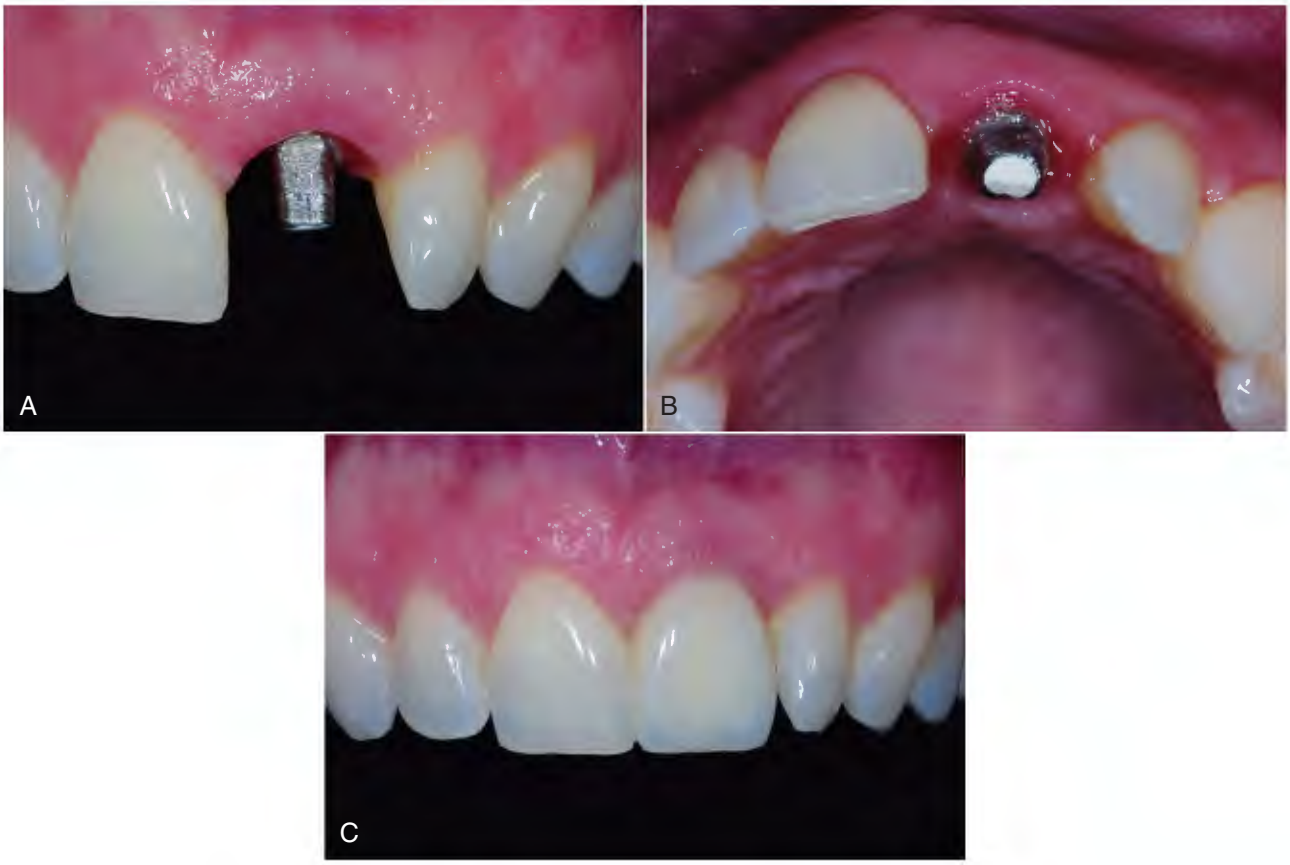


FIGURE 21-22. **A,** The implant is positioned in the middle of the missing tooth site, 1.5 mm or more from the adjacent teeth. **B,** The implant is positioned under the incisal edge of the future implant crown. **C,** The final crown emergence profile on the facial is similar to the adjacent teeth.

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cement retention emerges directly below the incisal edge[15] (Figure 21-22). Because the crown profile is in two planes, with the incisal edge more palatal than the cervical portion, the incisal edge position is ideal for implant placement and accommodates some of the facial bone loss that often occurs before implant placement.

The facial emergence of the crown mimics the adjacent teeth, proceeding from the implant body under the tissue (Figure 21-23). The angle of force to the implant is less from the long axis, which decreases the crestal stresses to the bone and abutment screws. When in doubt, the implant surgeon should err toward the palatal aspect of the incisal edge position, not to the facial aspect, because it is easier to correct a slight palatal position in the final crown contour compared with the implant body angled too facial.

The implant abutment selected for a maxillary anterior single-tooth implant is usually for a cemented restoration. A greater range of corrective prosthetic options exists with a cement-retained crown for implants not well positioned. Single anterior crowns do not require readily retrievable restorations. The abutment almost always should be greater than 5 mm in height. The location of the cervical margin of a cemented crown can be anywhere on the abutment post or even on the body of the implant, provided it is 1 mm or more above the bone and less than 1.5 mm below the FGM.

The implant body angulation under the incisal edge may also be used for screw-retained restorations. In these cases, an angled abutment for screw retention is inserted, and the coping screw for the crown may be located within the cingulum. This method does not require a facial ridge lap of the final crown, which decreases the risk of compromised hygiene. However, it should be noted that prosthetic screw loosening is one of the more common complications of maxillary anterior screw-retained crowns.[3] When this occurs, there is an increased risk of



FIGURE 21-23. The implant crown on the *left* is positioned under the incisal edge and has a facial emergence profile similar to the adjacent teeth. The implant on the *right* was positioned under the cingulum and requires a screw-retained crown with a facial ridge lap to have a similar facial crown emergence as the adjacent teeth.

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FIGURE 21-24. A surgical template for a maxillary anterior single tooth, with a guide hole under the incisal edge of the implant crown.

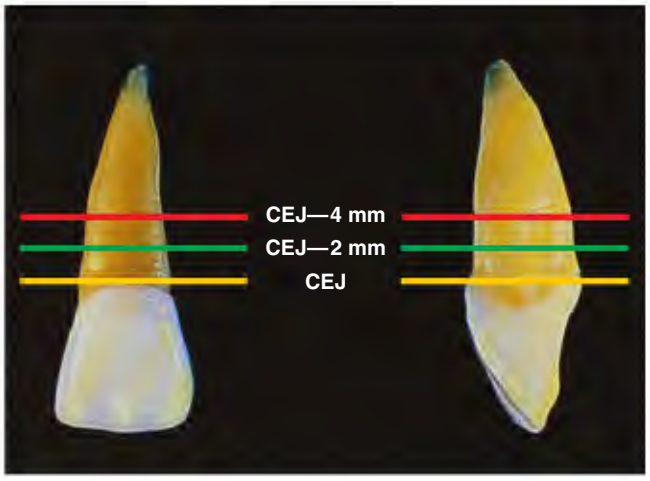


FIGURE 21-25. A central incisor root is 4 mm in diameter when it is measured 4 mm below the cementoenamel junction (CEJ).[16]

marginal bone loss as a result of the crown movement and microgap created by the loose screw.

When ideal bone volume is present, a surgical template that indicates the incisal edge and facial contour of the final prosthesis may be used. The incisal edge of the template may be notched for the drills because the best placement of the drill is directly through the incisal edge (Figure 21-24). However, most often the surgeon does not require a template because the adjacent teeth provide a guide for a single-tooth implant. In addition, the integrity of the facial cortical plate is more readily assessed during the surgery when a template is not used.

Implant Depth Position

More Than 4 mm from the Adjacent Cementoenamel Junction (Too Deep)

Some authors have suggested that the implant be countersunk below the crestal bone more than 4 mm below the facial CEJ of the adjacent teeth to develop a crown emergence profile similar to a natural tooth.[16,17] This provides a subgingival emergence transition of about 5 mm on the facial aspect to achieve the width of the natural tooth (4 mm below the CEJ, and the ideal FGM on the facial is 1 mm above the CEJ). This concept was originally developed for a 4-mm-diameter implant, and the diameter of a central incisor root is 4 mm at a position 4 mm below the CEJ[16] (Figure 21-25). Very esthetic restorations may be fabricated with this implant depth position because the bulk of subgingival porcelain provides good color and contour for the crown (Figure 21-26, *A*). However, several concerns arise regarding the long-term sulcular health around the implant when it is seated 4 mm or more below the CEJ (Figure 21-26, *B*).

The first year of function often corresponds to a mean bone loss range of 0.5 to 3.0 mm, depending partly on implant design. The bone is lost at least 0.5 mm below the connection of the abutment to the implant body and extends to any smooth or machined surface beyond the crest module.[18] For example, Malevez et al. noted more pronounced bone loss for conical implants that had a long, smooth, tapered crest modules.[19] This may lead to facial sulcular probing depths of 7 to 8 mm or greater. Grunder evaluated single-tooth implants in function for 1 year and noted the bone levels were 2 mm apical to the implant–abutment connection, and sulcular probing depths were 9.0 to 10.5 mm using a Brånemark implant design.[20] As a result, daily care devices cannot maintain the sulcus health, and anaerobic bacteria are more likely to develop. The interproximal regions of the implant crown, which correspond to the incidence or absence of interdental papillae, usually exhibit even greater probing depths (Figure 21-26, *C*). As a result, gingival shrinkage of the tissue is more likely to occur when the implant is placed more than 4 mm below the facial position of the adjacent CEJ.

The attachment mechanism of the soft tissue above the bone is less tenacious compared with a tooth, and the defense mechanism of the periimplant tissues may be weaker than that of teeth.[21] The clinician, to err on the side of safety for the best sulcular health conditions, should limit sulcular depths adjacent to implants to less than 5 mm.[22] This may be even more relevant for single-tooth implants because of the devastating consequences of gingival shrinkage for long-term esthetics. In addition, the interproximal regions of the single-tooth implant crown are shared with the adjacent teeth, and anaerobic bacteria that form in the region next to the implant may affect the adjacent natural tooth as a result of a horizontal defect (especially when the implant is closer than 1.5 mm to the tooth).

When the implant is countersunk below the crestal cortical bone (as with this depth technique), the trabecular bone around the crest module is weaker against occlusal loads. In addition, when the implant is placed below the crestal bone, the resultant initial crown height is increased, as are moment forces. An increased risk of additional bone loss also is present from the increased moment loads applied to weaker trabecular bone, which may also result in soft tissue shrinkage over the long term. The end result is longer clinical crowns, which also decrease gradually in width (as the narrowing dimensions approach the implant body). The interproximal region may result in black triangular spacings in lieu of interdental papillae. The increased crown height also increases forces to the abutment screw and increases the risk of screw loosening.

Less Than 2 mm Below the Free Gingival Margin (Too Shallow)

When the implant body is positioned less than 2 mm below the facial FGM of the crown, the cervical esthetics of the restoration are at an increased risk because limited space is present subgingivally to develop the facial emergence profile of the

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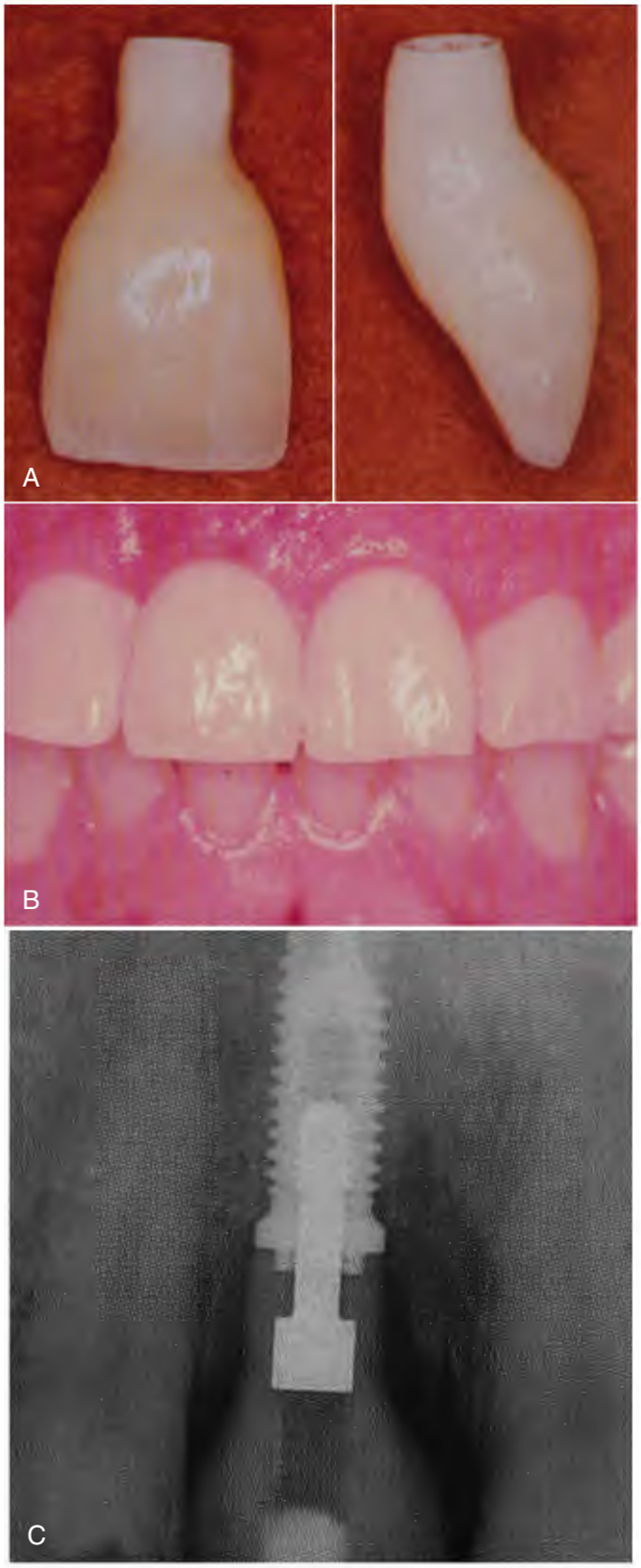


FIGURE 21-26. **A,** A maxillary central incisor implant crown that restores an implant inserted 4 mm below the cementoenamel junction. **B,** The maxillary central incisor seated within the mouth. **C,** A periapical radiograph of the previous patient. The sulcular probing depth is more than 6 mm.

crown. The porcelain of the crown may not be subgingival enough to mask the titanium color of the abutment or implant below the crown margin (Figure 21-27, *A*). If bone loss occurs, the titanium implant abutment or body may also cast a dark shadow to the gingival tissues. If apical shrinkage of tissue occurs, then the dark titanium abutment and implant body may become directly visible. Periodontal surgical procedures to position soft tissue over the exposed titanium are unpredictable.

On occasion, the crestal bone height is coronal to the ideal bone height (3 mm below the facial FGM). The two most common conditions that result in this finding are (1) when the adjacent teeth are closer than 6 mm (in agenesis of a lateral incisor) and (2) when a block bone graft regenerated excess width and height of bone. Ideally, the midcrestal bone is 3 mm below the interproximal bone and follows the interproximal scallop of the CEJ of the missing tooth. When the teeth are closer than 6 mm (i.e., a lateral incisor in the maxilla), the interproximal bone height of each adjacent tooth to the missing space is able to stimulate and maintain bone at the interproximal bone level. The same conditions may occur when bone augmentation gains height to the interproximal height of bone. When a single-tooth implant replaces a missing tooth with these conditions, an osteoplasty should be performed so that the midcrestal region is 3 mm apical to the FGM of the future crown. Otherwise, the implant position will be too shallow and result in a short crown height at the gingival margins.

To solve the problem of an implant body placed too shallow, the restoring dentist may need to prepare the implant crest module and place the margin of the crown directly on the implant body (even if esthetic crown lengthening of the surrounding bone and soft tissue is necessary) (Figures 21-27, *B* to *D*).

At 3 mm Below the Free Gingival Margin (Ideal Depth)

The best platform level for a two-stage implant is similar to the most desirable bone level before the loss of a natural tooth, which is 2 mm below the adjacent tooth CEJ.[15] This positions the platform of the implant 3 mm below the facial FGM of the implant crown. This position provides 3 mm of soft tissue for the emergence of the implant crown on the midfacial region and more as the soft tissue measurements proceed toward the interproximal regions. This depth also increases the thickness of the soft tissues over the facial of the titanium implant body, which masks the darker color than a natural root above the bone. The FGM of the adjacent teeth are easier to help determine the depth than attempting to observe to the CEJ (Figure 21-28). It should be noted that the FGM of a lateral incisor may be 1 mm more incisal than the adjacent central and canine natural tooth.

In conclusion, the ideal anterior implant body position is (1) mid-distance mesiodistal between the teeth (1.5 mm or more from the adjacent CEJ), (2) faciopalatal 1.5 mm or more from the facial plate at the crest and 0.5 mm or more from the palatal bone, (3) under the incisal edge angulation, and (4) 2 to 4 mm below the facial FGM of the future implant crown. The depth of an implant platform greater than 4 mm below the adjacent CEJ is too deep. An implant platform position less than 2 mm below the FGM of the crown is too shallow. The ideal depth position of the implant platform is more than 2 mm and less than 4 mm below the FGM of the future implant crown (Box 21-2).

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FIGURE 21-27. **A,** An implant replacing a maxillary lateral incisor that is inserted too shallow. The implant crown is not placed subgingival enough to develop an emergence profile or to mask the color of the abutment. **B,** The implant is positioned too shallow. **C,** An abutment is inserted, and a subgingival margin is created on the implant body. **D,** The final implant crown is inserted below the tissue 1.5 mm and on the implant body.



FIGURE 21-28. The ideal implant depth is 3 mm below the free gingival margin of the future implant crown. This implant is too shallow for an ideal placement.

BOX 21-2 Ideal Anterior Implant Position

1. Mesiodistal
   a. Mid-distance between teeth, 1.5 mm or more from adjacent CEJ
      (1) Central incisor: note the incisive foramen
2. Faciopalatal
   a. 1.5 mm or more of bone on facial
   b. 0.5 mm or more of bone on lingual
3. Angulation
   a. Under incisal edge of crown
4. Depth
   a. More than 2 mm and less than 4 mm below facial FGM

CEJ, Cementoenamel junction; *FGM,* free gingival margin.

Stage II Surgery and Soft Tissue Emergence Contours

The clinician should use radiographs to evaluate the crestal mesial and distal bone–implant interface relative to an absence of crestal bone loss before the abutment post is added to the implant body. Probing is necessary to evaluate the facial and palatal conditions. If bone loss is suspected, then the soft tissue should be reflected for direct evaluation. Correction of a cervical horizontal defect includes local autogenous grafts covered with a barrier membrane and reapproximation of the soft tissue. For a vertical bone defect less than 2 mm, autogenous bone may be added and the uncovery of the implant may proceed because bone growth is more probable in the presence of the lateral walls of bone.

When the implant–bone interface is acceptable, the exposure of the implant body should be accomplished with the soft tissue final architecture in mind. The soft tissue drape may be

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modified: (1) before a bone graft procedure, (2) in conjunction with the bone graft in the implant site, and (3) at the time of implant insertion. These procedures are not presented in this prosthetic text.

The fourth time in the implant esthetic sequence that the soft tissue may be addressed is at the stage II uncovery procedure. To achieve the proper soft tissue architecture, several options are available, depending on the soft tissue appearance before stage II uncovery. These soft tissue procedures may be classified as *subtractive, additive,* or *a combination of each.*

Subtractive Technique

The ideal goal of the soft tissue drape in a two-stage surgical approach after the implant insertion is for the soft tissue to be at the height of the desired interdental papillae (Figure 21-29, *A*). When the soft tissue along the edentulous crest is at the level of the desired interdental papillae and is of sufficient quality and volume, a subtraction technique (e.g., gingivoplasty with a coarse diamond) sculpts the crestal gingival tissues to reproduce the cervical emergence contour of the crown, complete with interdental papillae and proper labial gingival contour (Figure 21-29, *B*).

The contour of the midfacial position of the tissue after gingivoplasty is 1 mm more incisal than the contour of the adjacent teeth to allow for the gingival shrinkage commonly observed after gingivoplasty and during the first year of implant loading. The interdental papilla zones are also made slightly wider at the base than the final desired form to accommodate possible shrinkage. The contour of the tissue is then maintained or improved with the subgingival contour of the transitional restoration (Figures 21-29, *C* and *D*). The transitional restoration is more concave on the subgingival midfacial than the natural crown predecessor. The reduced facial contour increases the thickness of the soft tissue and helps prevent gingival shrinkage of the midfacial region.

A similar soft tissue technique may be used at stage I surgery of implant placement. A one-stage surgical permucosal extension (PME) is used to maintain the sculpted soft tissue during the healing process. This PME may require a customized contour by adding composite or resin around the contour of a prefabricated PME.

Addition Technique

If the gingival contour at stage II uncovery is insufficient for the proper architecture for the interdental papillae, then an additive surgery is performed to gain tissue thickness and height. Several addition techniques have been proposed.[23–25] For example, an incision is made on the palatal aspect of the ridge, from the palatal line angle of each adjacent tooth. The tissue is elevated from the crest of the ridge, and the first-stage cover screw is identified. After removal, a low-profile healing cap of 3 mm is inserted. A connective tissue graft or acellular tissue graft

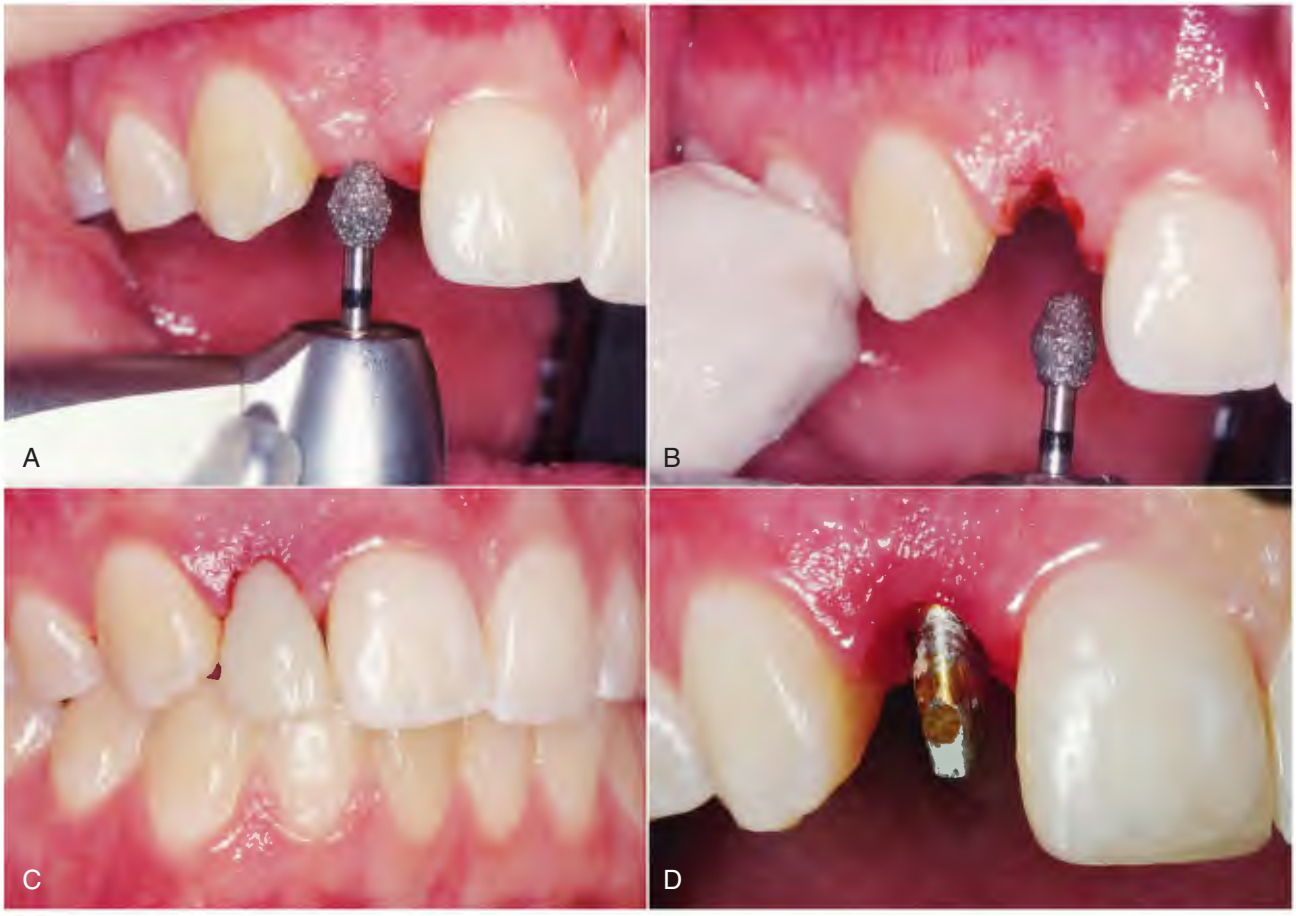


FIGURE 21-29. **A,** The ideal goal of the soft tissue drape at the implant site is at the desired height of the interdental papilla. **B,** A coarse diamond sculpts the soft tissue drape of the implant crown. **C,** The transitional crown maintains and helps improve the soft tissue drape. **D,** The soft tissue drape after 2 months.

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(AlloDerm) is placed around the low-profile healing cap. The crestal tissues are then draped over the healing cap and sutured to the palatal tissue. In other words, the PME acts as a soft tissue elevator to obtain space. The tissue heals by secondary intention in the palatal area, and excess tissue forms on the facial and interproximal regions, to the height of the interdental papilla (Figure 21-30). After 8 or more weeks, a stage II uncovery by gingivoplasty (a subtraction technique) is performed to the contour of the desired crown emergence profile. A similar technique may be used at stage I implant insertion surgery to elevate the papilla and crest region.

An alternative addition technique at the stage II uncovery procedure developed by the author is called the *split-finger technique*.[26] When the papilla height is less than 2 mm from the end goal, an incision is made in the gingival sulci of the adjacent teeth. The incision continues at the distolingual line angle of the adjacent teeth and forms a loop at the facial emergence location of the implant crown. This creates two "fingers" at least 2 mm in width at the base, adjacent to each natural tooth. After being elevated, these two facial fingers become the facial aspects of the interdental papillae.

A 3.5- to 4-mm-wide central palatally supported finger is also created during this process. The palatal tissue is then elevated, and the implant cover screw is exposed and replaced with an abutment. The palatal finger may then be split into two segments (i.e., the split-finger approach). The final abutment is positioned and modified as needed, and a transitional prosthesis is fabricated. Each palatal segment is rotated to the interproximal region to support the elevated two facial fingers. A 4-0 or 5-0 modified mattress suture positions the papillae in the proper location next to a transitional crown (Figure 21-31).

The split-finger technique may be used in conjunction with a connective tissue graft or acellular tissue (AlloDerm) to further augment the tissue height. The split-finger option may also be performed at the implant insertion surgery when a one-stage approach or immediate provisionalization is desired.

After the soft tissues are subtracted or added to obtain the desired emergence contour, the surgeon has primarily two options to maintain this region. The first option is that a PME abutment may be inserted. Its size and shape should be smaller than the cervical contour of the final crown and extend through the tissue 1 to 2 mm. It is often customized by adding composite or acrylic to the interproximal regions. The emergence of the PME abutment will develop the initial soft tissue form. A wider-profile PME abutment than the ideal soft tissue contour should not be used when the tissues are at the ideal position because it may cause gingival shrinkage on the facial and limit the restoring dentist's ability to shape it into its ideal form.

A removable transitional prosthesis is recontoured to fit over the healing cap for the next few weeks until the patient is seen for the first prosthetic appointment. The soft tissue heals to the contour of the healing abutment or permucosal device. The patient is referred to the restoring dentist for fabrication of the final crown after 6 to 8 weeks of tissue maturation. This is the simplest option when using the team approach to implant dentistry.

When the surgeon is also the restoring dentist or is able to make a fixed transitional crown, the initial restoration appointment may be combined with the stage II uncovery procedure.[27] A prefabricated, machined two-piece abutment is placed into the implant body at the conclusion of the soft tissue recontouring. The antirotational hex is engaged, and the abutment screw is hand tightened to approximately 5 to 10 N-cm (or moderate hand force). A periapical radiograph is taken of the crest module and abutment connection region to ensure proper component fit. After being confirmed, the abutment screw is then secured at 20 to 35 N-cm (depending on the manufacturer) while a hemostat holds the abutment with a countertorque resistance to reduce the shear forces to the crestal bone.

In the direct restoration technique, the abutment post is prepared in situ similarly to an anterior tooth preparation, with subgingival margins of less than 1.5 mm. The transitional single crown similar to the subgingival contour of the final restoration

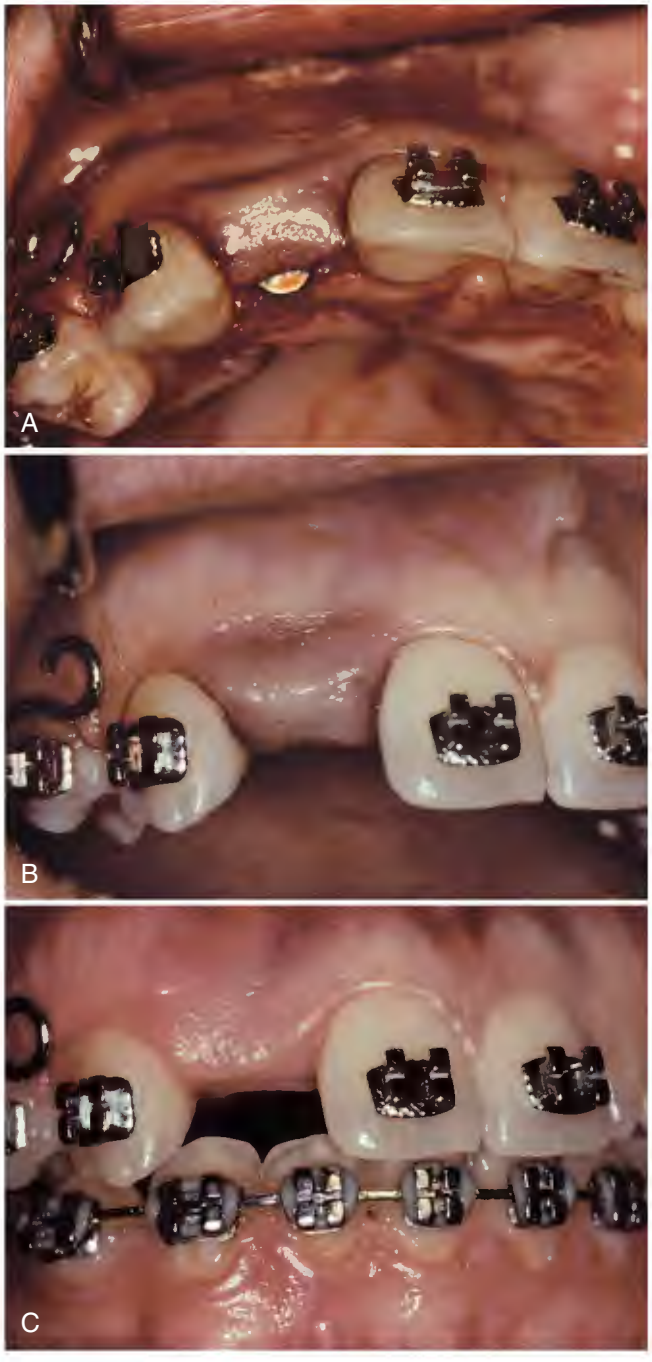


FIGURE 21-30. **A,** An incision is made on the palatal line angle to uncover the implant. **B,** The tissue is elevated to the height of the interdental papillae and allowed to heal over a soft tissue elevator (permucosal extension). **C,** After 2 months or more, a subtraction technique will carve the soft tissue drape around the future crown.

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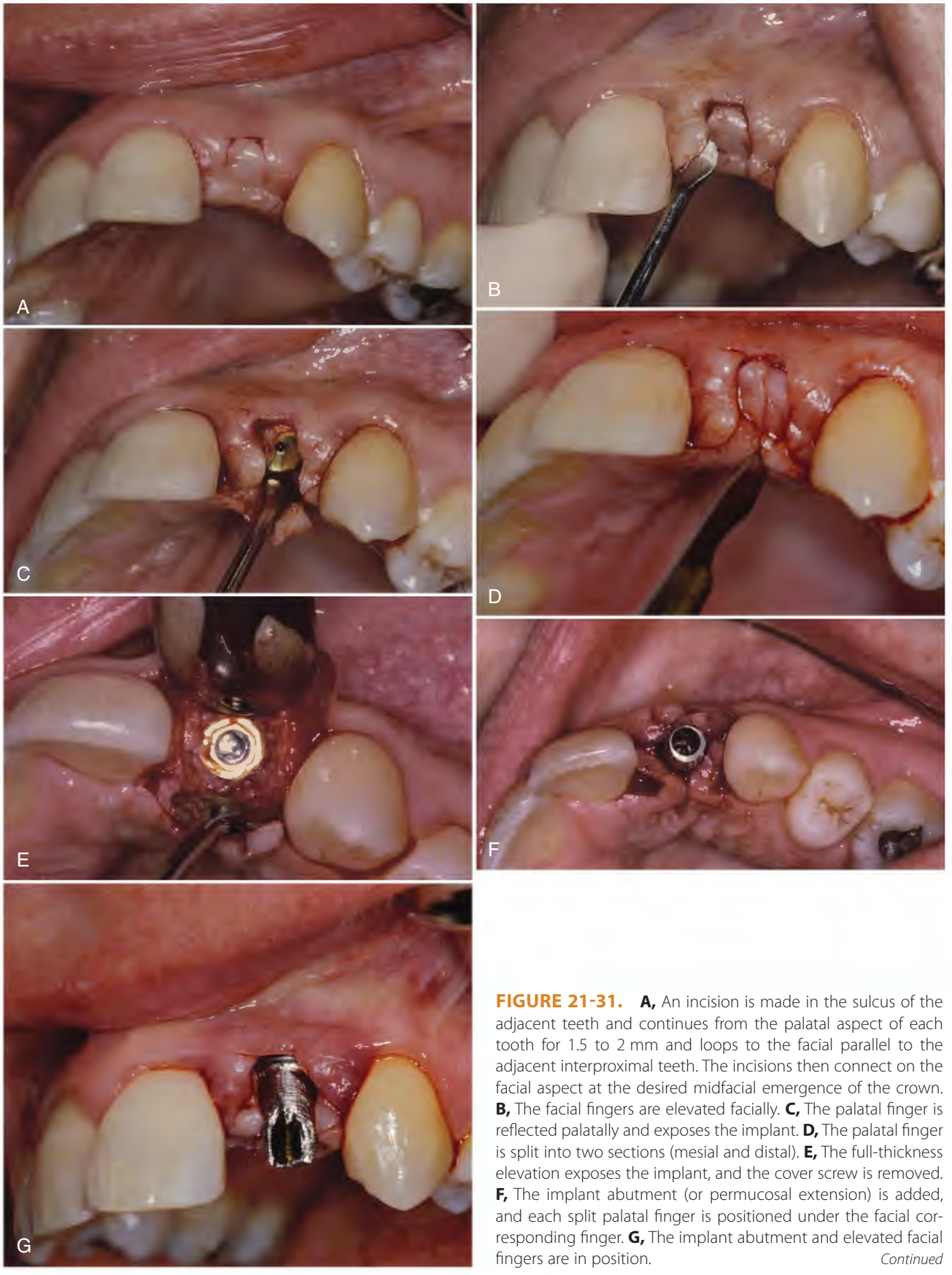


FIGURE 21-31. **A,** An incision is made in the sulcus of the adjacent teeth and continues from the palatal aspect of each tooth for 1.5 to 2 mm and loops to the facial parallel to the adjacent interproximal teeth. The incisions then connect on the facial aspect at the desired midfacial emergence of the crown. **B,** The facial fingers are elevated facially. **C,** The palatal finger is reflected palatally and exposes the implant. **D,** The palatal finger is split into two sections (mesial and distal). **E,** The full-thickness elevation exposes the implant, and the cover screw is removed. **F,** The implant abutment (or permucosal extension) is added, and each split palatal finger is positioned under the facial corresponding finger. **G,** The implant abutment and elevated facial fingers are in position.

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FIGURE 21-31, cont'd. **H,** The temporary crown is cemented, and the fingers are sutured into position. **I,** The final crown in position with properly developed interdental papillae.

is fabricated completely out of occlusion. The soft tissue is then permitted to heal using the transitional crown to help form the soft tissue drape.

Immediate Implant Insertion after Extraction

According to Kois, five diagnostic keys exist for predictable single-tooth periimplant esthetics when an immediate extraction and implant insertion is contemplated: (1) the tooth position relative to the FGM, (2) the form of the periodontium, (3) the biotype of the periodontium, (4) the tooth shape, and (5) the position of the osseous crest before extraction.[28,29] Therefore, the soft tissue and bone comprise three of the five factors for predictable esthetics. When all five diagnostic keys are present around the tooth to be extracted, an immediate implant placement may be considered.

The goal of the anterior implant restoration is to simulate the appearance of a natural tooth. Adequate bone volume must be present for correct hard and soft tissue contours. Available bone is lost in width as soon as 3 months after an extraction. Implant placement soon after the extraction and initial alveolar bone healing is usually advantageous if the existing bone after the extraction is ideal. As such, immediate implant placement in an extraction site has become a popular method in the esthetic zone.[30–33]

Advantages

The benefits of immediate implant insertion after tooth extraction are related to an improved preservation of the soft tissue drape and the bone architecture compared with their collapse after tooth extraction. As a result, bone augmentation and soft tissue grafts after socket healing and before implant insertion may be avoided. Because there are fewer surgeries, there is less treatment time and a reduced patient discomfort and cost. The procedure has been described as a preservation technique aiming at maintaining the harmonious gingival architecture.[34]

The tooth shape is one of the five diagnostic keys of Kois, and is a major factor related to risk when considering the immediate implant insertion technique.[28] Teeth may be classified as tapered, ovoid, or square in shape. Teeth with a tapered crown form have a higher risk of soft tissue compromise after extraction because the interdental papilla may be greater than 6 mm in height with this tooth shape. The tapered crown also has more interproximal bone between the teeth and more facial bone over the tapered root. This improves the condition for an immediate implant site. As such, under ideal conditions, the tapered tooth form may be more advantageous for extraction and immediate implant insertion because the soft tissue changes are greater than usual, more bone is present for implant fixation, and less void is present between the implant and the extraction socket. Therefore, under conditions, which include lack of pathology, thick gingival tissues, ideal bone contours, ideal soft tissue contours, and tapered tooth forms, an immediate implant insertion after tooth extraction is considered (Figure 21-32).

Disadvantages

When placing an implant in an immediate extraction site, the surgeon should consider the socket dimension and the defect between the labial plate of bone and the implant. The faciopalatal dimension of an anterior tooth may be greater than its mesiodistal dimension. The implant size is often 4 to 5 mm in diameter for a central incisor, and the extraction socket is often greater than 6 mm (especially in the faciopalatal dimension), so a surgical defect as large as 2 mm remains around the implant. More or less broad, oval or kidney-shaped spaces have been described to run coronoapically along the entire surface of the socket next to the implant.[33] As a consequence, the implant has less fixation and increased risk of mobility during early loading.

A square tooth form has the least height of the interdental papilla and may be only 2 mm in height. As a result, less gingival shrinkage after extraction occurs because less scalloping of the interproximal and facial bone with the adjacent tooth roots is exhibited. Therefore, there is less risk of complications related to the soft tissue drape with a delayed implant insertion protocol. There is also less bone between the roots of square-shaped teeth and larger spaces between the extraction site and the potential implant. Therefore, implant placement may be more difficult to obtain fixation, and the defect between the socket and the implant may require a bone graft to fill the defect. As a result, an immediate implant insertion after extraction offers less benefit for the soft tissue and greater risk for the implant–bone interface.

The disadvantages of tooth extraction and immediate implant insertion are necessary to consider when deciding to use this technique. The implant will predictably obtain rigid

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FIGURE 21-32. **A,** A tapered tooth form is extracted. **B,** The implant drill is positioned under the incisal edge. **C,** An autograft is positioned on the facial of the implant osteotomy. **D,** The implant is threaded into position 3 mm below the facial free gingival margin. **E,** A permucosal extension supports the soft tissue drape. **F,** An Essex transitional is worn during healing. **G,** After 4 months, the soft tissue drape and implant are ready to restore.

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fixation with these techniques. However, the goal of the anterior single-tooth implant is not limited solely to rigid fixation. The inability to achieve proper esthetic and health parameters constitutes a compromised result and increased risk of esthetic or implant failure.[35] The dentist (and patient) should be cognizant of the fact that on occasion implants fail during the initial healing period. An increased risk of failure is present when the implant is inserted immediately after tooth extraction even under ideal conditions.

If an implant failure occurs, the soft tissue drape may be significantly altered, and correction may be difficult even after several additional surgeries. Therefore, the tooth extraction and immediate insertion is a two-edged sword. It is one of the best methods available to have an ideal esthetic result. But if the implant fails, the esthetics may be forever compromised. It should be noted that when the soft tissue drape is ideal, it is most easy to maintain with the extraction and immediate one-stage implant insertion technique. However, if implant failure, bone loss, or incorrect implant position results, the soft tissue drape may be impossible to maintain or correct.

When an anterior tooth requires extraction, during the extraction process, the thin facial cortex often becomes compromised or lost. As a result, it may be several millimeters apical to the palatal cortical plate. Frequently bone grafting or membrane placement in conjunction with the implant insertion is suggested. Synthetic grafts placed around the titanium implant grow less dense quality bone, which is also limited in implant contact. The capacity of this less dense bone promoted by barrier membranes around implants to withstand loading seems to be limited, and animal studies indicate as much as 85% may be lost after loading.[36] An explanation may be that no blood vessels arise from the implant. To the contrary, it reduces the number of bony walls of the defect and limits blood supply to the facial bone graft. As a result, bone is less likely to form, and when it forms, it is less dense and more at risk of resorption when the implant is loaded.

Techniques for immediate implant placement after extraction include countersinking the implant 2 mm or more below the facial plate (which is already more apical than the palatal plate) and placing calcium phosphate ($CaPO_4$), resorbable HA, or autologous bone to fill the labial defect with or without the addition of connective tissue grafts or membrane.[33] When the implant is countersunk below the facial bone, the implant platform may be 4 mm or more apical to the CEJ of the adjacent teeth, which is not ideal and increases the anatomical crown height and the pocket depth, especially after crestal bone loss during the first year.

Immediate implant placement in the anterior region using a round implant often requires that the osteotomy and implant insertion engage the lingual wall of the alveolus and penetrate halfway to two thirds of the way down the extraction site into the remaining lingual apical bone for rigid fixation. As a result of the implant drills and implant engaging bone only on the palatal aspect for most of the osteotomy, the implant often becomes positioned too facial. This surgical approach is more challenging than preparing the osteotomy in a homogeneous bone density.

An increased risk of postoperative infection exists around the implant with an immediate tooth extraction and implant insertion because of the bacteria associated with the cause of tooth loss when judicious case selection has not been exercised. The presence of exudate lowers the pH, which causes a solution-mediated resorption of the grafted bone and contaminates the implant body with a bacterial smear layer, which in turn reduces bone contact.

The natural resorption of the facial plate may not be halted by implant insertion, and bone–implant contact is reduced when the facial plate resorbs.[36] In other words, the initial resorption process of bone loss after tooth extraction is not reduced just because an implant is inserted into the socket. As a consequence, one of the major factors that initially promoted this technique is not present. However, the soft tissue contours may be maintained with this treatment option when a one-stage PME or transitional crown supports the interdental papilla and emergence contour after the tooth extraction. Hence, this is viable treatment option when the five key diagnostic features of Kois are present (Box 21-3). Whenever an extraction and immediate insertion technique is considered, the technique of orthodontic extrusion before extraction and implant insertion offers many benefits.[23]

Extraction and Delayed Implant Placement

After tooth extraction and socket grafting, the soft tissue granulates over the extraction site, thus creating an increased zone of attached gingiva. An improved bone interface may be obtained if the large-diameter extraction site is grafted and heals before implant placement. If the labial plate is compromised, then additional intraorally harvested bone or guided bone regeneration (GBR) is indicated.[37] The delayed implant insertion method appears to enhance capillary propagation and trabecular formation before implant placement, facilitating a more ideal formation of an implant–bone interface.[38]

The result of the socket graft may be evaluated before implant placement with the delayed technique rather than dealing with compromises after implant integration. The cribriform plate of the socket has remodeled after healing and does not influence the position of the drills during surgery or the final implant position. In this way, the implant may more easily be placed in an ideal position in relation to the crestal bone and adjacent teeth and within the exact contours of the final restoration. However, the soft tissue drape is more often compromised with the delayed technique, especially the height of the interdental papillae.[39] Regardless of whether an immediate implant insertion after extraction or a delayed insertion technique after initial healing, the position of the implant should be within the ideal guidelines previously addressed.

BOX 21-3 Immediate Implant Insertion After Extraction

Advantages
1. Maintain ideal soft tissue drape
2. Reduce number of surgeries
   a. Decrease cost
   b. Decrease discomfort
3. Decrease treatment time

Disadvantages
1. Implant failure severely affects esthetics
2. Need for bone grafting
   a. Less bone–implant contact
3. Risk of crestal bone loss
4. Altered implant position
   a. Too deep
   b. Too facial

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Prosthetic Phase

Abutment Selection

The single-tooth implant requires an antirotational abutment feature. Interlocking features to stabilize the implant prosthetic abutment connection have been designed along with a better understanding and application of biomechanical parameters such as torque, preload, clamping, thread mechanics, micromovement, and settling.[40–44] The quest for an ideal prosthetic abutment implant connection appears to continue (Figure 21-33). Presently, a hexagon with an internal connection remains the most widely used. As a result of the specific anatomical limitations of the single-tooth implant, the prosthetic abutment not only must be designed with antirotational features (which requires a two-piece system) but also may need to be angled to compensate for implant body insertions that are not within the contours of the final restoration. This also requires at least two pieces: the abutment that engages the hexagon or antirotational design and an abutment screw that connects the abutment to the implant body.[45]

Four prefabricated abutment subgingival contour designs are used to restore implants. These include (1) an abutment the same size (or slightly smaller) in diameter as the implant, (2) an abutment with a 1-mm flare 1 to 2 mm above the implant body, (3) an abutment with a 2-mm flare 1 to 2 mm above the implant body, and (4) an anatomic abutment similar in cervical diameter and contour to the tooth being replaced.[46] These abutments may be titanium or its alloy, titanium with a titanium nitride coating, or ceramic (alumina or zirconium). They may also be angled or straight. The preangled abutment has varied angulations provided by manufacturers, usually 15 and 25 degrees off-axis.

Abutments may also be custom in design. Three general choices of abutments for cement retention for custom abutments are available[47,48]: (1) a plastic castable type coping, (2) a machined coping with a plastic cylinder, and (3) a CAD-CAM customized abutment of titanium (alloy) or ceramic (Box 21-4).

Prefabricated Abutments

Narrow-Diameter Abutments

An abutment that is the same diameter (or more narrow) than the implant crest module has several advantages:

1. One size of abutment may be used for almost all patients.
2. The abutment is seated on the implant platform and engages the hexagon without circumferential hard or soft tissue interference, which is beneficial because the abutment-to-implant connection may be several millimeters below the tissue.
3. Minimal preparation is required if the implant is not in ideal position (i.e., too close to a tooth or facial position).
4. The emergence profile of the crown is used to create the gingival contour and may be customized to the specific requirement of each patient condition.
5. The margin of the crown may be a knife edge and may be placed anywhere on the abutment.
6. The abutment can be used for direct and indirect crown fabrication techniques.
7. In the indirect (laboratory-assisted) technique, a knife-edge margin may be extended or shortened in the laboratory after the tissue model is fabricated.
8. The soft tissue below the crown margin is thicker and less likely to recede.
9. The soft tissue is thicker, so a grayish line below the crown is less observed.

The abutment that is similar in diameter to the implant body (or more narrow as in platform switching) also has disadvantages: (1) It is at considerable disadvantage to modify the soft tissue drape. The subgingival contour is only developed by the crown, which is 1.5 mm or less below the FGM. This dimension may be inadequate to fully modify the soft tissue drape. Hence, this abutment design is limited to situations in which the soft tissues are more ideal or minimum space is a variable between the implant and the adjacent tooth. (2) The abutment is less tapered because it is more narrow at the base. Hence, it is more difficult to modify the path of insertion of the crown. (3) There is a thinner outer wall of the abutment, so less material is present to prepare a taper or a margin when a chamfer or shoulder margin is preferred. (4) There is no clear marking for the laboratory to determine the desired crown margin location unless a small chamfer is present or prepared on the abutment selected.

Wider-Diameter Abutments

An abutment flare 1 to 2 mm wider than the implant body is the most common type provided by manufacturers and is the most popular abutment used for the direct intraoral technique. It is provided in a straight and angled configuration (Figure 21-34). An abutment with a 1- to 2-mm "flare" positioned 1 to 2 mm above the implant platform presents several advantages. The wider cervical region improves the emergence profile of the soft tissue starting 1 to 2 mm above the bone. The wider abutment also provides a greater surface area for retention and provides a greater premade taper of the abutment (Figure 21-35). Because the implant is often positioned 1.5 mm more palatal than the emergence of the adjacent teeth, the 1- to 2-mm flare begins the process of developing the ideal emergence profile of the crown 1 to 2 mm above the bone. The dentist can



FIGURE 21-33. A wide range of abatement types may be used to restore an implant.

BOX 21-4 Abutment Selections

1. Prefabricated
   a. Same size or smaller diameter than implant
   b. 1-mm flare wider than implant
   c. 2-mm flare wider than implant
   d. Anatomic abutment
   e. Angled abutments (15–30 degrees)
2. Custom
   a. Plastic castable
   b. Machined coping/plastic cylinder
   c. CAD-CAM (titanium [alloy], ceramic)

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FIGURE 21-34. A premanufactured abutment that is wider at the base than the implant crest module is the most popular design used in the industry. It may be angled *(top)* or straight *(bottom)*.

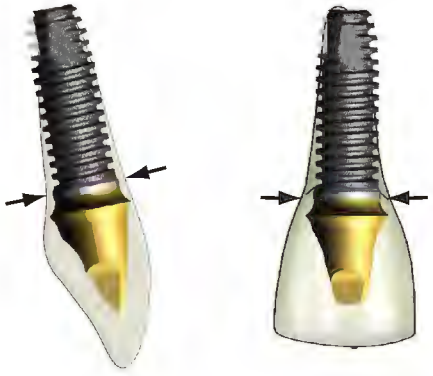


FIGURE 21-35. When the abutment flare is wider than the implant, it permits more taper for path of insertion, more retention, and the ability to modify the soft tissue drape starting 1 to 2 mm above the bone.

modify the abutment preparation for each patient, condition, and site. Unlike a custom abutment made with a plastic component, the accuracy of fit of the premade implant–abutment interface decreases the force to the abutment screw and reduces the risk of abutment screw loosening. It is a less expensive abutment than one customized and may even be provided at no charge by the manufacturer when the implant body is purchased (e.g., BioHorizons).

The wider abutment design also has disadvantages:

1. The wider abutment is wider all around the implant body. When too close to the adjacent tooth or implant, too facial, or too lingual, the abutment must be modified.
2. The wider abutment creates a flare with an undercut where it tapers down to the implant body, with several inherent problems. The crown margin must be placed at or above the undercut. Too often, the dentist perceives the abutment flare as a crown margin, which may be several millimeters below the tissue. This makes it most difficult to capture the "flare" in an impression, difficult to seat the crown, and difficult to remove the excess cement. The crown margin should be related to the FGM and should only be 1 mm ± 0.5 mm subgingivally for esthetics, regardless of where the abutment flare is located (Figure 21-36).
3. If the implant was placed below the crestal bone, the restoring dentist cannot seat the abutment on the implant platform without an osteoplasty around the implant. If the stage II PME is of the same dimension as the wider abutment, the osteoplasty would be performed by the surgeon at implant insertion.
4. It is more difficult to seat the abutment below the tissue margin because it must push the tissue away from the more narrow implant body.



FIGURE 21-36. The crown margin is subgingival 1 mm ± 0.5 mm below the free gingival margin, not to the abutment flare. This permits easier access to remove any residual cement (as on the distal of this crown).

Premade Anatomic Abutment

A premade anatomic abutment appears attractive to inexperienced implant dentists. It seems logical to have an abutment copy a natural tooth crown preparation.[46] The premade anatomical abutments present similar advantages and disadvantages as the wider abutment posts. The added advantage is that because anterior teeth are wider faciolingually than mesiodistally, the abutment can reflect the natural tooth cross-section.

However, additional disadvantages include the following:

1. Of necessity, the surgeon must more precisely position the hexagon of the implant platform. This is in addition to the correct faciopalatal, mesiodistal, and angulation positions. A rotation of even 10 degrees can affect the final crown esthetics.
2. The emergence angle of the implant and abutment should vary, depending on the tissue thickness. Therefore, for a premade anatomical abutment, several abutment types often are provided with different height and collar thicknesses,

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which must be stored and selected by the dentist or laboratory at increased overhead costs.

3. The premade abutment design has a premade finish line prepared on the abutment. The margin position is preselected with varying height and angulation of the metal collar below the margin so that even more abutments are required for selection.
4. This abutment is designed primarily for the indirect impression technique using implant body analogs, which increase the cost of the restoration and fabrication of the prosthesis directly on the implant abutment.
5. When used with a direct approach, the impression must capture the complete 360-degree shoulder of the implant margin. If any impression material migrates below the marginal undercut, the thin stone margin of the die often breaks off when removed from the impression. As a result, the abutment crown margin fabricated on such a die often results in abutment overhangs (reversed crown overhang) extending into the soft tissue.

As a consequence of these disadvantages, this category of abutment is rarely used by the profession.



FIGURE 21-37. A ceramic premade abutment.

Ceramic Abutments

The ceramic premade abutments are usually white in color (Figure 21-37). Ceramic premade abutments have become popular to prevent metal below the crown margin from causing a grayish hue to be seen through the cervical tissues when there is a thin biotype (Figure 21-38). The white ceramic abutment below the tissue makes the tissues appear more coral pink in color (Figure 21-39).

Two types of ceramic abutments are generally found by manufacturers, a milled all-ceramic abutment or a ceramic abutment attached to a milled titanium component. The one-piece milled abutment does not have a metal to ceramic connection and hence is stronger (and usually less expensive). However, the material is harder than the implant body connection; it is more difficult to control the variance of size; and any misfit will wear the antirotation feature, which will increase the risk of screw loosening. The machined coping is more accurate to engage the antirotational component of the implant body and is made of a similar material hardness, which decreases the risk of abutment screw loosening. However, the cemented interface of the metal coping to ceramic abutment may be an intermediate to long-term complication not yet appreciated.



FIGURE 21-38. A thin biotype (or implant too facial) may result in the titanium abutment casting a grayish hue to the cervical tissues.



FIGURE 21-39. **A,** A ceramic abutment in situ. **B,** The crown and abutment allow the soft tissue drape to appear more coral pink in color.

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Angled Abutments

The premanufactured angled abutment may be made of titanium or its alloy or of ceramics. The weaknesses of prefabricated angled abutment designs have been discussed previously, and their use should be limited to situations in which a facial or angled implant position precludes restoration without correction of the angulation. When the implant body is not favorably positioned, the angled abutment may be the only rational solution to restore the patient (Figure 21-40). The angled abutment is most efficient when the flat of the antirotational design within the implant body is positioned to the midfacial position. Otherwise, the angle of the abutment will be rotated from the center, making it more difficult to ideally prepare and restore.

Customized Abutments

A trend toward laboratory-customized anatomical or esthetic abutments has emerged. In the past, a custom-made abutment usually was fabricated from a plastic castable pattern or machined cylinder and plastic castable coping. This abutment type was developed originally by the University of California, Los Angeles (hence UCLA abutment).[47] The laboratory waxes and casts metal for the customized abutment design to the plastic or metal sleeve.

The primary advantage of the custom abutment is that the abutment is fabricated for each specific patient condition. The subgingival crown margin position and contours can be extended only where necessary. Another major advantage of the customized abutment is that the abutment may be fabricated with crown and bridge precious metal, so the facial region may be covered with porcelain (the color of the tooth, the root, or the soft tissue) and may be extended close to the implant–abutment connection for improved facial esthetics[15] (Figure 21-41). The facial crown margin on this abutment is usually a porcelain butt joint 1 mm below the tissue that is fabricated and developed in the laboratory. In this way, if tissue shrinkage occurs in the long term, a metal margin of the abutment is not seen. This is most beneficial when placing a single-tooth crown in a young patient to account for a potential remodeling of the gingival profile over time.

The disadvantages of the custom-made abutment are related primarily to the laboratory phase. With the castable plastic pattern, the abutment can be fabricated out of any precious metal (to decrease corrosion risk between the coping and cast metal) without a two-metal interface. The plastic pattern



FIGURE 21-40. The prefabricated angled abutment is provided in several different angulations, usually ranging from 15 to 30 degrees off-axis.



FIGURE 21-41. **A,** A customized anatomical abutment can be contoured to fit the existing implant and soft tissue. The undercut portion of the abutment may be pink or tooth-colored porcelain. **B,** The customized abutment with subgingival pink porcelain is seated into position. When the tissue blanches, the gingival tissues are being molded into a different position. To avoid facial shrinkage, the facial contour of the customized abutment should be reduced when the blanching does not return to normal within 10 minutes. **C,** The implant crown usually has a porcelain butt joint for improved esthetics. **D,** An implant abutment and crown in situ.

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abutment also is much less expensive. However, the abutment-to-implant connection is less precise. A diamond lapping tool is suggested to improve the flat-to-flat finish of the abutment to implant connection, but overzealous finishing may create a gap. In addition, the internal platform for the abutment screw cannot be cast accurately. Hence, the shoulder of the abutment screw does not seat precisely, which causes an increased risk of abutment screw loosening and associated complications.[49] Therefore, the plastic coping is not suggested whenever a customized situation is used.

UCLA abutments with a machined metal coping within a castable custom abutment have a high degree of fit at the implant–abutment connection with the added advantage of decreased screw loosening. Therefore, although the cost may be greater, the machined abutment metal coping is suggested.[48,49]

CAD-CAM Abutments

The CAD-CAM abutment may be customized and fabricated from almost any material and to almost any angulation. An indirect laboratory technique is necessary. The dentist makes an implant body impression (using a closed- or open-tray technique) that uses an impression transfer that engages the antirotational feature of the implant body. After the abutment is designed in the laboratory with the computer, it is milled or fabricated by digital technology. As digital technology increases in the fabrication of implant prostheses, this restorative approach will become more popular.

In conclusion, the restoring dentist has many abutment options to restore an anterior single tooth. Most often when the implant body was positioned correctly, a direct approach is used with a prefabricated abutment, slightly wider than the implant body. It may be easily modified when too flared to the facial or too close to an adjacent tooth. When the implant is positioned correctly, the 2- to 3-mm vertical depth of tissue on the facial most often hides the color of the metal abutment below the crown. When the prefabricated titanium alloy abutment has a gold-color titanium nitride coating, it is an esthetic subgingival benefit.

When the implant was positioned too coronal and the depth of tissue is minimal or thin tissue biotype exists, a ceramic abutment or customized abutment with cervical ceramics is of benefit. These abutments permit the subgingival areas below the crown margin to be more favorable for the cervical esthetics of the restorations. When the interdental papilla is flat and a prosthetic method is desired to elevate the papilla height, a custom abutment also has many benefits.

Final Preparation and Impression

Direct versus Indirect Prosthesis Fabrication

Before reading this section, Chapter 26 on principles of cement-retained restorations and Chapter 28 on principles of screw-retained components should be reviewed. Primarily two methods are used to restore an implant prosthesis: direct and indirect crown (prosthesis) fabrication. The direct crown fabrication technique is most similar to the fabrication of a crown on a natural tooth. In fact, the technique is the same as the fabrication of a crown on a natural tooth with an endodontic post and core, and stone dies represent the abutment in the cast. The indirect crown fabrication requires use of an implant analog, and the laboratory performs the majority of the work related to abutment preparation and crown fabrication directly on the implant abutment.

In either the direct or indirect method, the teeth adjacent to the implant crown are often reshaped before the final impression. If the adjacent tooth is longer than ideal, or rotated, it may be improved with an enameloplasty. The opposing teeth are also evaluated and modified for improved esthetics and occlusion.

The interproximal region of the adjacent teeth is especially addressed. The interproximal contact should be just above the height of the papilla. When the papilla is depressed, the interproximal contact of the adjacent teeth may be lowered to the tissue.[15,50]

Option 1: Direct Technique

Several weeks after the stage II uncovery soft tissue procedures, the restoring dentist evaluates the soft tissue contour around the PME of the implant. The soft tissue drape around an implant in a healed site is usually depressed in the interproximal region, and often the crest of the soft tissue ridge is slightly coronal to the mid FGM. The goal of the restoring dentist when these conditions are observed is to elevate the interproximal papillae and contour the facial FGM to be integrated within the adjacent dentition.

When too much soft tissue is present for an ideal emergence from the implant body, it is festooned with a coarse diamond and high-speed handpiece or laser. The gingival contour is shaped to be similar to the corresponding natural tooth (when it is ideal). It may be necessary to remove the PME to contour the subgingival regions. When the interdental papilla zone(s) is deficient and a surgical option to correct it is not considered, the subgingival crown contour and the interproximal crown contact should be modified.

Most often, the two-piece abutment for cement retention that is wider than the implant body by 1 to 2 mm is seated with a hand torque of 5 to 10 N-cm and checked radiographically for proper placement. If the facial tissue is deficient in contour, the facial flare of the abutment is eliminated before seating into the implant body. After abutment seating is confirmed, the abutment is countertorqued and tightened 20 to 35 N-cm (depending on the manufacturer) and then loosened and retightened. The science of screw mechanics to decrease abutment screw loosening is addressed in Chapter 28.

The abutment height is first prepared 2 to 3 mm directly inferior to the incisal edge position of the final abutment crown. The post may be prepared intraorally, similar to a tooth, under copious amounts of irrigation and with a crosscut fissure carbide bur (#702). The final height of the abutment should be greater than 4 mm in height, when a subgingival margin of 1 mm is used, so a 5-mm minimum abutment height is present for cement retention.

The facial aspect of the incisal third of the abutment is then prepared in the same plane as the incisal edge position, which ensures adequate material thickness on the facial for esthetics. An abutment post labial to the incisal edge position compromises the final facial esthetics of the restoration at the incisal one third of the crown.

The labial margin of the abutment may then be prepared to the height of the tissues for a porcelain butt joint, a chamfer, or a knife-edge margin, depending on the facial position at the cervical region. The farther facial the abutment is compared with the ideal cervical position, the more likely is a butt joint prepared (Figures 21-42, *A* to *D*). The farther palatal the abutment position is compared with the facial crown contour, the more often a knife-edge margin is prepared. A chamfer is

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FIGURE 21-42. **A,** A maxillary right canine implant with a permucosal extension (PME) will be restored with a direct technique. **B,** The manufacturer-premade two-piece straight abutment for cement is inserted. A radiograph confirms its complete seating. **C,** The incisal edge is prepared, then the facial incisal third, and then the cervical portion to the height of the free gingival margin. **D,** The adjacent tooth interproximal contacts are modified on the palatal aspect so that they are elongated toward the interdental papillae. **E,** A temporary crown is fabricated level with the soft tissue margin. **F,** The two-piece abutment is removed, and a PME inserted to prevent the soft tissue contour from collapsing over the implant platform.

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FIGURE 21-42, cont'd. **G,** The abutment for cement retention is inserted onto an implant body analog (and handle). The margin on the abutment is extended 1 to 1.5 mm below the free gingival margin. **H,** The temporary crown is inserted onto the lubricated abutment extraorally, and acrylic or composite is added to extend the crown margin to the subgingival margin. The subgingival crown contour is developed with the transitional crown. **I,** The prepared abutment is placed onto another implant body analog (without the handle), and an impression is made. The abutment and analog are inserted into a dappen dish. This impression represents an exact duplicate of the abutment. A full-arch intraoral impression will be used for occlusion and interproximal contacts and emergence contours. **J,** The margins on the crown can be fabricated from this abutment impression because it represents the die of the abutment. **K,** The prepared abutment is reinserted into the implant body. **L,** The temporary crown with proper subgingival contour is seated. The tissue blanches because the temporary crown displaces the tissue around the margin. *Continued*

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FIGURE 21-42, cont'd. **M,** After the tissue returns to normal color, the transitional crown may be removed, and a final impression made of the abutment, soft tissue emergence, and surrounding teeth. **N,** A soft tissue model is made from the traditional closed-tray impression. The coping for the crown may be fabricated on the individual die made from the dappen dish impression of the abutment. The coping then is placed on the full-arch cast for final reconstruction of the crown. **O,** At the final delivery appointment, the temporary crown is removed, and the abutment and soft tissue drape are evaluated. **P,** The final crown is seated, occlusion is modified with a heavy bite-force evaluation, and the crown is cemented. This crown has adequate contour, color, and soft tissue drape.

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prepared when the implant is in an intermediate position to the facial contour. The lingual aspect of the crown preparation is most often a knife-edge margin at the level of the tissue. The interproximal areas also usually are prepared with a knife-edge margin because they are 1.5 mm or more from the adjacent tooth.

An impression cord is inserted around the abutment. The retraction cord is usually easier to place between the tissues and abutment post compared with a natural tooth because there are no connective tissue fibers attached to the implant abutment. Usually the cord is inserted 1.5 mm below the gingival margin. The final facial and interproximal crown margins are then prepared 1 to 1.5 mm below the FGM, which ideally places the crown margin 1.5 to 2 mm above the bone. This crown margin position is usually above the abutment "flare" of the wider abutment. A subgingival margin on the lingual is only used when additional retention is required for the crown.

The abutment screw access is obturated after a cotton pellet is inserted to protect the head of the abutment screw from cement or material. The obturation material may be endodontic access materials, composites, or elastic materials (i.e., Fermit). The patient then occludes, and the occlusal clearance is evaluated. The patient then positions the mandible in protrusive and excursions, and the clearance of at least 1.5 to 2 mm is evaluated. A transitional prosthesis is then made on the abutment for cement retention. Its marginal contour follows the profile sculpted by gingivoplasty and is similar to that of the desired emergence profile in harmony with the existing natural dentition.

All of the line angles of the abutment preparation are made smooth, especially on the occlusal of the preparation. A stone die will represent the abutment in the laboratory, and breakage or chipping of a sharp edge will cause the casting to not seat completely in the mouth.

The subgingival contour of an abutment or a crown (transitional or final restoration) is directly related to the contour of the soft tissue drape. The gingival tissues may be slightly modified by pressure against the soft tissues, almost as if they were a balloon filled with water.[51] There are no connective tissue fibers attached to the implant abutment. The circular fibers that surround the abutment above the bone have a junctional epithelial attachment (less tenacious than a tooth). As a

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consequence, the subgingival contour of the abutment and crown may modify the soft tissue drape. The subgingival contour of the crown may increase the height of the papillae (when next to a tooth) or raise the cervical margin in the midtooth position.

On occasion, to develop the subgingival contour, the abutment post is removed from the implant and replaced with a PME. The PME prevents the soft tissue from collapsing over the implant platform. The abutment is inserted into an implant body analog. The final crown margin preparation on the abutment may be extended 1 to 1.5 mm below the level of the tissue on the facial and interproximal region while holding the abutment out of the mouth. Hence, the subgingival margins are prepared while on the implant body analog without tissue trauma and under direct vision (Figure 21-42, *E* to *G*).

The transitional crown margins and emergence profile also are placed while on the extraoral abutment and finalized. To do this, the abutment is lubricated and the transitional prosthesis seated on the abutment. Flowable composite may be added to the temporary crown margin to extend it where necessary or contour it as desired (Figure 21-42, *H*).

An extraoral impression is made of the two-piece abutment for cement and implant body analog by seating them 2 mm beyond the prepared margins into an elastic impression material held in a small segmented tray. This impression is poured in die stone and represents the stone die of the abutment post without the need for die trimming on the master stone cast. Although this technique provides a precise abutment margin, die, and temporary crown, an intraoral impression still is required to correlate the abutment to the other teeth and soft tissues (Figure 21-42, *I* and *J*).

The two-piece abutment for cement is reinserted in the implant body. A periapical radiograph ensures its complete seating. A torque wrench is used to tighten the abutment screw to 30 N-cm (depending on manufacturer specifications, implant material, design, and post thickness) while a hemostat holds the abutment, acting as an antitorque device. This preload technique is used to stretch the abutment screw and helps prevent abutment screw loosening at a later date. The abutment is then again obturated (Figure 21-42, *K*).

A retraction cord may again be placed around the implant post below the margin preparation but is usually not required. The transitional crown then is seated with gradual pressure, expanding the soft tissue, because the margins are extended subgingivally. The crown is allowed to remain in position for several minutes because it is acting as an impression cord. The transitional crown is also inserted to mold the emergence profile of the tissue for 5 to 10 minutes before the final impression. The temporary crown is removed and the soft tissue evaluated. The intraoral impression then is made after removing the crown. The retraction cord (when used) may stay in place below the crown margin during the final impression (Figure 21-42, *L* and *M*).

This technique provides the advantages of (1) subgingival margins without risk of trauma to the tissue as in the direct technique, (2) customized emergence profile created by the doctor instead of standard shape from a prefabricated anatomical abutment or made in the laboratory, (3) delivery of a transitional prosthesis during the same appointment, and (4) precise margins of the final crown because working on the extraoral individual die is as accurate as working on the actual abutment.

When soft tissues are not ideal and require manipulation at the initial prosthetic appointment, the transitional prosthesis may be used for 2 to 3 months before making the final impression. In this way, the interproximal papillae height and width may be assessed before the final impression along with the crown emergence from the soft tissue drape.

Progressive bone loading of the implant can reduce implant failure, and bone density increases have been reported while minimizing early crestal bone loss in softer bone types.[52] In a comparison study of replacement of maxillary first premolars, less crestal bone loss occurred in progressively loaded implants compared with implants that were not gradually loaded. Therefore, the acrylic provisional restorative delivered at the impression appointment is not placed in function during the next 4 to 6 weeks. In addition, the patient is instructed to avoid the area while eating.

Laboratory Phase

Soft Tissue Model. The stone cast to fabricate the final crown may be similar as for crowns fabricated on natural teeth. However, unlike a crown on a natural tooth, the implant crowns have a customized subgingival contour. The implant platform is only 3.5 to 5.5 mm wide and 2 to 4 mm below the soft tissue. On the master cast, it is below the stone, and the subgingival margin and its position must be correlated precisely with the emergence profile of the soft tissues. After the technician trims the dies for the fabrication of a crown, the soft tissue portion of the model is destroyed. As a result, the laboratory technician often is unable to contour the crowns properly in the interproximal regions to avoid triangular spaces above the tissue. Therefore, unlike restorations on natural teeth, a soft tissue model often is fabricated for a single-tooth implant crown. A soft tissue model enables the technician to maintain the soft tissue contour around the abutment and has become a popular aid in the fabrication of cervical contours of implant crowns.

The direct technique for single-tooth restoration uses stone dies to represent the abutment. In this scenario, the final impression is poured first in die stone. After separation, a second pour is made in the impression. The abutment portion is filled with epoxy resin or cold-cure acrylic resin. A retentive device is placed into the resin and projects from the abutment resin several millimeters. After it is set, a soft, resilient material representing the soft tissue is injected around the acrylic base. The remainder of the impression is poured in dental stone. When separated, the abutment for cement retention is represented in acrylic and surrounded by the soft, resilient material representing the soft tissue (Figure 21-42, *N*). A stone die is made from the first cast (as usual) and is used to fabricate the crown coping. When an individual abutment impression is made, it is used for this intent. The soft tissue cast is used to finalize the emergence profile during the different laboratory steps.

The soft tissue model brings attention to the interproximal regions and the height of the interdental papillae. The subgingival crown in the interproximal region should be slightly overcontoured, if necessary, to fill any potential triangular spaces and undercontoured on the facial cervical region. In other words, the facial contour is concave below the FGM, and the mesial and distal subgingival contour is convex. The soft tissue cast may be modified before the fabrication of the crown to improve the emergence profile. Hence, if inadequate space is available for an ideal emergence contour, the soft tissue model may be recontoured. The crown then may be fabricated to the ideal form (Figure 21-42, *O* and *P*; Box 21-5).

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BOX 21-5 Direct Crown Fabrication

1. Evaluate and modify implant site
   a. Rigid fixation
   b. Keratinized tissue
   c. Papillae height
   d. Cervical tissue height
   e. Bone loss
2. Modify natural teeth
   a. Interproximal contacts
   b. Rotated or uneven teeth
   c. Occlusal contacts
3. Select prefabricated abutment
   a. Titanium alloy
   b. Ceramic
4. Modify abutment
   a. Incisal
   b. Facial-incisal
   c. Facial-cervical
   d. Subgingival
5. Fabricate transitional
6. Modify subgingival margin and transitional if needed
   a. Intraoral or extraoral techniques
7. Obturate abutment screw access
8. Final impression or opposing impression
9. Deliver transitional crown

Laboratory Phase

1. Master cast preparation
2. Soft tissue model
   a. Modify as needed
3. Final crown
   a. Subgingival contour concave on facial and convex interproximally

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Option 2: Indirect Technique

The indirect technique for crown fabrication has become more popular in recent years. As in the direct technique, the PME is removed and the soft tissue contoured to the desired emergence (Figure 21-43, *A* and *B*). However, instead of inserting an abutment, a two-piece impression transfer, which engages the hexagon of the implant body, is attached and radiographically confirmed. An implant body impression then is made of the maxillary arch with an elastic impression material (Figure 21-43, *C*).

For a single-tooth implant, an open- or a closed-tray impression technique may be used. The key to keep in mind is that a two-piece transfer must be used to capture the antirotational feature of the implant body in the impression. When the impression transfer coping is designed with undercuts that lock into the impression, an open tray should be used to allow access to the fixation screw. After the impression has set, the transfer abutment screw is unthreaded to liberate the impression–transfer coping complex. The PME then is reinserted into the implant body. When the soft tissue was modified, the PME should be customized to the desired subgingival contour of the restoration.

In the closed-tray technique the transfer coping does not remain locked within the impression. This transfer must also be a two-piece coping (to capture the implant hexagon position), which uses a ball screw for retention, or it also can be a system using a cap impression that snaps on or into the antirotational feature (Figure 21-43, *D*). The cap remains attached to the impression and provides a secure orientation mechanism for the analog, which is inserted in the cap–impression complex. The shade of the final crown is made along with any necessary laboratory instructions.

Laboratory Technique

Soft Tissue Model. The method to fabricate a soft tissue model is easier for the indirect laboratory technique. An implant body analog is attached to the impression transfer and, if necessary, is replaced in the impression (Figure 21-43, *E*). A soft, resilient material mimicking the soft tissue is injected around the abutment and analog. Dental or die stone then is poured into the remainder of the impression. When separated, the implant body analog is held firmly in stone, with soft, resilient material representing the soft tissue around it. The soft tissue may be detached and replaced on the cast, which may serve as the master cast to fabricate the final restoration and evaluate the emergence profile of the crown (Figure 21-43, *F*).

The dental laboratory technician then may select a machined, two-piece abutment and prepare the post, similar to the doctor in option 1. Or the laboratory may fabricate a two-piece custom abutment, usually with a combination of metal coping and plastic sleeve. The custom abutment may also be developed with CAD-CAM technology (Figure 21-43, *G*).

After the abutment is customized to the particular situation, two methods may be used. In the first method, the laboratory fabricates a transitional restoration and returns it to the doctor. The doctor then inserts the custom abutment (or prepared two-piece abutment) and confirms the preparation margins and proper seating with a radiograph. The dentist makes a final impression and makes an impression of the temporary subgingival contour, and the transitional restoration is cemented with a soft cement on the final abutment. The laboratory then fabricates the final crown on a stone model, and another appointment is necessary to have a final delivery of the crown.

The second method of restoring the implant has the laboratory finish the final restoration on the abutment. Hence, the doctor may insert the abutment and deliver the final restoration in one appointment. This is the most common treatment option for the indirect laboratory technique (Figure 21-43, *H* to *J*; Box 21-6).

The first method is the safest to ensure an ideal crown because the dentist can confirm the laboratory preparation and contour of the transitional prosthesis before final crown fabrication. The dentist also may elect to deliver the abutment and temporary crown and wait several weeks for the soft tissue contour to stabilize before making the final impression. This allows the patient and doctor to assess the appearance of the tooth and soft tissue and to make modifications as needed before the final crown fabrication. This method also permits progressive loading for implants in soft bone.

Final Prosthesis

Implant crowns are often porcelain-to-metal, fabricated with noble alloys, which are less likely to cause metal corrosion, especially with subgingival margins on a metal implant. When a shoulder preparation is used, a porcelain butt joint margin is preferable. When all-porcelain crowns are fabricated, the higher impact force on implants is more likely to cause fracture. In addition, when the implant post is a metal color, little advantage accrues from a full-porcelain crown.

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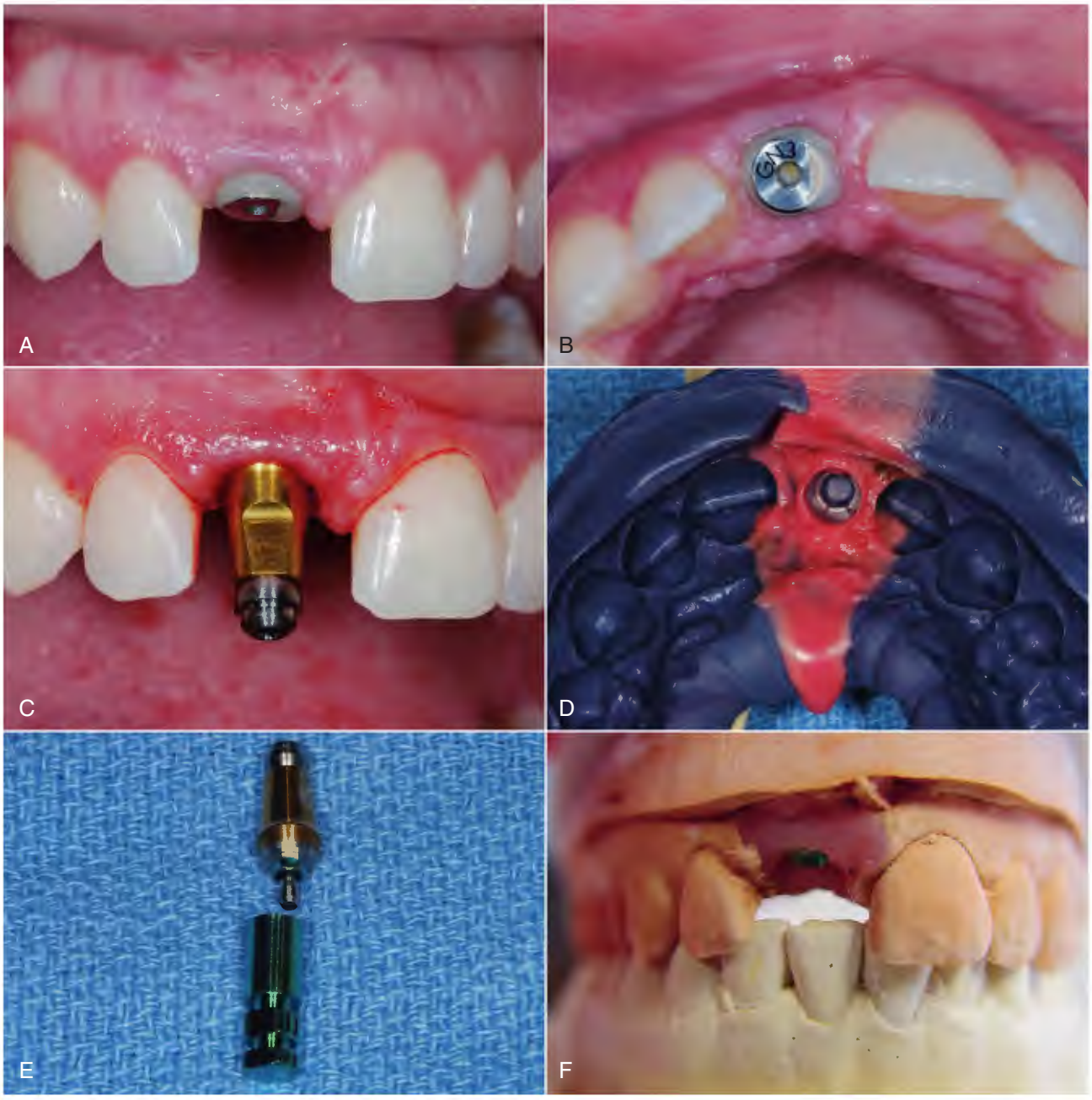


FIGURE 21-43. **A,** A maxillary right central incisor implant with a customized permucosal extension (PME) during one-stage implant healing. **B,** The customized PME allows the interdental papilla height to be maintained. **C,** A two-piece impression transfer coping which engages the antirotational hex is inserted into the implant body. **D,** A closed-tray impression is made of the impression transfer and surrounding teeth. **E,** The impression transfer is inserted into an implant body analog and then reinserted into the final closed-tray impression. **F,** A soft tissue model is prepared from the final impression, with the implant analog in position.

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FIGURE 21-43, cont'd. **G,** The laboratory selected a premade ceramic abutment and prepared the finish lines for the crown. **H,** The coping is made for the final crown on the implant abutment. **I,** The crown is fabricated on the coping. **J,** The final crown contour is developed with the soft tissue model. **K,** This crown represents the emergence profile similar to the adjacent teeth at the free gingival margin. The subgingival contours of the final crown are unique to each patient. Most often they are convex on the interproximal regions and concave on the facial subgingival regions. **L,** The indirect technique first seats the final abutment prepared by the laboratory.

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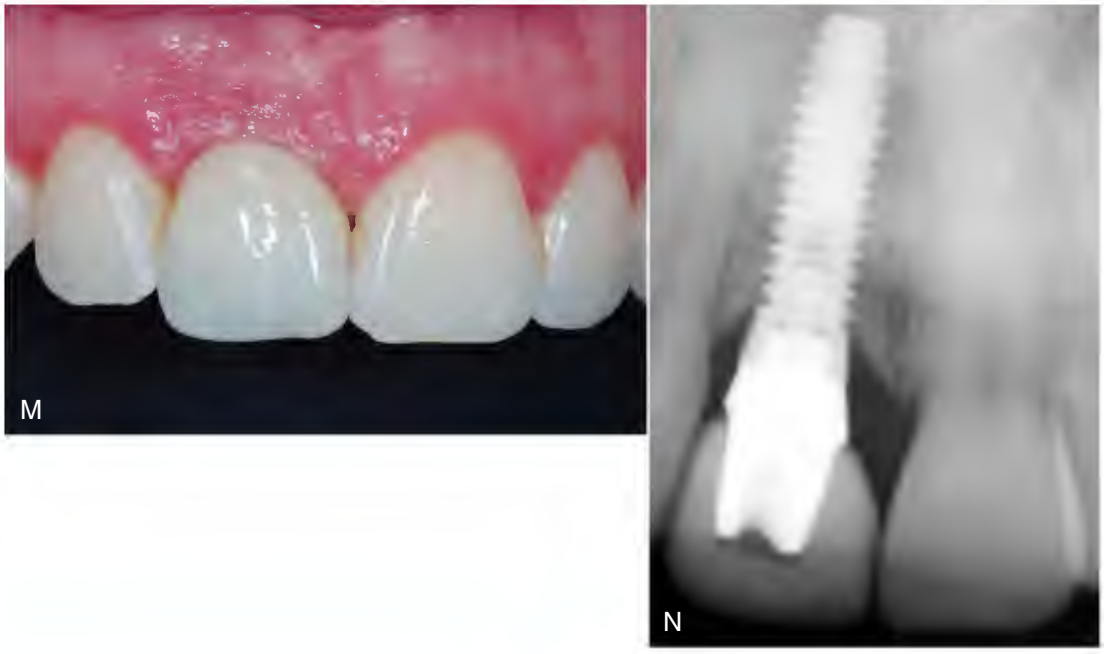


FIGURE 21-43, cont'd. **M,** The final crown is evaluated for the shade, hue, contours, and occlusion. **N,** A periapical radiograph confirms that no residual cement is present.

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BOX 21-6 Indirect Crown Fabrication

1. Evaluate and modify implant site
2. Modify natural teeth
   a. Interproximal contacts
3. Open- or closed-tray impression
   a. Two-piece implant body transfer impression
4. Replace permucosal extension (modify as indicated)

Laboratory Phase

1. Fabricate master model or soft tissue model
2. Select abutment
   a. Prefabricated
   b. Custom
3. Prepare abutment
4. Fabricate crown

The contours of the final crown are dictated by the surrounding hard and soft tissue characteristics. Ideally, by the time the final crown is fabricated, all parameters for a harmonious, well-integrated crown ideally should be in place. The crown should follow the normal criteria for an anterior tooth, independent from the support system in the bone, implant, or natural tooth. However, most often the subgingival contours must be customized to improve the soft tissue drape. The thickness of bone on the facial aspect of a natural root is usually 0.5 mm thick. The implant is 1 mm more palatal than the facial emergence of the adjacent crowns at the crest of the bone. The final restoration will compensate for the emergence from the FGM to be similar to the adjacent teeth (Figure 21-43, *K*).

Final Crown Delivery

In the indirect technique, the abutment must be delivered before the final crown delivery (Figure 21-43, *L*). The final crown is then seated and evaluated for shade, hue, contour, and occlusion. A high bite force followed by a heavy bite force is used to evaluate both centric and excursions before cementation. This is important because the adjacent teeth are more mobile in the anterior regions of the mouth compared with posterior single-tooth situations (Figure 21-43, *M*). The crown is seated with a radiopaque cement, so it may be evaluated with a periapical radiograph (Figure 21-43, *N*). Most often, this is a zinc polycarbylate cement, so the crown may be removed if abutment screw loosening occurs.

At the final crown delivery, the larger emergence profile of the subgingival crown contour will blanch the tissue for about 10 minutes while it expands and reorganizes itself around the emergence profile of the crown. If the tissue does not return to normal color within 10 minutes, the expansion may cause the tissue to recede at the expense of the papilla or labial tissue, with unlikely regeneration. Hence, the subgingival contour may need to be developed over a period of 10-minute intervals. First the crown is seated one third to halfway for 10 minutes, and when the soft tissue color returns to normal, it is then finally seated (Figure 21-44).

Complications

Complications of maxillary anterior single-tooth implants primarily include interproximal papilla deficiencies, abutment screw loosening, and crestal bone loss (with or without gingival shrinkage after crown delivery). The complication of abutment screw loosening and crestal bone loss is addressed in earlier chapters. The complication addressed in this chapter is related to the prosthetic methods to address the soft tissues.

Soft Tissue Compromise

The primary esthetic complications of maxillary anterior single-tooth implants include interdental papillae deficiency, facial contour deficiencies, and gingival shrinkage after crown delivery. The interproximal CEJ of a natural tooth exhibits a scallop toward the incisal edge. The same pattern is followed by the

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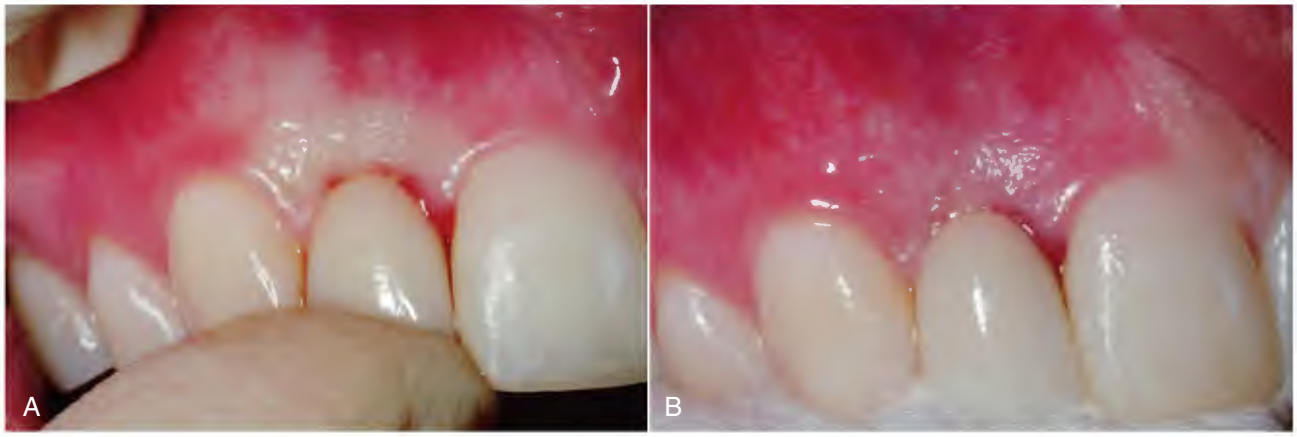


FIGURE 21-44. **A,** The final crown is often inserted in stages. When the tissue blanches, the soft tissue drape is being modified. **B,** The soft tissue drape should return to a normal color within 10 minutes. If not, incremental seating is indicated.

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alveolar interproximal bone, which is more coronal in the interproximal regions than in the facial or lingual plates. As a result, the probing depth in the papilla region of a natural tooth is similar to the facial or palatal probing depths.

Interproximal bone around an implant does not follow such a contour. As a result, the interdental papillae, when it looks natural and rises to fill the interproximal regions between healthy adjacent teeth, exhibits greater probing depths than the other surfaces of the implant crown. In fact, when the interproximal bone height is lost next to the adjacent teeth, the dental or implant papilla also corresponds to a greater interproximal probing depth next to the adjacent natural tooth. A greater sulcus depth increases the risk of shrinkage after gingivoplasty or later with good daily care. As a result, even years later, the tissue may shrink and result in a poor interproximal esthetic situation.

The facial probing depth around an implant crown is also greater than a natural tooth. The implant abutment, even when the implant crest module is placed 3 mm below the facial tissue margin, does not have a connective tissue attachment. In addition, crestal bone loss of 0.5 mm from the abutment connection is usual and may occur as far as the rough surface or the first thread on the implant body, which is up to 3 mm from the abutment connection.[18] As a consequence, facial probing depths may be greater than 4 mm. The increase in pocket depths increases the risk of gingival shrinkage and exposure of the implant crown margin.

The facial position of the implant may not have 1.5 mm of bone around the implant body. The crown contour (or facial aspect of a wider abutment) may be overextended. The net result is often that the facial aspect of the final crown may recede and expose more of the implant crown.

Interdental Papilla Deficiency

As previously addressed, four surgical time sequences exist to address the interproximal tissue height: (1) before a bone graft with a free tissue or connective tissue graft; (2) in conjunction with a bone graft, often using an acellular tissue graft (i.e., AlloDerm); (3) at implant insertion, with an elevation of the tissue over a PME; and (4) at implant uncovery (i.e., split-finger technique). In addition, there are several other methods to improve the soft tissue drape. Many of these approaches used to modify the soft tissue are prosthetic-related methods.

A prosthodontic solution may be used to alleviate soft tissue limitations.[51] These techniques are helpful when soft tissue surgery has not recreated an ideal interproximal papilla height. The most common method used is to modify the interproximal crown contact position and cervical crown contour.[50] The interproximal region may be treated similar to the pontic interproximal region of a three-unit FPD (Figure 21-45). Rarely are full-contour interdental papillae present next to the pontics of a fixed prosthesis. Instead, rather than raising the tissue to the interproximal contact, the interproximal contact is extended toward the tissue, and the cervical region of the pontic is slightly overcontoured in width.

A similar interproximal approach may be applied to the single-tooth implant.[50] The interproximal contacts of the adjacent teeth are recontoured, especially on the palatal line angle, to become oblong and extend toward the tissue (Figure 21-46). This is especially advantageous for lateral or canine implant crowns. The mesial of the canine or first premolar is often overcontoured in relation to the interproximal CEJ. The interproximal contact of the adjacent teeth can be lowered toward the tissue, and because the contralateral tooth is not directly observed (especially when looking at a canine), the patient is unaware of the slight change in adjacent tooth contour.

When a central incisor papilla is depressed and the adjacent tooth interproximal contact needs to be modified, the enameloplasty is performed on the lingual line angle of the contact position. The cervical region of the single-tooth implant is overcontoured slightly in width, similar to the pontic of a fixed prosthesis. This concept does slightly compromise the crown and soft tissue contour of the interproximal esthetics (Figure 21-47). The papilla is not as high next to the implant crowns as between the natural teeth, and the cervical width of the crown is 0.5 mm or more wider. However, the sulcus depth is reduced compared with an elevated papilla, and the daily hygiene conditions are improved. In addition, long-term shrinkage of the tissue is less likely to occur. Perhaps the most important reason to follow this protocol is that the patient is less aware of a decrease in papilla height compared with the absence of the papilla filling the interproximal space. This option should be the method of choice whenever possible when the papilla height is not ideal.

The technique of changing the contact shape and position and increasing the cervical width of the tooth is best as the tooth

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FIGURE 21-45. **A,** The anterior teeth have been prepared for a traditional fixed partial denture (FPD). **B,** The six-unit FPD in situ. The interproximal regions have the interproximal contacts and tooth shape fill the interproximal region, rather than having triangular spaces between the teeth.



FIGURE 21-46. **A,** The interproximal contact of the lateral incisor is recontoured, so it may extend toward the interdental papilla. **B,** The final crown contour is modified to be more ovoid to fill the interproximal space.

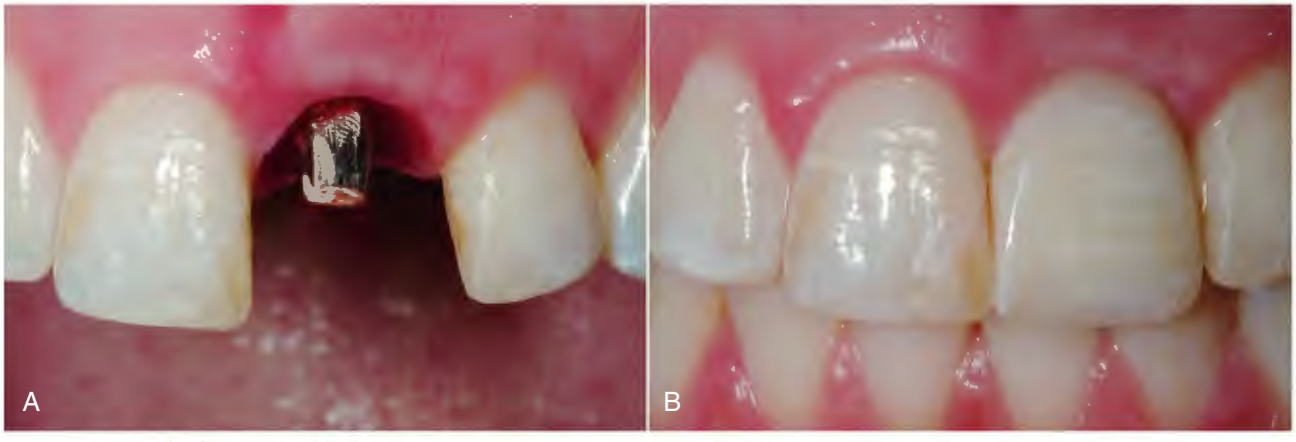


FIGURE 21-47. **A,** A central incisor implant with a depressed interdental papilla height. **B,** The interproximal contacts extend to the tissue, especially on the palatal line angle. The contour of the crown is also more square to ovoid.

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restored is farther from the midline. When the distal papilla height of a canine is observed, the other canine cannot be seen. Hence, the subtle changes in crown contour are unnoticed. However, when the deficient papilla is around a central incisor crown, the difference in the cervical region is obvious. One can hope the high lip line during smiling does not demonstrate any of the soft tissue drape.

The subgingival contour of the implant crown in the mesial or distal dimension may be extreme to push the tissue toward the adjacent tooth and elevate the interdental papilla. The technique for pushing the interproximal tissue against an adjacent tooth is usually the last treatment option when the patient is unwilling to undergo a surgical or orthodontic solution (by extruding the adjacent teeth). The interproximal contacts are lowered to the tissue, especially on the palatal line angle. The transitional crown is a square tooth form, first made to the height of the tissue. The abutment is then removed and attached to an analog (handle), and the transitional crown is seated on the prepared abutment. A square 1- to 1.5-mm subgingival emergence profile is created with a composite resin on the transitional crown. The abutment is reseated in the implant, and the transitional crown is seated, in steps of time increments based on the blanching of the tissue. After the tissues are normal color, the temporary is removed, and a final impression is made.

The final crown is made similar to the square transitional tooth form. When seated, it is also seated in intervals based on the color of the tissue. A radiopaque cement is used (e.g., zinc phosphate), and a radiograph is taken to ensure no residual cement remains below the tissue (Figure 21-48). The square crown contour is less noticeable to the patient than the triangular space next to the implant crown. The square tooth form may be exaggerated along with some interproximal staining (Figure 21-49). The final esthetic result is not ideal. However, the triangular spaces below the interproximal contacts of a crown with an ideal tooth form are more of an esthetic compromise. The patient is more aware of the tooth shade, value, and hue than the tooth form.

A custom abutment is often used for this exaggerated subgingival emergence contour for two reasons: (1) It may start near the implant platform. When only the subgingival contour of a cemented crown is used for this purpose at the implant abutment connection level, residual cement is a common consequence. (2) The abutment screw may seat the abutment in several stages. The abutment is initially inserted until the tissue blanches. When the soft tissue color returns to normal, it is threaded again until the tissue blanches again. After the color returns, it is finally completely seated. The crown is also designed with an exaggerated mesial or distal contour. This contour begins 1.5 mm below the interproximal FGM.

When an abutment is used for this intent, the facial and lingual "flare" of the wider abutment is often reduced when the midfacial soft tissue drape is not excessive. Otherwise, the midcervical tissues recede, resulting in a crown that appears longer in the midfacial region. In addition, pushing the tissue in all directions may actually cause the interproximal tissue to recede rather than elevate (Figure 21-50).

On occasion, the lack of interdental papilla is significant. This occurs most often with tapered tooth forms adjacent to the missing space. This condition should be especially noted when the missing tooth is a central incisor. As a consequence of the tooth shape and interdental papilla position, the restoring dentist should consider a crown or veneer on the adjacent central incisor. The tooth forms of the two central incisors may be modified to an ovoid to square crown shape, which lowers the interproximal contact and decreases or eliminates the triangular space between the tissue and interproximal contact. In addition, the shade, value, and hue of the adjacent central incisor crowns (implant and natural tooth) are easier to match when two adjacent crowns are fabricated at the same time (Figure 21-51).

A composite resin may be used on the interproximal region of a tooth next to an implant site to modify the adjacent tooth form and lower the interproximal contact to the height of the tissue. This is more often performed on lateral incisors or first premolars when the CEJ region is especially narrow compared with the crown of the tooth.

On occasion, the difference in the soft tissue drape is primarily on the midfacial region of the crown. Making the implant crown concave below the FGM may improve this condition. When the patient has a high smile line and exposes the mid FGM during smiling, the dentist may opt to perform esthetic crown lengthening to the anterior natural teeth. It is easier to elevate the FGM by esthetic crown lengthening on the adjacent teeth than to advance the soft tissue drape on the implant crown.

The last treatment option to restore a deficient soft tissue drape is with pink porcelain. Although this method is often the treatment of choice when multiple adjacent teeth are restored and the soft tissue drape is compromised, it is less a treatment option for a single-tooth crown. Pink porcelain is more difficult to match the existing, surrounding soft tissue compared with the crowns of the adjacent teeth. When a high smile displays the pink porcelain of the implant crown and the eye can directly compare it with the surrounding tissue, a compromise in color is usually seen. The line between the soft tissue and porcelain is usually easy to observe. The concept works best when the compromise of the soft tissue drape does not include the interproximal region (Figure 21-52).

One option to restore the soft tissue with pink porcelain is to make a custom abutment with pink porcelain and a butt joint margin for a crown. This method is more effective when the midcervical aspect of the soft tissue is deficient rather than the interdental papilla region (Figure 21-53).

Time Technique

It has been noted by Jemt that the height of the interdental papilla increases over a 2-year period after crown delivery 80% of the time.[53] He published a papilla classification, which states a type 3 papilla is ideal in height (filling the interproximal space). A class 2 papilla fills half or more of the interproximal space. A class 1 papilla fills less than half the interproximal region. A class 0 papilla was a complete lack of papilla height (Box 21-7). At implant crown delivery, evaluating both mesial

Text continued on p. 538

BOX 21-7 Jemt Papilla Classification[53]

INDEX SCORE	DESCRIPTION
0	Absent papilla
1	< ½ papilla height
2	≥ ½ papilla height but short of interproximal contact
3	Entire space is filled
4	Overfilled, hyperplastic tissue

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FIGURE 21-48. **A,** A central incisor implant and abutment with a compromised soft tissue drape. **B,** A transitional crown is made to the soft tissue (after the interproximal contacts have been extended toward the tissue on the palatal line angles). **C,** The abutment is removed and inserted into an implant body analog and handle. The crown margin preparation is extended 1.5 mm below the free gingival margin (FGM). The transitional crown is seated on the lubricated abutment. **D,** Composite resin is added to the transitional crown to form a square tooth form. **E,** The abutment and crown are reinserted into the implant and maintained in position for at least 10 minutes and may remain for several months. **F,** The transitional crown is removed, and a final impression is made.

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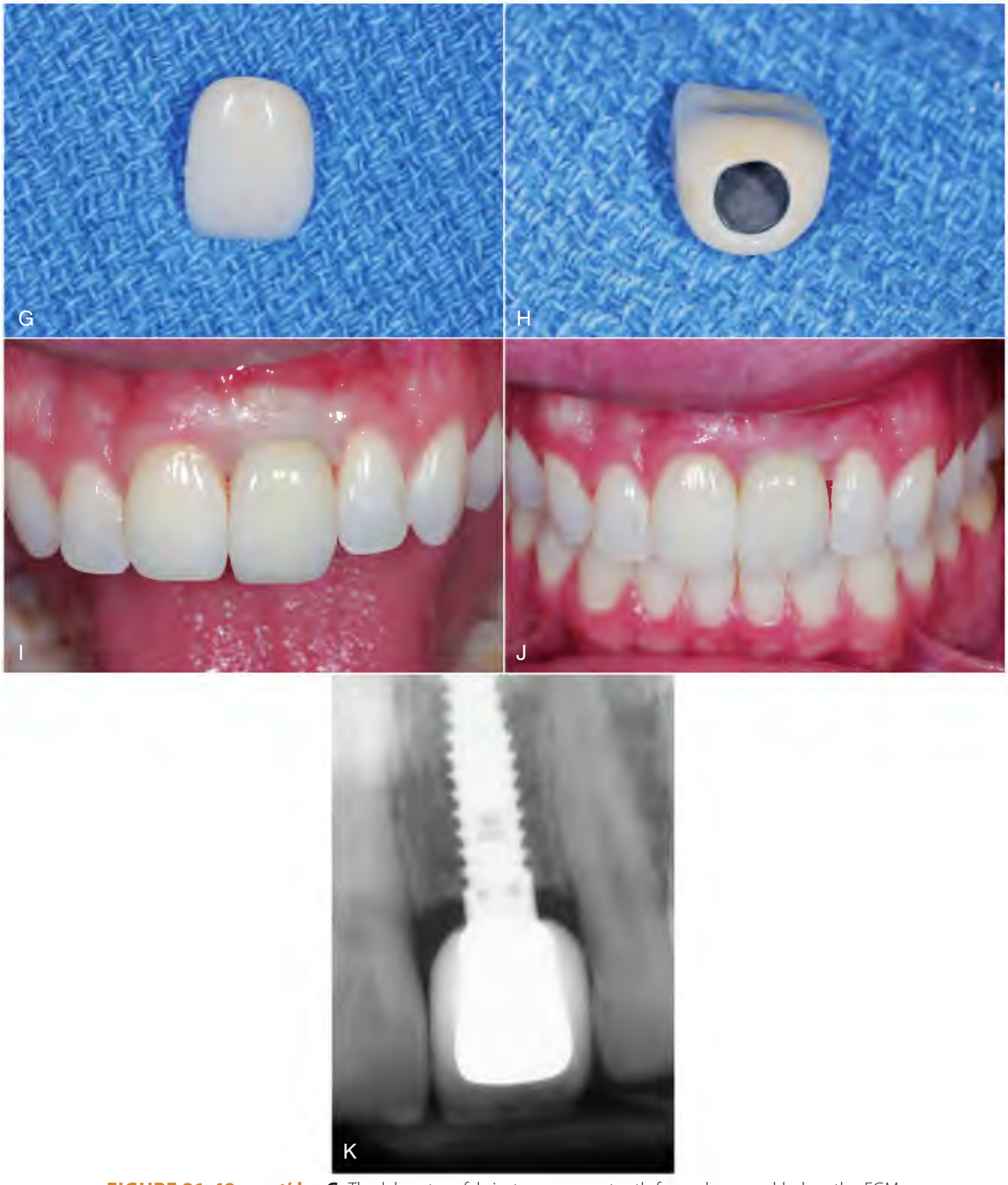


FIGURE 21-48, cont'd. **G,** The laboratory fabricates a square tooth form above and below the FGM. **H,** The square tooth extends subgingival to modify the tissue. **I,** The maxillary left central crown is seated in increments of 10 minutes and blanches the soft tissue as it is modified. **J,** The tissue should return to normal color within 10 minutes when finally seated. **K,** A periapical radiograph confirms no residual cement is present below the crown margin after cementation.

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FIGURE 21-49. **A,** A maxillary right central implant and abutment with lack of interproximal papillae. **B,** A square tooth form is fabricated. **C,** The square tooth form fills the interproximal space. **D,** The maxillary right central crown in position with a square tooth form and interproximal shading. The final result is not ideal but is less compromised compared with large triangular spaces below the interproximal contacts.

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FIGURE 21-50. **A,** An overcontoured custom abutment. **B,** The custom abutment is overcontoured 360 degrees. The tissue is still blanched and did not return to the normal color after 10 minutes. **C,** The facial and distal papillae receded, and the tissue is still blanched after 10 minutes. **D,** The facial and distal papillae have receded as a consequence of too much pressure for too long.

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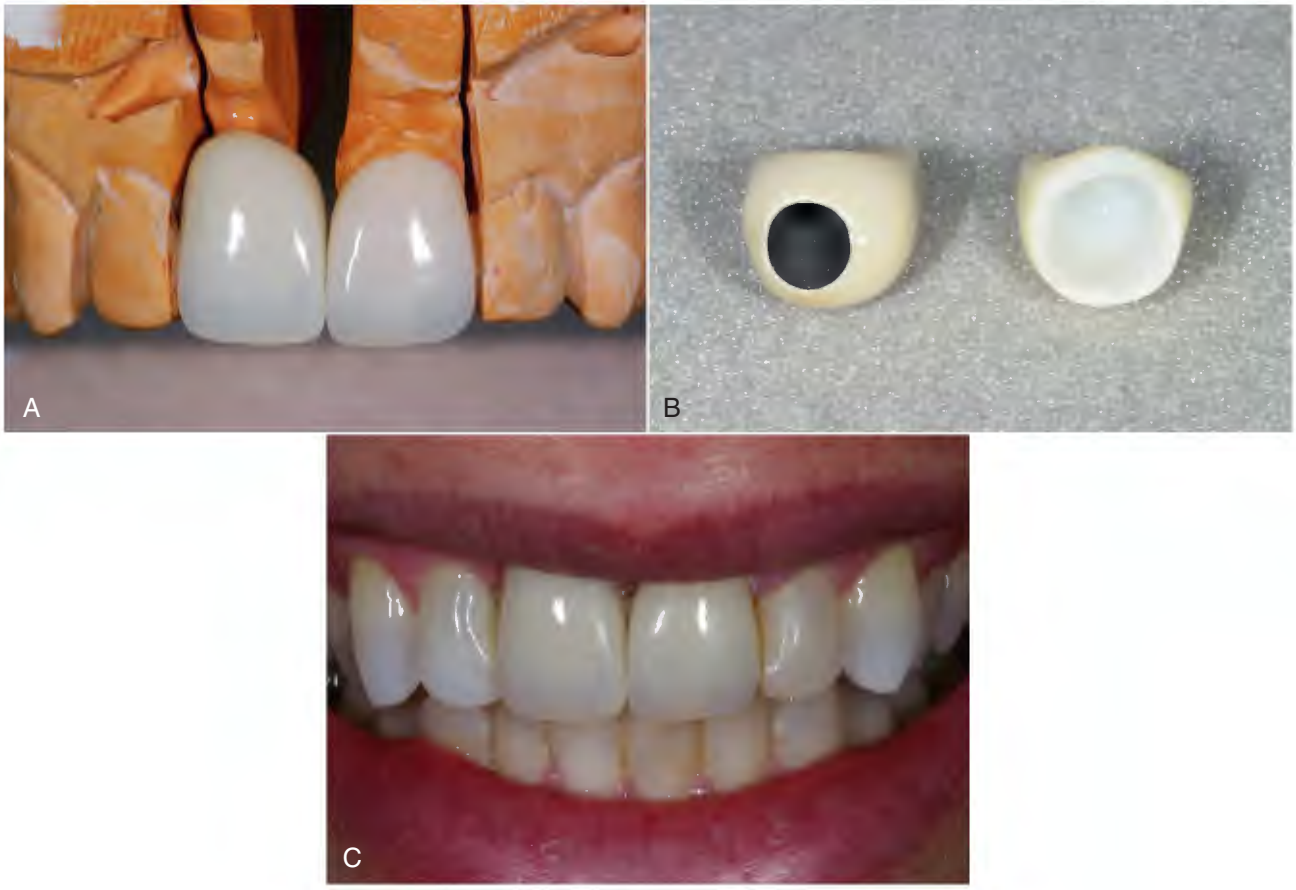


FIGURE 21-51. **A,** An implant crown and an adjacent porcelain crown for two central incisors that were tapered tooth forms converted to ovoid to square tooth forms. **B,** The implant crown *(left)* and tooth crown *(right)* have a square tooth form. **C,** The shade, value, hue, and contour of the adjacent crowns are more in control of the dentist when they are restored together.

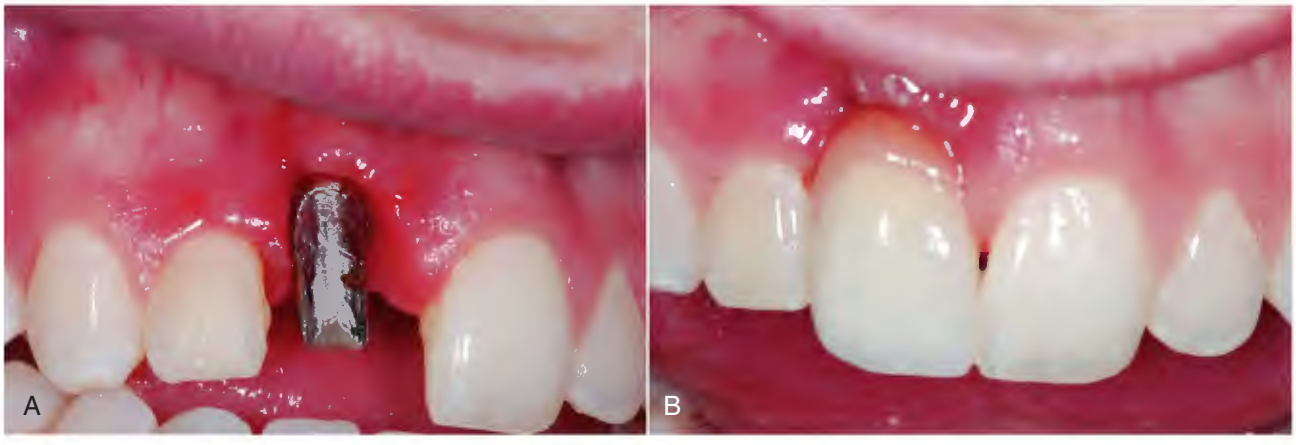


FIGURE 21-52. **A,** An implant and abutment with a compromised soft tissue drape. **B,** The pink porcelain added to the implant crown attempts to replace the cervical lack of soft tissue around the left lateral incisor implant.

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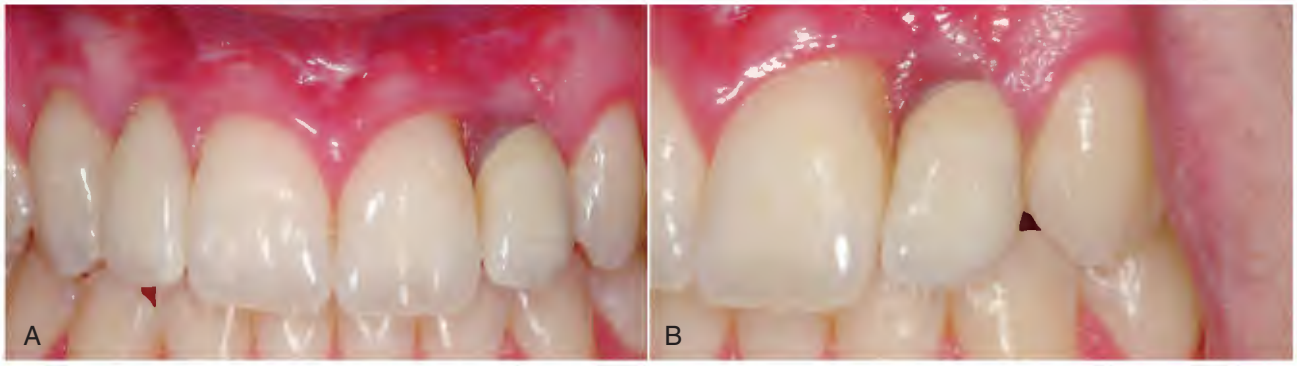


FIGURE 21-53. **A,** A customized abutment with pink porcelain below the crown margin used to replace the lack of soft tissue. **B,** The composite restoration on the adjacent central incisor and lack of interproximal bone have compromised the soft tissue drape in the region. The custom abutment with pink porcelain attempts to improve the esthetic result.



FIGURE 21-54. **A,** A maxillary right lateral incisor implant and abutment. **B,** The interproximal regions have Jemt type 2 interdental papillae. **C,** After 2 years, the interdental papilla has filled the mesial interproximal space, and the distal papilla is also improved.

and distal interdental regions, the average class papilla was type 2. After 2 years, 80% of the papillae were class 3. Even more important, in this report at initial crown delivery, half of the papillae were class 0 or 1. Two years later, fewer than 10% were class 0 or 1, and the majority were class 3 (Figure 21-54).

Some restoring dentists prefer to leave the patient in a temporary crown for 1 to 2 years to take advantage of this soft tissue improvement before final crown fabrication. The disadvantage of this technique is that the patient is looking at this specific region for 2 years. Instead, this technique may be used to divert a patient asking about the lack of interdental tissue in the interproximal area. If the patient notices this deficiency at crown delivery, he or she is told it will be addressed in 2 years because it usually improves. Most of the time, the patient forgets about this deficiency during that time frame.

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It should be understood the lack of interdental papilla in the interproximal space is not a failed restoration. Interproximal spaces frequently exist in normal, healthy natural teeth. In a study by Tarnow et al., the lack of interdental papilla filling the interproximal space is a common observation.[54] Almost 90% of the interproximal height from the bottom of the crown contact to the level of the bone in the natural dentition was 5, 6, or 7 mm. Eighty percent of the time it was 6 mm or more (Figure 21-55). When the distance was more than 5 mm, an interproximal space was found between the teeth 40%, 75%, and 80%, respectively (Figure 21-56). Hence, this condition frequently occurs with natural teeth (Figure 21-57).

Prosthesis Fabrication

The patient most often comes to the restoring dentist for the first prosthetic appointment with a low-profile permucosal healing extension in place. At this preliminary appointment, the restoring dentist should verify that implant placement is within restoring guidelines, is rigid, and is surrounded by mature, keratinized soft tissue (Figure 21-58). The probing depths around the implant should be less than 4 mm, and the crestal bone on radiographs should be within 1.5 mm of the abutment-to-implant connection.

The dentist evaluates the contours of the adjacent teeth and occlusal plane and corrects them when necessary. Most often, the opposing natural tooth has exfoliated or extruded, and the occlusal plane (especially the cusp tips) should have enameloplasty to correct the occlusal contact positions. The adjacent interproximal contacts should often be recontoured, especially when the adjacent tooth has tipped toward the edentulous site. Otherwise, a large triangular interproximal space will exist after implant crown delivery and result in a food and plaque trap. The dentist should evaluate the occlusion of the patient. During this appointment, the dentist also can identify all necessary implant prosthetic components and screwdrivers that will be required for the next prosthetic appointment. A multitude of abutment designs are available in each system and was previously presented. When time is available, the dentist may take the opposing impression and determine the shade of porcelain.

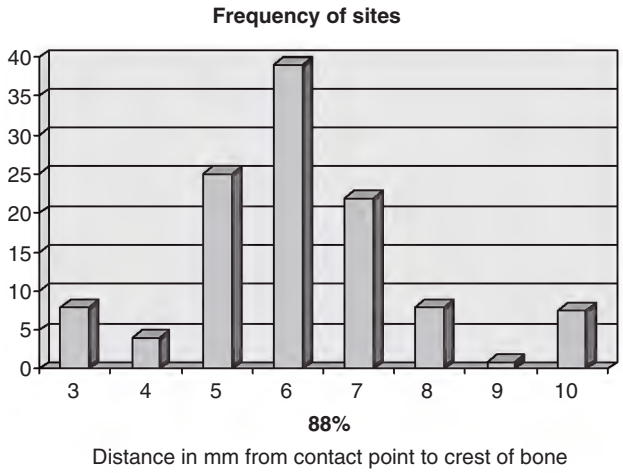


FIGURE 21-55. Tarnow et al. measured the distance from the bottom of the interproximal contact to the level of the interdental bone in natural teeth. Measurements of 5, 6, or 7 mm were present 88% of the time.[54]

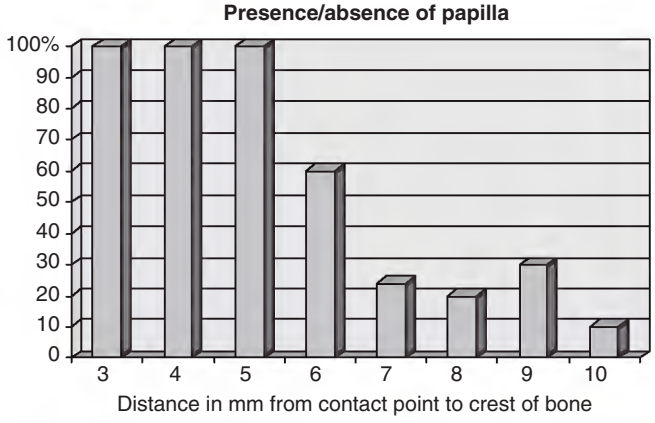


FIGURE 21-56. When the interproximal contact–to-bone distance was 6, 7, or 8 mm, the papilla did not fill the interproximal space 40%, 75%, 80% respectively.[54]

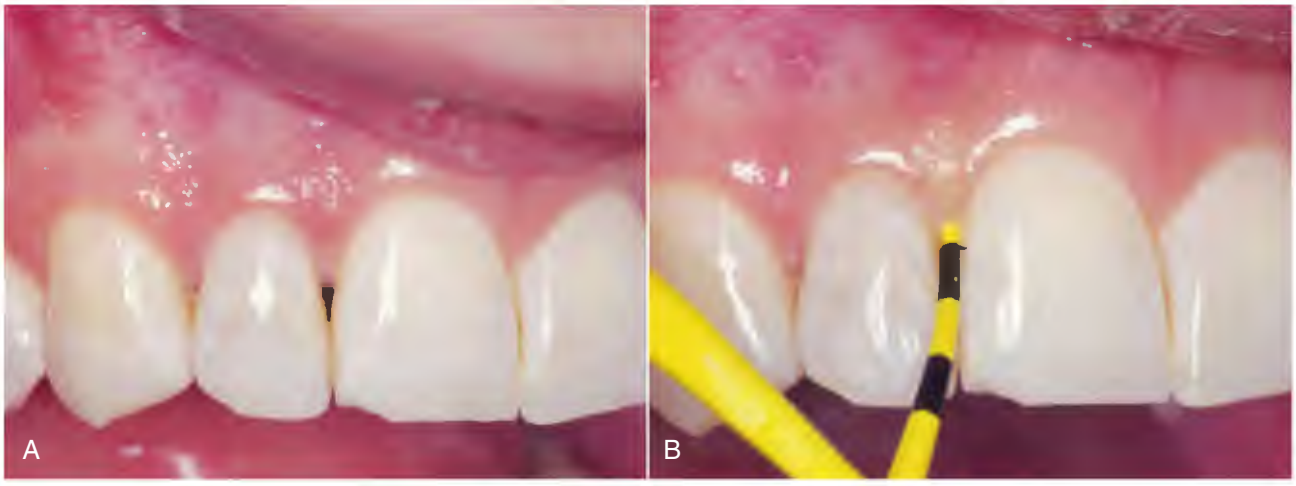


FIGURE 21-57. **A,** A patient with natural dentition and an interproximal space on the mesial of the lateral incisor crown. **B,** Bone sounding to the bottom of the interproximal contact is 3 mm. This triangular-shaped tooth is healthy, but a triangular open space is present.

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At this appointment, the restoring dentist should decide if the restoration will be fabricated with a direct approach or an indirect technique. The direct technique restores the implant similar to fabricating a tooth with a prefabricated endodontic post. The indirect technique uses implant body analogs, and the laboratory prepares the abutment and fabricates the crown directly on the abutment. A closed tray with an indirect impression transfer or an open tray with a direct impression transfer may be used for the indirect (laboratory-assisted) technique (Figure 21-59).

Direct Restorative Technique

The next restorative appointment is the key to a restoring practice and represents the main production time for the procedure. For an experienced dentist, this procedure also may be performed at the first evaluation appointment. In nonesthetic areas, a two-piece standard abutment (wider than the implant body) is the first choice. Areas with specific esthetic or contour requirements may require the fabrication of a custom abutment. In this instance, the dentist should not select the direct method. Instead, the dentist should obtain an implant body impression for fabrication of the abutment and crown in the laboratory with an indirect method technique.



FIGURE 21-58. A mandibular second premolar site with a permucosal healing extension in position. The implant is rigid, has adequate surrounding nonmobile tissue, and is within the contours of the final restoration.

The dentist unthreads the PME, usually with a 0.50-inch hexagonal tool and most often without anesthesia. The dentist then inserts a two-piece abutment engaging the antirotational feature of the implant body (Figure 21-60, *A*). The dentist immediately inserts the abutment onto the implant crest module without delay upon removal of the permucosal healing extension. Otherwise, the circular connective tissue fibers may collapse around the implant crest module, and the restoring dentist will need to excise the tissue with a tissue punch, scalpel, or high-speed diamond bur over the top of the implant. This procedure requires anesthetic and prolongs the process, and the gingival bleeding may complicate the final impression of the abutment.

After the abutment engages the antirotational feature and the abutment screw is inserted initially, the abutment should fit within the contours of the restoration. If the implant body is angled more than 15 degrees to the occlusal plane, it may be angled beyond the contour of the final restoration, and the dentist should select a preangled abutment of 15, 20, or 30 degrees (available from most manufacturers) to correct the angled implant body. A periapical or vertical bitewing radiograph confirms the proper seating of the components (Figure 21-60, *B*). On occasion, the abutment does not engage the hexagon properly or has captured soft tissue in the interface and needs to be seated completely and again radiographically confirmed.

After confirming the abutment is in proper position, the dentist uses a torque wrench to tighten the abutment screw. The most common torque applied to the screw is 30 N-cm and represents 50% to 75% of the elastic modulus of the material and design of the screw. The dentist uses a hemostat to hold the abutment during torquing to reduce the shear forces applied to the crestal bone around the implant body. This is especially important in D4 bone quality. The dentist then loosens the abutment screw and tightens it again to 30 N-cm. This slightly increases the stretching of the thread and reduces screw loosening.

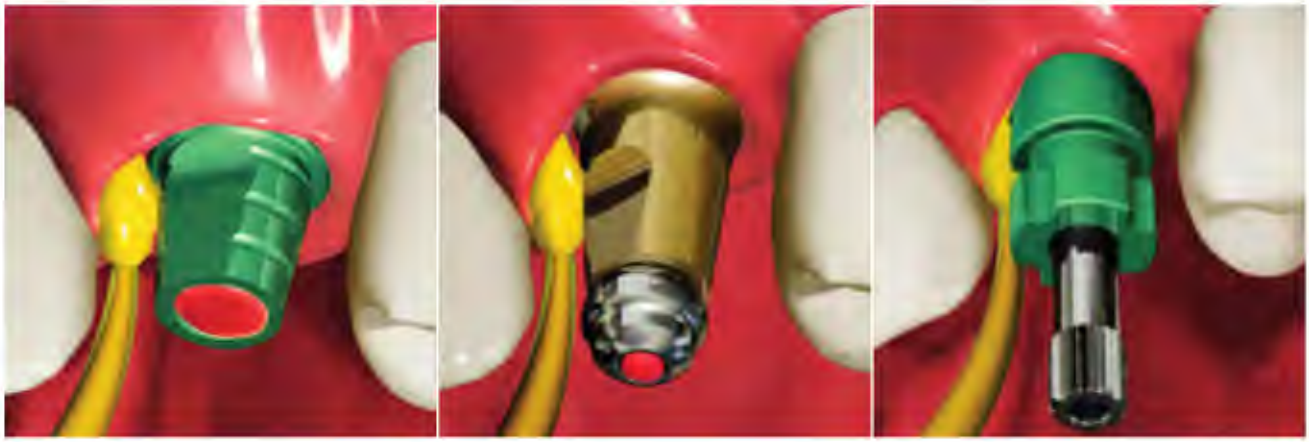


FIGURE 21-59. There are three restorative options for the restoration of a prosthesis: (1) the direct restorative technique, which uses a prefabricated abutment *(left);* (2) an indirect closed-tray procedure, which uses an indirect impression transfer *(middle);* and (3) an indirect open-tray technique, which uses a direct impression transfer *(right)*.

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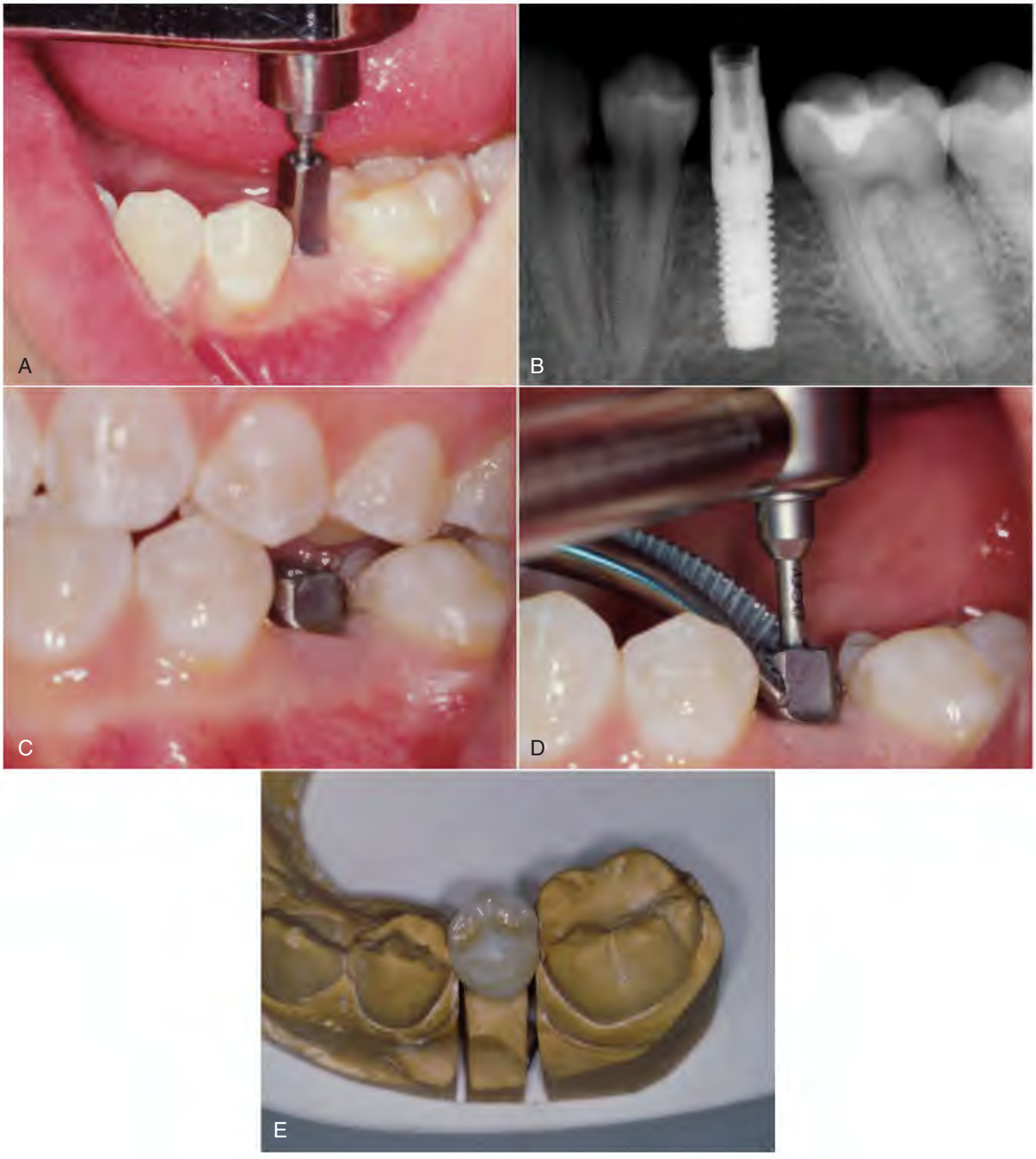


FIGURE 21-60. **A,** A two-piece abutment for cement is positioned onto the antirotational hexagon of the implant body. The abutment should be within the contours of the restoration and within 15 degrees of the occlusal plane. **B,** The abutment is completely seated on the crest module. A periapical radiograph is used to confirm the position. **C,** The premolar implant abutment is 4 mm in height above the tissue. Therefore, a subgingival margin is indicated. **D,** A 30–N-cm torque wrench is used again to tighten the abutment screw and places a shear force on the implant, so a countertorque is used with a hemostat. **E,** The implant crown is made on a stone die, similar to a crown on a natural tooth, but with a wider central fossa directly over the implant abutment for the primary occlusal contact.

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The dentist uses a high-speed handpiece and copious amounts of water and a new crosscut fissure bur (e.g., #702 or #703) to prepare the height of the abutment for cement retention. There should be 2 mm of occlusal space for esthetic restorative materials. The occlusal material is selected before abutment preparation because it may affect the amount of post height reduction (metal occlusals only need 1 mm of occlusal space).

The abutment is then prepared for taper and path of insertion. The finish line may be a knife edge or a chamfer. The abutment post may need to be prepared with a chamfer if less than 1.5 mm of space is found between any abutments (natural or implants). When two implants restore one molar, the interimplant region of the abutment posts may require a chamfer preparation to increase space between them and ensure adequate interproximal contour and hygiene access. Some abutments are machined with a particular finish line. In those cases, the dentist evaluates the position of the manufactured finish line and modifies it as required.

At least one side of the abutment (usually the facial) should have a flat (rather than round) contour. In addition, a buccal or lingual groove (or both) is often prepared in the abutment post and is engaged by the restoration. In this way, compressive forces are applied to the cement and resist the rotational shear forces to the cement seals of the crown.

The margins of the final crown in the posterior regions of the mouth are most often at or above the gingival level if crown retention is adequate and out of the esthetic zone. If the implant cervical region is not in the esthetic zone, a finish line at or above the tissue allows easier impression making and daily hygiene. However, the abutment should be at least 5 mm in height to ensure adequate retention of the final crown. When the implant abutment is 4 mm above the tissue, a 1 mm subgingival margin is indicated (Figure 21-60, *C*). If the implant crown is in the esthetic zone, a subgingival margin is also indicated on the facial and interproximal regions. In esthetic regions or short interarch spaces with reduced height of abutments, the dentist makes a subgingival margin on the abutment. As a result, before preparing the subgingival margin, the dentist inserts a retraction cord into the sulcus. This procedure is easier than that for a natural tooth because no connective tissue fibers are inserted into the implant abutment.

A torque wrench at 30 N-cm and hemostat countertorque is used again on the abutment and screw after the crown preparation (Figure 21-60, *D*). This confirms that the abutment screw did not vibrate loose during crown preparation. In addition, the time of the abutment preparation has permitted some rebound of the strain in the abutment screw, and retorqueing the screw stretches it again.

After the second screw tightening procedure, the access hole to the abutment screw is obturated with an endodontic access filler (e.g., Cavit, composite, or resin). Before obturation, a cotton pellet is placed over the head of the abutment screw. If the obturation materials fill the screw slot, it will be difficult to retighten the screw if it ever becomes loose.

All of the line angles of the preparation are made smooth, especially on the occlusal of the preparation. A stone die will represent the abutment in the laboratory, and any sharp edges may result in breakage or chipping of the stone die upon removal from the impression and will cause the casting to not seat completely in the mouth.

The dentist makes a final impression of the implant abutment with an elastic impression material along with a closed-mouth bite registration and opposing impression. The shade and crown materials are then selected. The dentist fabricates a transitional restoration in the esthetic zone, completely out of occlusion to reduce the risk of early crestal overload. In good-quality bone (D1, D2) and regions out of the esthetic zone, no transitional crown is required unless the abutment post feels sharp or bothersome to the tongue. The dentist dismisses the patient until the next appointment.

Laboratory Procedure

The laboratory pours the impression in die stone and mounts the opposing arch with the closed-mouth bite registration. It should be noted that the abutment is represented by a dental stone die. This stone die may fracture when removed from the impression because it is only 4 to 5 mm in diameter. To decrease the risk of fracture, the stone is allowed to set for more than 1 day before separating it from the impression. This extended period increases the strength of the die stone.

The final crown is fabricated with a wider and flatter than usual central fossa over the top of the implant abutment for the primary occlusal contact (Figure 21-60, *E*). When porcelain is used on the occlusal surface, the metal coping extends toward the marginal ridges to ensure that no shear forces are applied to areas of unsupported porcelain on the marginal ridges (Figure 21-61). The buccal crown contour in the mandible and lingual contour in the maxilla often are reduced to decrease offset loads on the implant during occlusal loading.

Abutment screw loosening is an increased risk in the posterior regions of the mouth in some implant systems, especially in a patient with moderate to severe bruxism. When these conditions are present, an occlusal access hole is prepared in the cemented crown as a preventive measure. This is an access hole for the abutment screw, not for a coping screw for prosthesis fixation. The abutment screw is larger in diameter than the coping screw and therefore is stronger. The abutment screw is usually also longer and therefore more retentive. Hence, abutment screw loosening occurs less than prosthetic screw loosening.

The crown is cemented onto the abutment for cement retention, not screw retained. However, if abutment screw loosening occurs, the dentist can use the occlusal access hole to retighten the abutment retaining screw. The occlusal access hole for the abutment screw need only be the diameter of the screwdriver (usually 2 mm). The occlusal access hole is surrounded by a metal shaft to minimize the risk of porcelain fracture when selected as the occlusal material (Figure 21-62). A cotton pellet and composite will obturate the access hole after cementation. Primary occlusal contacts are directed along the implant body, which extends 3 mm around the central access opening.

Final Crown Delivery

The posterior single crown is delivered at the next prosthetic appointment. The dentist seats the crown, evaluates the interproximal contacts with dental floss, and confirms the marginal integrity. The dentist first makes an occlusal adjustment, similar to that of a natural tooth, with a light bite force and reduces or eliminates any off-axis occlusal contact. A heavy bite force then is used to evaluate the final occlusion[63,64] (Figure 21-63).

The final restoration usually is cemented with a radiopaque cement stronger than temporary zinc oxide cements but not as strong as a definitive cement (i.e., polycarboxylate cement). This cement still allows the restoration to be removed if abutment screw loosening or porcelain fracture occurs. The dentist tells the patient that on occasion this cement does not retain the restoration adequately but, unlike natural teeth, it does not

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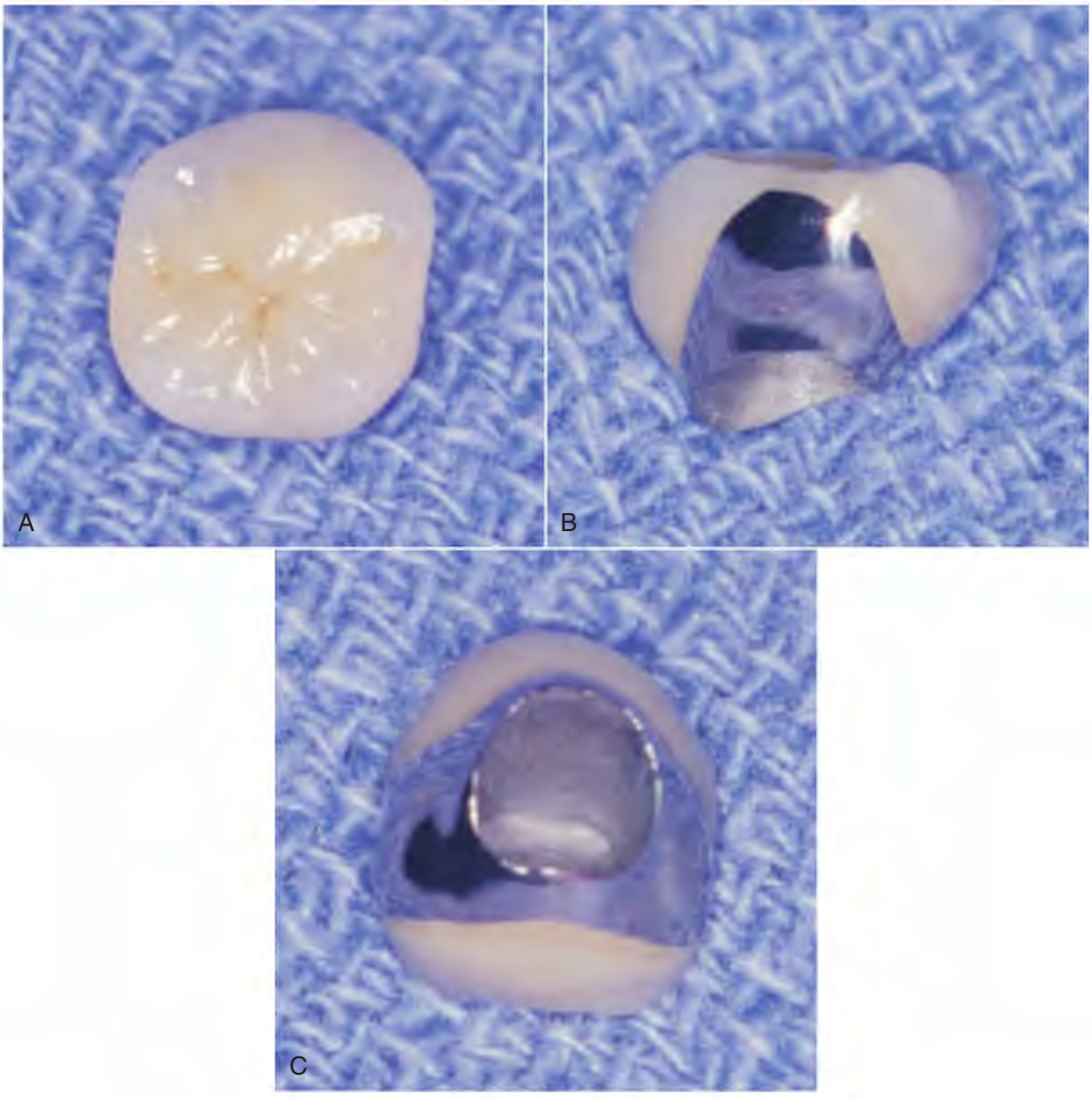


FIGURE 21-61. **A,** A porcelain–metal implant crown. **B,** The metal coping is extended to the marginal ridges to reduce shear loads to the marginal porcelain ridges. **C,** The marginal ridges are supported by the framework to decrease porcelain fracture.



FIGURE 21-62. An access hole to the abutment screw surrounded by metal to reduce porcelain fracture is used when an increased risk of abutment screw loosening is present.



FIGURE 21-63. The final mandibular posterior crown has a reduced buccal contour when not in the esthetic zone. This helps improve hygiene and decreases the offset load on the buccal cusp.

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cause decay or sensitivity if the crown becomes loose. If the restoration becomes uncemented in the first year, the dentist may use a harder cement (i.e., zinc phosphate).

Indirect Crown Fabrication

The restoring dentist may choose to use an indirect crown fabrication technique. The first restoring appointment replaces the permucosal healing extension with a two-piece impression transfer coping (Figure 21-64). A one-piece impression transfer does not engage the hexagonal fixture and should not be used for a single-tooth implant. To transfer the antirotational hexagon feature requires a two-piece transfer similar to a two-piece abutment. An open-tray technique allows the impression tray to be removed after the fixation screw to the implant body transfer is unthreaded. In the open-tray technique, a two-piece impression transfer that engages the hexagon feature is fixated by a transfer screw that extends several millimeters above the transfer coping and through the top of the impression tray (hence the "open"-tray technique). The tray is fabricated by the laboratory on a preliminary impression or can be a modified plastic stock tray by the dentist.

Most companies provide a two-piece transfer that connects to the antirotational feature for use with a closed-tray procedure. The two-piece impression transfer is inserted into the implant and engages the antirotational feature (Figure 21-65, *A*). The screwdriver hole in the indirect (closed tray) impression transfer is obturated with endodontic filler (i.e., Cavit, Fermet) (Figure 21-65, *B*). This prevents impression material capturing this feature, which results in a positive feature in the impression. As a result, the impression transfer may not completely seat when it is reintroduced into the impression. A full-arch final impression with a closed tray is made of the implant site and remaining teeth. The dentist then removes the indirect impression transfer and replaces the PME into the implant body. The dentist also obtains an opposing arch impression and closed bite registration.

Laboratory Procedures

The laboratory technician inserts an implant body analog into the impression transfer coping and reinserts the device into the impression (Figures 21-65, *C* and *D*). A soft tissue model may be made to indicate the existing gingival contour (Figure 21-65, *E*). After the stone has hardened, the laboratory technician removes the direct impression transfer from the implant body analog and places a two-piece abutment (Figure 21-66). The bite registration helps mount the opposing arch model.

The abutment then is prepared for height, taper, and crown finish line location. A transfer line or dot is placed on the facial aspect of the abutment to help the dentist orient the abutment in the mouth in the same position (Figure 21-67).

The laboratory technician then may use the actual implant abutment as the dental die for the crown fabrication. A precise marginal adaptation for the final coping can be obtained as a result (Figure 21-68) the master cast for contour and occlusal contacts and finishes the restoration (Figure 21-69).

Final Crown Delivery

The final delivery of the posterior single-tooth crown also seats the abutment for cement retention prepared in the laboratory (Figure 21-70).The crown is seated to confirm that the rotational placement position is correct. A radiograph confirms the abutment fully engages the implant crest module and antirotational feature. After the radiograph confirms that the abutment and crown are in proper location, use of the torque wrench on the abutment and occlusal adjustment on the crown are similar to the direct crown fabrication procedures (Figure 21-70, *C*; Table 21-1).

Posterior Implant Crowns

Ideally, the implant surgeon may place the implant body perpendicular to the occlusal plane, yet the restoring dentist may then load the implant crown at an angle. Greater crestal bone strains with angled forces have been confirmed with photoelastic and three-dimensional finite element analysis methods.[63,64,71,72] Whether the occlusal load is applied to an angled implant body or an angled load (e.g., premature contact on an angled cusp) is applied to an implant body that is perpendicular to the occlusal plane, the resultant stresses are similar (Figure 21-71). A biomechanical risk is increased to the implant system (e.g., the abutment, implant–bone interface).

Angled forces also increase the shear force, decrease the bone strength, and increase shear loads to implant to bone components and the abutment screws. Hence, an angled implant body or an angled load on the implant crown increases the amount of crestal stresses on the implant system; transforms a greater



FIGURE 21-64. A permucosal healing extension is removed on a mandibular first molar implant to be restored through an indirect crown fabrication technique.

TABLE 21-1
Comparison of Direct versus Indirect Technique

	Direct	Indirect
Chair time	More	Less
Laboratory cost	Less	More
Components	Less	More number
Steps	Less	More
Finish line	Intraoral	Laboratory
Impression	Traditional	Transfer coping
Temporary	Optional	None
Progressive load	If temporary	No
Radiographs	Yes	Yes
Custom abutment	No	Yes

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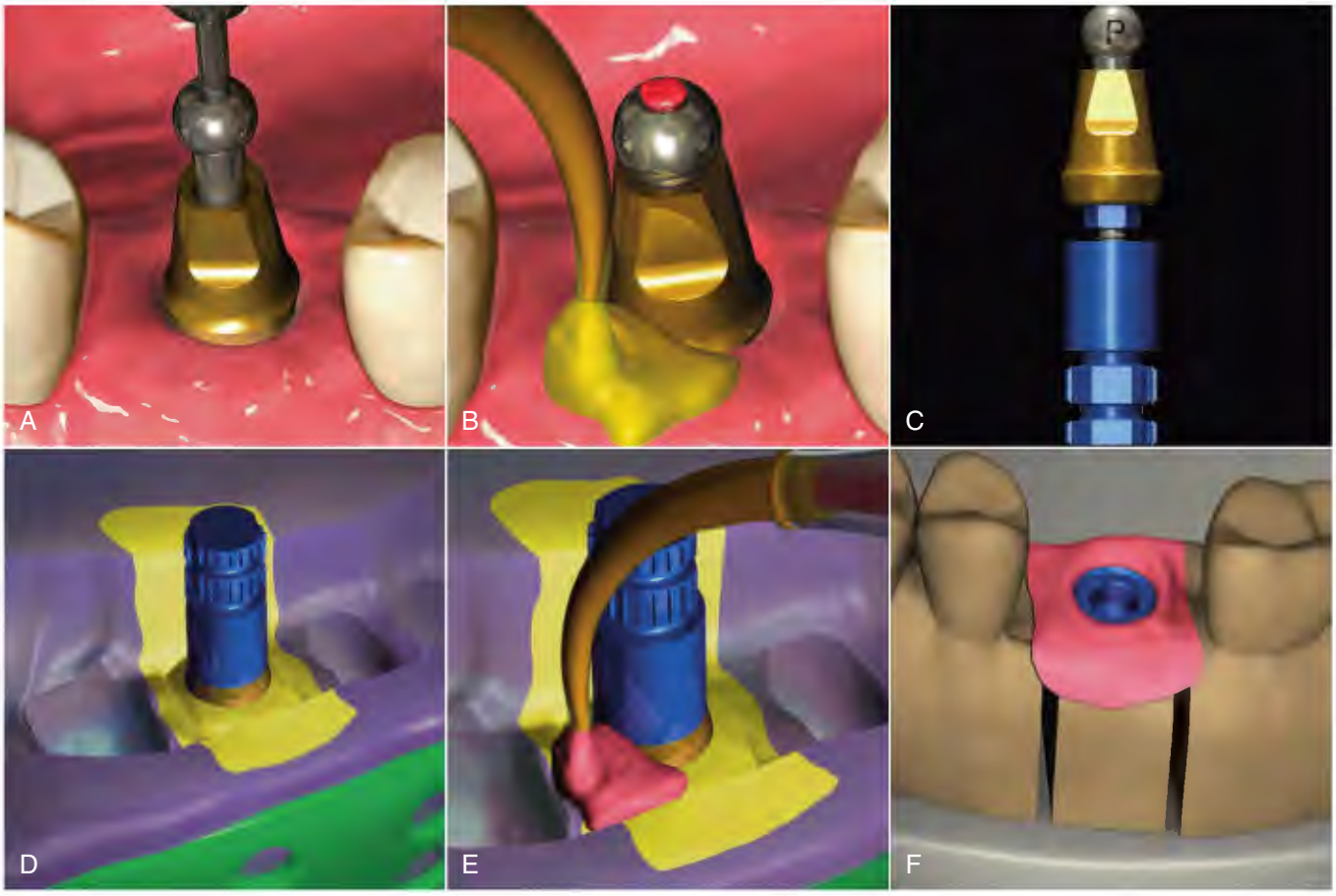


FIGURE 21-65. **A,** A two-piece indirect (closed-tray) impression transfer is inserted into the implant body and engages the antirotational feature. **B,** The screwdriver hole in the indirect impression transfer is obturated, and a full-arch final impression is made. **C,** The laboratory inserts the two-piece impression transfer into an implant body analog. **D,** The combined transfer and implant body analog are reinserted into the final impression of the implant site. **E,** A soft tissue model is fabricated with a soft, resilient material poured around the cervical aspect of the implant body analog. **F,** The soft tissue model with implant body analog.



FIGURE 21-66. The abutment is screwed into the implant body analog and may be prepared to receive the crown.



FIGURE 21-67. The abutment is prepared by the laboratory technician, including the crown finish line position.

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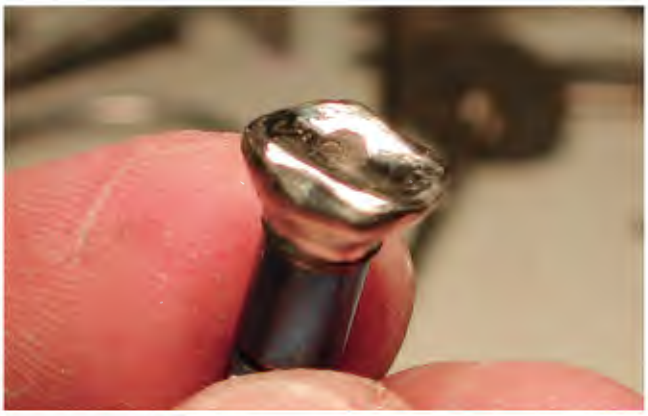


FIGURE 21-68. The final crown margin is fabricated on the implant abutment.



FIGURE 21-69. The final crown is fabricated on the master model.

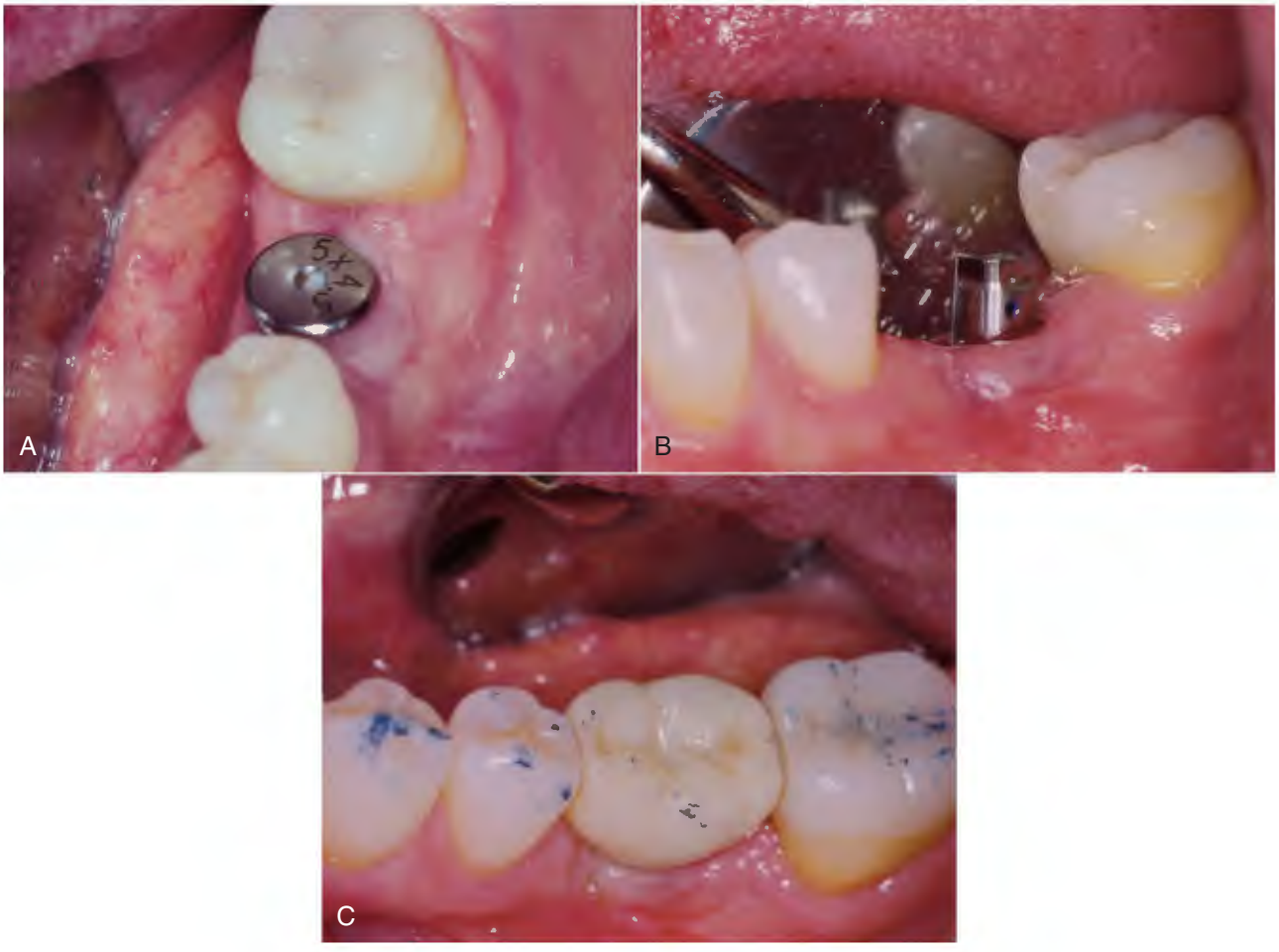


FIGURE 21-70. **A,** The first molar implant site with a permucosal extension (PME) for the final crown delivery. **B,** The PME is removed and the laboratory-prepared abutment is seated. **C,** The final crown is delivered using the indirect (laboratory-assisted) technique.

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percentage of the force to shear force; and reduces bone, porcelain, and cement strength. In contrast, the surrounding implant system stress magnitude is least and the strength of bone, porcelain, and cement is greatest under a long-axis load to the implant body. All of these factors mandate the reduction of angled forces to the implant system.

Posterior Crown Cusp Angle

The angle of force to the implant body may be influenced by the cusp inclination of the implant crown in similar fashion as an angled load to an implant body.[63,64] The posterior natural dentition often has steep cuspal inclines, and 30-degree cusp

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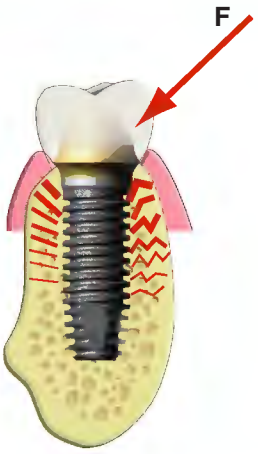


FIGURE 21-71. An angled load to an implant body increases tensile and shear forces to the implant system.

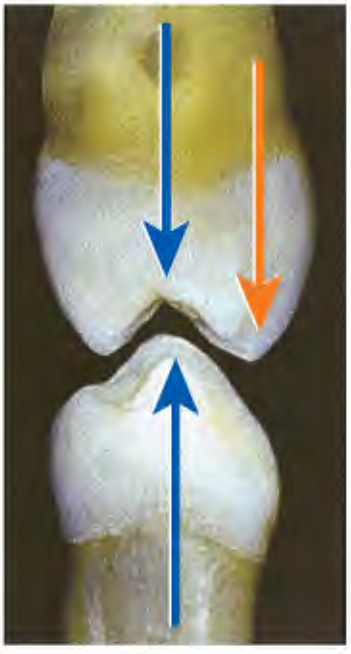


FIGURE 21-72. A 30-degree cusp angle is often used to restore an implant crown.

angles have been designed in denture teeth and natural tooth prosthetic crowns (Figure 21-72). The greater cusp angles are often considered more esthetic and may even incise food more easily and efficiently. However, to negate the negative effect of an angle cusp contact, the opposing teeth need to occlude at the same time in two or more exact positions on the ipsilateral cusp angles of the crowns (Figure 21-73). This is not possible in a clinical setting.

The occlusal contact along only one of the angled cusps results in an angled load to the implant system even when it is not premature to other occlusal contacts (Figure 21-74). The magnitude of the force is minimized when the angled occlusal contact is not a premature contact but instead is a uniform load over several teeth or implants. However, the angled cusp load does increase the resultant tensile and shear stress with no observable benefit. Hence, no advantage is gained, but the biomechanical risk is increased (e.g., increased abutment screw loosening, porcelain fracture, and unretained restoration).

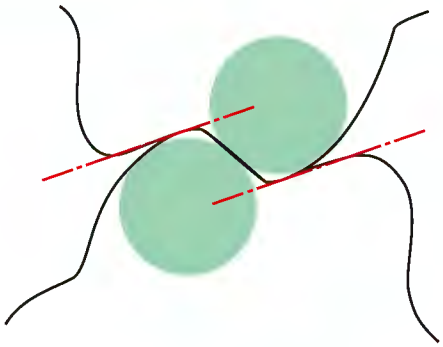


FIGURE 21-73. To negate an angled load to the implant body from a crown with cusp angles, two or more simultaneous contacts are necessary.



FIGURE 21-74. An occlusal contact on an angled cusp results in an angled load to the implant system.

The occlusal contact over an implant crown therefore should be ideally on a flat surface perpendicular to the implant body. This occlusal contact position usually is accomplished by increasing the width of the central fossa to 2 to 3 mm in posterior implant crowns, which is positioned over the middle of the implant abutment. The opposing cusp is recontoured to occlude the central fossa of the implant crown directly over the implant body (Figure 21-75). In other words, the laboratory technician should identify the middle of the implant body and then make a central fossa 2 to 3 mm wide over this position parallel to the curve of Wilson and Spee (Figure 21-76). The buccal and lingual contours of the crown may then be established (reduced on the buccal for the posterior mandible and the lingual for the posterior maxilla). The opposing tooth may require recontouring of an opposing cusp to help direct the occlusal force along the long axis of the implant body.

Posterior Implant Crown Contour

A buccal or lingual cantilever in the posterior regions is called an *offset load*, and the same principles of force magnification

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FIGURE 21-75. A posterior crown usually has a widened central fossa positioned over the implant abutment. This directs the occlusal load along the long axis of the implant body.

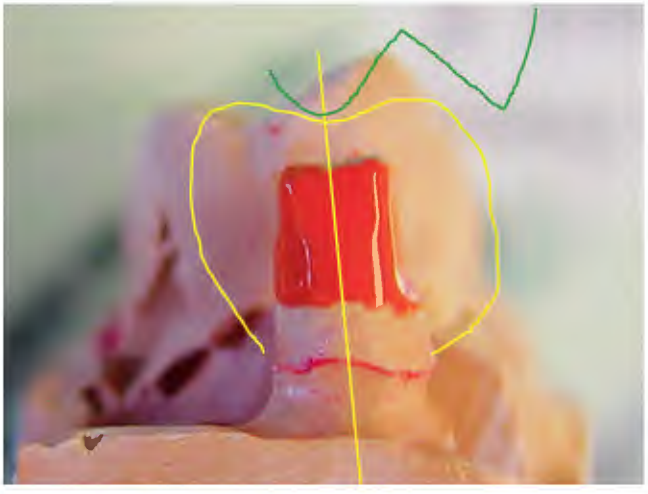


FIGURE 21-76. The dental laboratory technician determines the position of the implant related to occlusal load on the implant crown.

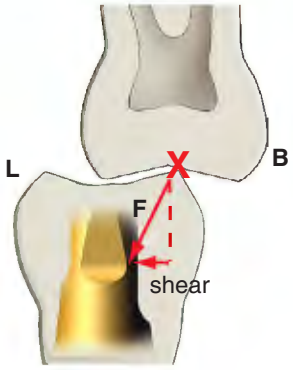


FIGURE 21-77. An occlusal contact to a buccal cusp of an implant crown is often an offset load to the implant, which increases the shear component of a load.



FIGURE 21-78. An implant crown contour similar to a natural tooth often results with facial ridge laps at the cervical region.

from class 1 levers apply. In other words, the greater the offset, the greater the load to the implant system.[63,64] Offset loads may also result from buccal or lingual occlusal contacts and create moment forces, which increase compressive, tensile, and shear forces to the entire implant system (Figure 21-77).

The laboratory technician often attempts to fabricate an implant crown with occlusal facial and lingual contours similar to those of natural teeth. The posterior implant crown should have a reduced occlusal width compared with a natural tooth when out of the esthetic zone. A wide occlusal table favors offset contacts during mastication or parafunction. The narrower occlusal contour of an implant crown also reduces the risk of porcelain fracture.

A facial profile similar to a natural tooth on the smaller-diameter implant (e.g., 10-mm tooth vs. a 4- to 6-mm implant) results in cantilevered restorative materials. This cantilever crown contour is often designed as a ridge lap pontic of a FPD (Figure 21-78). The facial porcelain most often is not supported by a metal substructure because the gingival region of the crown is also porcelain. As a result, shear forces result on the buccal cusp on the mandibular crown or lingual cusps in the maxillary crown and are more likely to increase the risk of porcelain fracture. This risk is compounded further by the higher impact force developed on implant abutments compared with natural teeth.

The extended crown contours not only increase offset loads but also often result in ridge laps or porcelain extension at the facial gingival margin of the implant abutment. As a result, home care in the sulcular region of the implant is impaired by the overcontoured crown design. The dental floss or probe may reach under the ridge lap to the FGM, but it cannot enter the gingival sulcus. Hence, daily hygiene is almost impossible to perform. The narrower posterior occlusal table facilitates daily sulcular home care.

Thus, a narrow occlusal table combined with a reduced contour facilitates daily care, improves axial loading, and decreases the risk of porcelain fracture. However, in the esthetic zone, the ridge lap design may be necessary to restore the implant rather than removing it, bone grafting, and replacing the implant in a more ideal position for esthetics.

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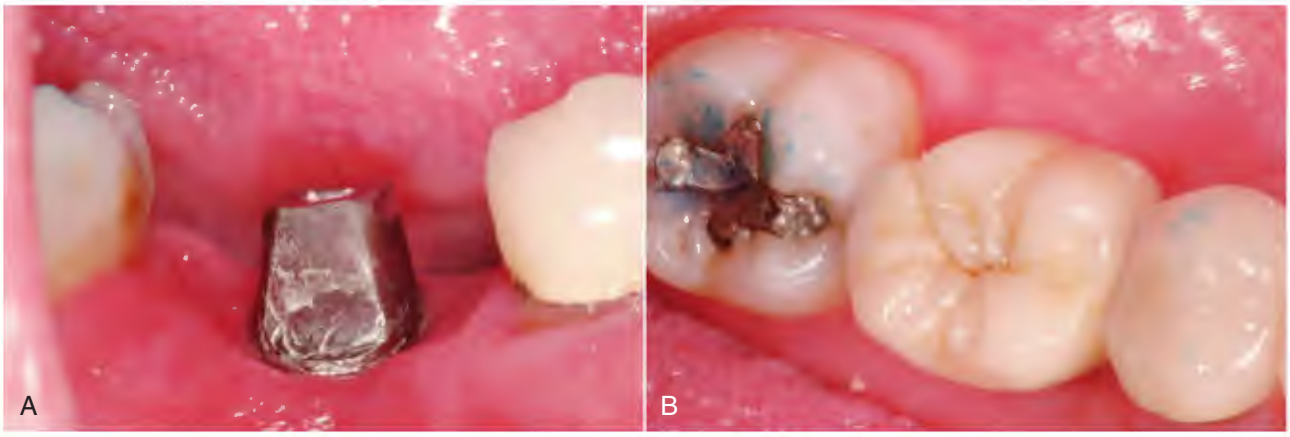


FIGURE 21-79. **A,** A mandibular first molar implant and abutment. **B,** The implant crown is reduced in width on the buccal. The lingual contour is similar to the adjacent teeth to prevent biting the tongue during occlusion.

Mandibular Posterior Crowns

The posterior mandible resorbs lingually as the bone resorbs from division A to B.[73] As a result, endosteal implants are also more lingual than their natural tooth predecessors. The division C–h and D mandibular ridge shifts to the buccal compared with the maxillary arch. However, endosteal implants typically cannot be inserted because the available bone above the mandibular nerve is inadequate for endosteal implants.

The mandibular implant crown should be reduced from the buccal (and the maxillary crown reduced from the lingual). Thus, the "stamp cusp" offset load is reduced. The reduced buccal contour in the posterior mandible is of no consequence to cheek biting because the buccal horizontal overjet is maintained (and increased). The lingual contour of the mandibular implant crown is similar to a natural tooth (Figure 21-79). This permits a horizontal overjet to exist and push the tongue out of the way during occlusal contacts (just as natural teeth). As with the natural tooth, the lingual cusp has no occlusal contact.

In the posterior mandible as the implant diameter decreases, the buccal cusp contour is reduced. This decreases the offset length of cantilever load. The lingual contour of the crown remains similar regardless of the diameter of the implant. The lingual contour permits a horizontal overlap with the maxillary lingual cusp, so the tongue is pushed away from the occlusal table during function. The mandibular lingual cusp is not occlusal loaded (as with natural teeth).

During mastication, the amount of force used to penetrate the food bolus may be related to occlusal table width. For example, less force is required to cut a piece of meat with a sharp knife (narrow occlusal table) than with a dull knife (wider occlusal table). The greater surface area of a wide occlusal table requires greater force to achieve a similar result. Hence, the wider the occlusal table, the greater the force developed by the biological system to penetrate the bolus of food. However, these functional forces are typically less than 30 psi. The real culprit in biomechanical forces relate to parafunction because forces 10 to 20 times greater may be generated.

Maxillary Posterior Crowns

In the esthetic zone (high lip position during smiling), the buccal contour of the maxillary implant crown is similar to a natural tooth. This improves esthetics and maintains the buccal overjet to prevent cheek biting. But just as with the natural teeth, there is no occlusal contact on the buccal cusp. Ideally, when maxillary posterior implants are in the esthetic zone, they are positioned more facial than the center of the ridge. The lingual contour of a maxillary implant crown should be reduced because it is out of the esthetic zone and is a stamp cusp for occlusion (which is an offset load).



FIGURE 21-80. The posterior maxillary first molar implant crown has primary contact over the implant. When the implant is under the central fossa to lingual cusp, the crown contour is reduced on the lingual, and occlusal load is directed along the long axis of the implant.

The ideal functional position for the maxillary posterior implant is under the central fossa when the cervical region is not in the esthetic zone. Hence, the lingual cusp is cantilevered from the implant similar to the buccal cusp of the posterior mandible. Therefore, the reduced lingual contour reduces the offset load to the lingual (Figure 21-80).

The maxillary dentate posterior ridge is positioned slightly more facial than its mandibular counterpart because the teeth have a maxillary overbite. When the maxillary teeth are lost, the edentulous ridge resorbs in a medial direction as it evolves from division A to B, division B to C, and division C to D.[73] As a result, the maxillary permucosal implant site gradually shifts toward the midline as the ridge resorbs. Sinus grafts permit the placement of endosteal implants in the posterior maxilla even

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in previous division D ridges. However, because of resorption in width, the maxillary posterior implant permucosal site may even be palatal to the opposing natural mandibular tooth.

In the esthetic zone, many of the crown contours are made to resemble the natural tooth as closely as possible. However, out of the esthetic zone, in the posterior regions of the mouth, the crown contour should be different than a natural tooth. The implant body buccolingual dimension is smaller than the natural tooth. The center of the implant most often is placed in the center of the edentulous ridge. Because the crest of the ridge shifts lingually with resorption, the implant body is most often not under the opposing cusp tips but rather near the central fossa or even more lingual and in the maxilla may even be under the lingual cusp of the original natural tooth position. Most often the laboratory fabricates a posterior implant crown that is similar in size to a natural tooth, with a cantilevered facial contour. In addition, the occlusal contacts are often on the "stamp cusp" of the mandible (buccal cusps). However, these "stamp cusps" are often offset loads (buccal cantilevers).

When the maxillary posterior teeth are out of the esthetic zone, the crown may be designed for a crossbite (Figure 21-81). The lingual overjet prevents tongue biting, the buccal overjet (from the mandibular tooth) prevents cheek biting, the implant is axial loaded by the lingual cusp of the mandible, and hygiene is improved.

In summary, restorations mimicking the crown contour and occlusal anatomy of natural teeth often result in offset loads (increased stress and risk of associated complications), complicated home care, and an increased risk of porcelain fracture. As a result, in nonesthetic regions of the mouth, the occlusal table should be reduced in width compared with natural teeth.

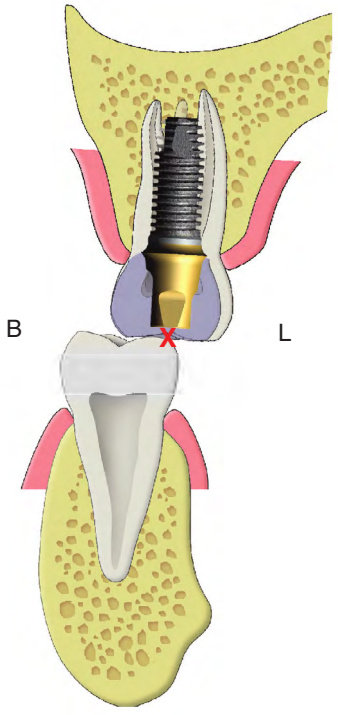


FIGURE 21-81. When the implant site is out of the esthetic zone and the implant is positioned more lingual, a crossbite may be designed in the implant crown. *B*, Buccal; *L*, lingual.

Conclusion

The implant body should be loaded in an axial direction. In a division A maxillary ridge, the implant can be placed between the central fossa region and buccal cusp of the natural teeth. The buccal cusp of the natural tooth in the mandibular arch is the dominant occluding cusp. The palatal contour of the maxillary posterior implant crown is reduced to eliminate offset loads. The position of the maxillary buccal cusp should remain similar to that of the original tooth for proper esthetics and should remain out of occlusion in centric relation and all mandibular excursions. When further resorption occurs and the ridge evolves into division B to C bone, the maxillary palatal cusp may become the primary contact area, situated directly over the implant body. The palatal cusp angle is reduced, and a contact area is created directly over the implant abutment. Hence, the occlusal contacts differ from those of a natural tooth.

Whereas in mandibular division A bone, the implant is located under the central fossa, in division B, the implant is located closer to the lingual cusp region of the preexisting natural tooth. In other words, mandibular endosteal implants are always positioned more medial than the original buccal cusp of the natural tooth. All occlusal contacts are in a widened central fossa and often more medial than those on natural mandibular teeth.

Summary

Treatment options for single-tooth replacement include a removable prosthesis, a resin-bonded restoration, a three-unit fixed prosthesis, a cantilevered prosthesis, not replacing the tooth, and a single-tooth implant. In the past, the most common choice to replace the missing tooth was the three-unit FPD. The resin-bonded restoration initially was designed to decrease economic hardship in patients, but this method typically exhibits greater complication rates and lower survival rates. This type of prosthesis is suggested in an esthetic zone during bone graft healing before implant insertion. A removable prosthesis yields the poorest survival rates and highest risk of abutment tooth loss. However, the removable prosthesis still represents the easiest interim treatment modality during implant submerged healing for posterior teeth in esthetic regions. The choice of not replacing the tooth is a more frequent option for mandibular second molars, but this option also may be selected when the intratooth space is small and the occlusion prevents migration. Today, with the improvements in implant materials, design, surgical approach, and prosthetic guidelines and with reported success rates greater than 97%, the use of implants to replace a single tooth is often the treatment of choice. Improved hygiene, less risk of decay of the adjacent teeth, less endodontic risk, less risk of adjacent tooth loss, maintenance of bone, and prosthesis longevity all favor an implant restoration compared with the three-unit FPD.

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CHAPTER 22

Maxillary Posterior Edentulism: Treatment Options for Fixed Prostheses

Carl E. Misch

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Maxillary posterior partial or complete edentulism is one of the most common occurrences in dentistry. Seven percent of the adult population in the United States (12 million people) are missing all of their maxillary teeth and have at least some mandibular dentition—a condition that occurs 35 times more frequently than complete mandibular edentulism opposing maxillary teeth.[1,2] The complete edentulous rate of the adult population is 10.5%. Therefore, 30 million people in the United States or 17.5% of the adult population are missing all of their maxillary teeth. In addition, 20% to 30% of the adult partially edentulous population older than 45 years of age are missing maxillary posterior teeth in one quadrant, and 15% of this age group are missing maxillary dentition in both posterior regions.[2] In other words, approximately 40% of adult patients are missing at least some maxillary posterior teeth. Therefore, the maxillary posterior region is one of the most common areas to be involved in an implant treatment plan to support a fixed or removable prosthesis.

The maxillary posterior edentulous region presents many unique and challenging conditions in implant dentistry. However, existing proven treatment modalities make procedures in this region as predictable as in any other intraoral region. Most noteworthy surgical methods include sinus grafts to increase available bone height, onlay grafting to increase bone width, and modified surgical approaches to insert implants in poorer bone density.[3] This chapter addresses the treatment planning concepts specific to the maxillary posterior partial or complete edentulous regions.

Implant Treatment Plan–Related Factors

Several conditions make the posterior maxilla unique in the development of an ideal treatment plan. These items include bone width, crown height space (CHS), bone density, bone height, occlusal forces, implant size, implant number, and implant design (Box 22-1).

Bone Width

The dentate posterior maxilla has a thinner cortical plate on the facial compared with the mandible. In addition, the trabecular bone of the posterior maxilla is finer than in other dentate regions (Figure 22-1). The loss of maxillary posterior teeth results in an initial decrease in bone width at the expense of the labial bony plate. The width of the posterior maxilla decreases at a more rapid rate than in any other region of the jaws.[4] The resorption phenomenon is accelerated by the loss of vascularization of the alveolar bone and the existing fine trabecular bone type. However, because the initial residual ridge is so wide in the posterior maxilla, even with a 60% decrease in the width of the ridge, adequate-diameter root form implants usually can be placed.

Unlike the resorbed atrophic mandible, the maxillary posterior resorbed ridge progressively shifts toward the palate until the ridge is resorbed into a medially positioned narrower bone volume[5] (Figure 22-2). This results in the buccal cusp of the maxillary final restoration in the moderate to severe atrophic ridges often being facially cantilevered to satisfy esthetic requirements at the expense of biomechanics for occlusal loading (Figure 22-3).

BOX 22-1 Unique Implant Treatment Plan Considerations

1. Bone width
2. Crown height space
3. Bone density
4. Bone height
5. Occlusal forces
6. Implant size
7. Implant number
8. Implant design



FIGURE 22-1. The posterior dentate maxilla has a thinner cortical plate on the facial and finer trabecular bone than the mandible.

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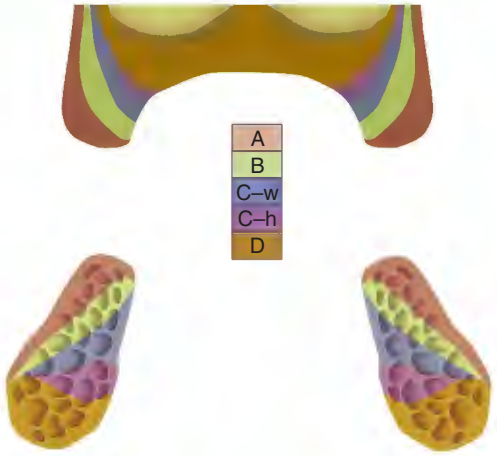


FIGURE 22-2. The loss of posterior teeth causes resorption of the posterior maxilla. As the edentulous ridge resorbs from division A to division D, the crest of the ridge shifts toward the palate. As a consequence, without facial augmentation, the endosteal implant may be placed under the lingual cusp of the original natural tooth position.



FIGURE 22-3. The resorbed width of the bone requires augmentation in width or a facial cantilevered prosthesis in the esthetic zone.

Crown Height Space

The CHS should be evaluated before implant placement. After the occlusal plane is properly restored or modified, the CHS ideally should be greater than 8 mm for a fixed restoration and 12 mm for an implant overdenture. It is not uncommon for excess tissue thickness to be present in this region, and when less clinical space is available for prosthodontic reconstruction due to gingival thickness, a gingivectomy is first considered. However, if tissue reduction cannot correct the clinical crown height problem, osteoplasty or vertical osteotomy of the maxillary posterior alveolar process is indicated to restore the correct ridge orientation before surgery (Figure 22-4). This procedure may reduce the available bone height. Sinus grafting to restore vertical height is very predictable. Therefore, after an osteoplasty, a sinus floor grafting is often required to increase the CHS and still allow implants of adequate length to restore the patient.

Poor Bone Density

In general, the bone quality is poorest in the edentulous posterior maxilla compared with any other intraoral region.[6] A literature review of clinical studies from 1981 to 2001 reveals the poorest bone density may decrease implant loading survival by an average of 16% and has been reported as low as 40%.[7] The cause of these failures is related to several factors. Bone strength is directly related to its density, and the poor density bone of this region is often five to 10 times weaker compared with bone found in the anterior mandible.[8] Bone densities directly influence the percent of implant–bone surface contact, which accounts for the force transmission to the bone. The bone–implant contact (BIC) is least in D4 bone compared with other bone densities (Figure 22-5). The stress patterns developed in poor bone density migrate farther toward the apex of the implant. As a result, bone loss is more pronounced and more often occurs along the implant body rather than only crestally as in other denser bone conditions. Type IV (D4) bone also exhibits the greatest biomechanical elastic modulus difference when compared with titanium under load.[8] This biomechanical mismatch develops a higher strain condition to the bone, which may be in the pathologic overload range. As such, strategic choices to increase bone–implant contact are suggested.

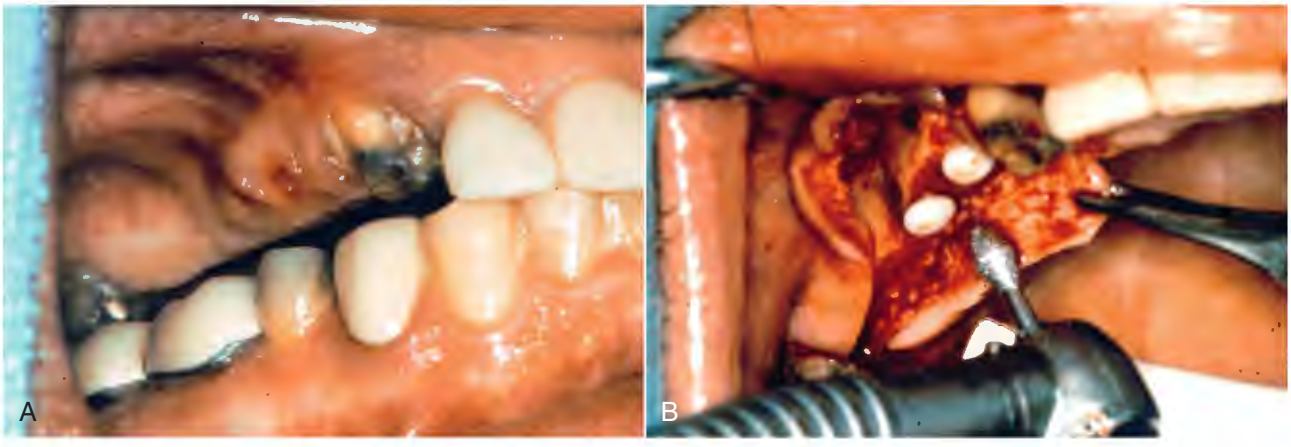


FIGURE 22-4. **A,** The crown height space (CHS) is inadequate to restore the posterior teeth. **B,** An osteoplasty increases the CHS but reduces the available bone height.

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FIGURE 22-5. The bone–implant contact is the lowest in D4 bone, which is often found in the posterior maxilla.

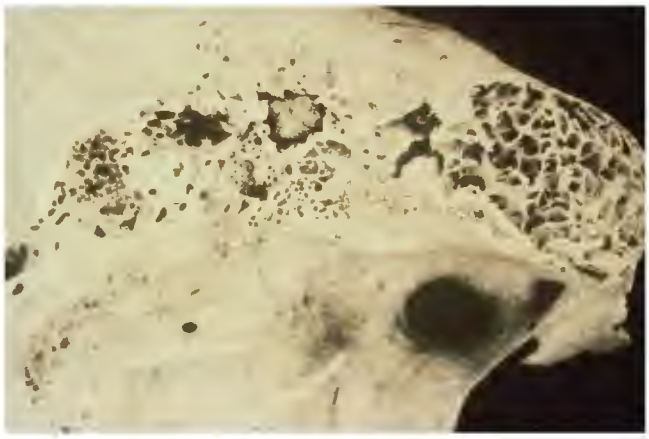


FIGURE 22-6. The density of the bone in the edentulous posterior maxilla is poorer than in any other region. Because of the lack of cortical bone on the crest, the thin trabecular bone is less strong and has a lower modulus of elasticity.

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In the posterior maxilla, the deficient osseous structures and an absence of cortical plate on the crest of the ridge further compromise the initial implant stability at the time of insertion (Figure 22-6). The labial cortical plate is thin, and the ridge is often wide. As a result, the lateral cortical BIC to stabilize the implant is often insignificant. Therefore, initial healing of an implant in D4 bone is often compromised, and clinical reports indicate a poorer initial healing success than with D2 or D3 bone.

Bone Height

Local anatomical conditions of the edentulous alveolar ridges in the posterior maxilla may be unfavorable for implant placement. The available alveolar bone height is lost in the posterior maxilla as a result of periodontal disease before tooth loss. The maxillary molar regions have distal furcation involvement frequently because the furca is directly under the distal contact and has no facial or palatal access for hygiene. The furca is also narrower than many dental curettes, and it is difficult to eliminate calculus after it has formed. As a result, periodontal disease is common and is associated with loss of bone height before tooth loss.

Although the maxillary sinus maintains its overall size while the teeth are present, an expansion phenomenon of the maxillary sinus occurs with the loss of posterior teeth[9] (Figure 22-7). The antrum expands in both inferior and lateral dimensions. This expansion after loss of posterior teeth may even invade the canine eminence region and proceed to the lateral piriform rim of the nose. It also expands toward the crest of the edentulous ridge, often until only a thin layer of cortical bone separates the antrum from the crest of the residual ridge (Figure 22-8). The sinus expansion is more rapid than the crestal bone height changes. The dimension of available bone height of the posterior maxilla is greatly reduced as a result of dual resorption from the crest of the ridge and pneumatization of the sinus after the loss of teeth. As a result of the inferior sinus expansion, the amount of available bone in the posterior maxilla greatly

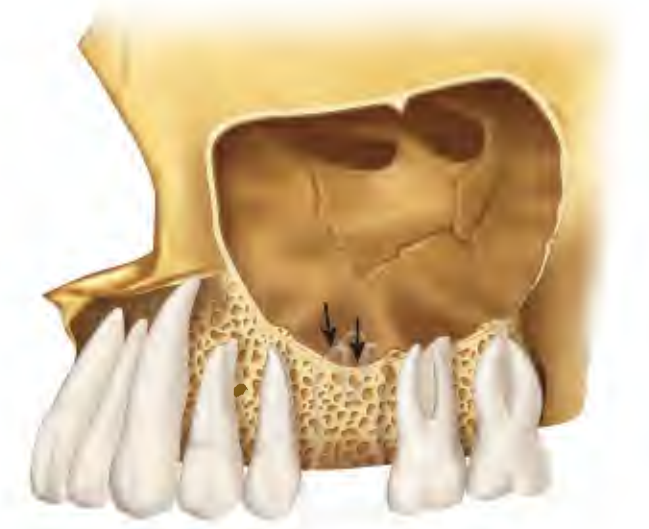


FIGURE 22-7. When a posterior maxillary tooth is lost, the maxillary sinus begins to expand into the residual bone and decrease available bone height for an implant. (From Watzek G: *Implants in qualitatively compromised bone,* London, Quintessence Publishing Company, 2004.)

decreases in height. As a consequence, knowledge of the maxillary sinus and bone augmentation to the antral floor is necessary to develop an ideal treatment plan.

Maxillary Sinus Anatomy

The maxillary sinuses were first illustrated and described by Leonardo da Vinci in 1489 and later documented by the English anatomist Nathaniel Highmore in 1651. The maxillary sinus or antrum of Highmore lies within the body of the maxillary bone and is the largest and first to develop of the paranasal sinuses (Figure 22-9). Adult maxillary sinuses are pyramid-shaped, air-filled cavities that are bordered by the nasal cavity. There is much debate about the actual function of the maxillary sinus. Possible theorized roles of the sinus include weight reduction of the skull, phonetic resonance, participation of warming and humidification of inspired air, and olfaction. A biomechanical adaptation of the maxillary sinus directs forces away from the orbit and cranial cavity when a blow is delivered to the midface.[10]

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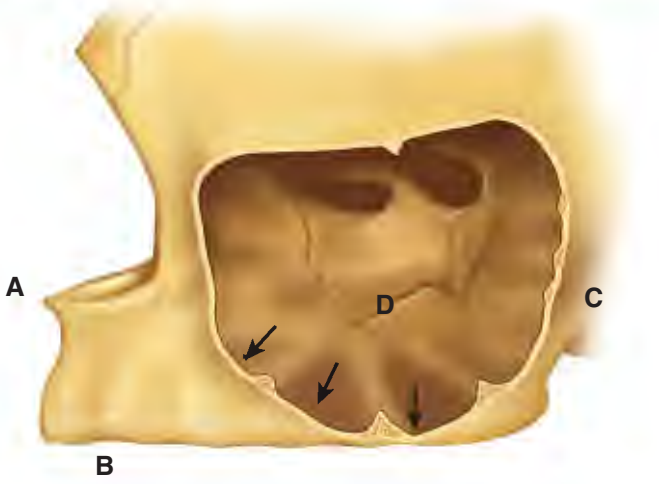


FIGURE 22-8. When all maxillary posterior teeth are lost, the sinus expansion often extends to the crest of the residual ridge. **A,** Nasal spine. **B,** Anterior maxillary ridge. **C,** Posterior maxilla. **D,** Maxillary sinus. (From Watzek G: *Implants in qualitatively compromised bone,* London, Quintessence Publishing Company, 2004.)

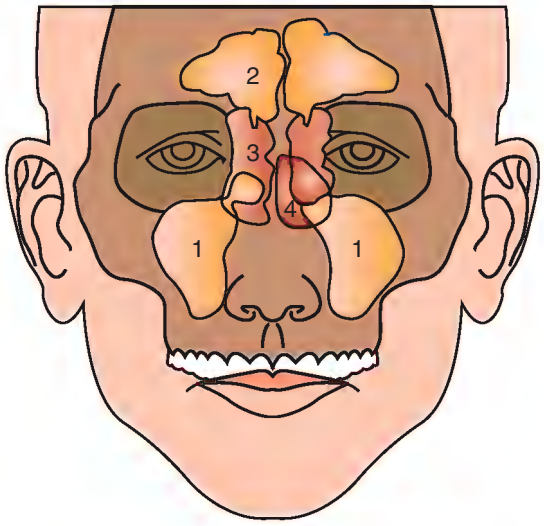


FIGURE 22-9. The maxillary sinus *(1)* is the largest of the four paranasal sinuses. The initial maxillary sinus formation is completed at age 16 to 18 years. *2,* Frontal sinus; *3,* ethmoid sinus; *4,* sphenoid sinus.

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Expansion of the Maxillary Sinus

A primary pneumatization of the maxillary sinus occurs at about 3 months of fetal development by an outpouching of the nasal mucosa within the ethmoid infundibulum. At that time, the maxillary sinus is a bud situated at the infralateral surface of the ethmoid infundibulum between the upper and middle meatus.[11] Prenatally, a secondary pneumatization occurs. At birth, the sinus is still an oblong groove on the mesial side of the maxilla just above the germ of the first deciduous molar, and the sinus cavities are filled with fluid.[9] Postnatally and until the child is 3 months old, the growth of the maxillary sinus is closely related to the pressure exerted by the eye on the orbit floor, the tension of the superficial musculature on the maxilla, and the forming dentition. As the skull matures, these three elements influence its three-dimensional development. At 5 months, the sinus appears as a triangular area medial to the infraorbital foramen.[12]

During the child's first year, the maxillary sinus expands laterally underneath the infraorbital canal, which is protected by a thin bony ridge. The antrum grows apically and progressively replaces the space formerly occupied by the developing dentition. The growth in sinus height is best reflected by the relative position of the sinus floor. At 12 years of age, pneumatization extends to the plane of the lateral orbital wall, and the sinus floor is level with the floor of the nose. During later years, pneumatization spreads inferiorly as the permanent teeth erupt.

The main development of the antrum occurs as the permanent dentition erupts and pneumatization extends throughout the body of the maxilla and the maxillary process of the zygomatic bone. Extension into the alveolar process lowers the floor of the sinus about 5 mm. Anteroposteriorly, the sinus expansion corresponds to the growth of the midface and is completed only with the eruption of the third permanent molars when the young person is about 16 to 18 years of age.[13] The adult sinus has a volume of approximately 15 mL (34 mm × 33 mm × 23 mm) (Figure 22-10).

In an adult, the sinus appears as a pyramid of five bony walls, the base of which faces the lateral nasal wall and the apex of which extends toward the zygomatic bone (Figure 22-11). The floor of the maxillary sinus cavity is the opposing landmark of available bone height and reinforced by bony or membranous septa joining the medial or lateral walls with oblique or transverse buttresslike webs. They develop as a result of genetics and stress transfer within the bone over the roots of teeth. These have the appearance of reinforcement webs in a wooden boat and rarely divide the antrum into separate compartments. These elements are present from the premolar to the molar region and tend to disappear in the maxilla of the long-term edentulous patient when stresses to the bone are reduced. Karmody et al. found that the most common oblique septum is located in the superior anterior corner of the sinus or infraorbital recess (which may expand anteriorly to the nasolacrimal duct).[14] The medial wall of the maxillary sinus is juxtaposed with the middle and inferior meatus of the nose.

After periodontal disease, tooth loss, and sinus expansion, frequently less than 10 mm of available bone remain between the alveolar ridge crest and the floor of the maxillary sinus, resulting in inadequate bone quantity for implant placement. A limited review of the literature reveals implants that were 9 mm or less in height may have a 16% lower survival rate compared with implants longer than 10 mm.[7] Therefore, the height of bone is of primary importance for predictable implant support. This limited dimension is compounded by the decrease in bone density and the problem of the resultant medial posterior position of the ridge after resorption of bone width. As a result, failure and complications in the long term of many endosteal implant systems are reported.

High Occlusal Forces

The occlusal forces in the posterior region are greater than in the anterior regions of the mouth. Studies have shown that the maximum bite force in the anterior region ranges from 35 to 50 lb/in^2. The bite force in the molar region of a dentate person ranges from 200 to 250 lb/in^2. As a consequence, to resist these higher bite forces, the maxillary molars of the natural teeth have 200% more surface area than even the premolars and are significantly wider in diameter (Figure 22-12). Both of these features reduce the stress to bone, which also reduces the strain of

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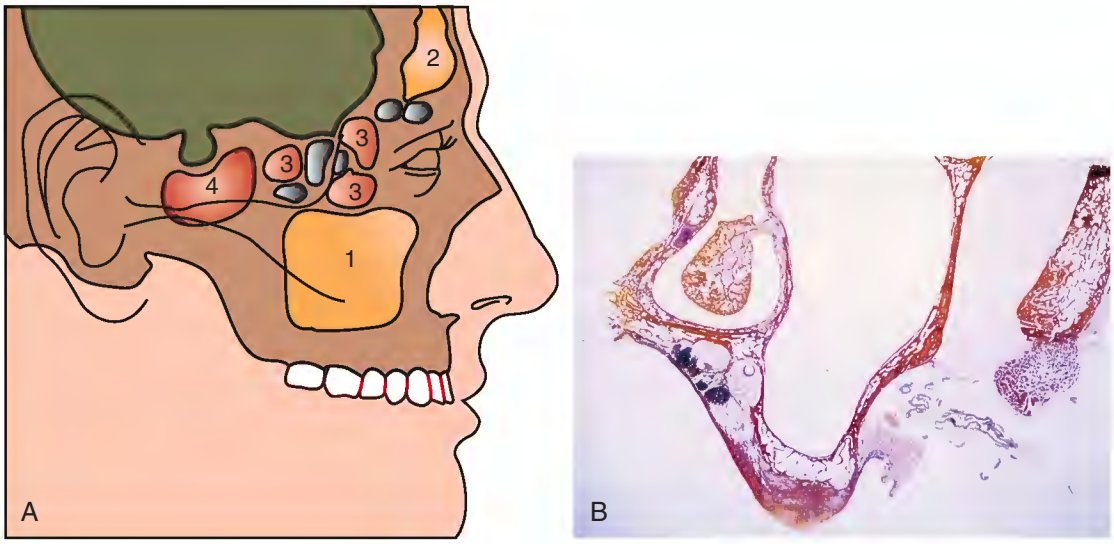


FIGURE 22-10. **A,** The adult maxillary sinus is formed by age 16 to 18 years. The average anteroposterior and coronal-apical dimension is 34 mm × 33 mm, lying above the posterior roots of the second premolar to third molar. *1,* Maxillary sinus; *2,* frontal sinus; *3,* ethmoid sinus; *4,* sphenoid sinus. **B,** Coronal section of the posterior region of the edentulous human maxilla. Note expansion of the sinus floor inferiorly far below the level of the floor of the nose. Bone of alveolar ridge is markedly atrophied while the ridge submucosa became fibrotic (×2.4). Stained with Resorcin Fuchsin stain and counterstained with van Gieson. (**B,** Courtesy Mohamed Sharawy, Augusta, GA.)



FIGURE 22-11. The adult maxillary sinus has five bony walls and extends toward the zygomatic process.

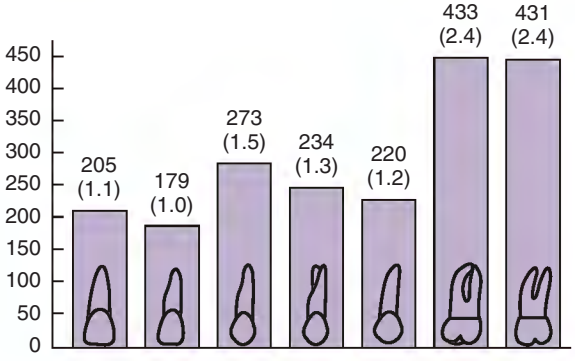


FIGURE 22-12. The posterior molars have the largest diameter and most surface area of root support compared with any other teeth in the mouth. An implant treatment plan should duplicate this support.

the bone during occlusal loading. Following this natural selection, implant support should be greater in the posterior molar region than any other area of the mouth.[3] The decrease in bone quantity and quality and increased forces should be considered in the treatment plan of this region of the mouth.

Implant Size

Implant treatment plans should attempt to simulate the conditions found with natural teeth in the posterior maxilla. Because stresses occur primarily at the crestal region in good bone quality, biomechanical designs of implants to minimize their noxious effects should be implemented.[15] Implant diameter is an effective method to increase surface area at the crestal region.[16] Ideally, division B implants (narrower diameter) are not used in the posterior maxilla. Instead, implants of at least 4 mm in diameter are suggested, and 5- to 6-mm implants are encouraged in the molar region.

The length of the implant is directly related to the implant width, design, amount of the forces, and bone density. Because implant success after loading is reduced in implants 10 mm and shorter, it is logical to plan for longer implants in the region. In general, 4-mm threaded root form implants should be at least 12 mm in length when the bone density is poor (D3). This usually provides adequate BIC to dissipate the loads applied to the prosthesis. When the bone density is very poor (D4), 5-mm implants (or two implants per tooth) are suggested, also at least 12 mm in length.

Implant Number

Key Implant Number

The key implant positions for a posterior maxilla primarily relate to (1) no cantilever, (2) no three adjacent pontics, and (3) the first molar rule. The key implant positions are determined before the available bone evaluation. Hence, when the second premolar, first molar, and second molar are missing, three key implant positions are required: the first premolar and

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second molar (rule 1) and the first molar (rule 3).When the first premolar, second premolar, and first molar are missing, the key implant positions are the first premolar and first molar (rules 1 and 3).

A common treatment plan is to cantilever a first molar from two or more implants placed in the premolar region. As previously stated, the first molar region has twice the bite force as the premolar region. As a result, a molar with 2.4 times more surface area is placed in that location. When a cantilever replaces the molar, the highest bite force is then multiplied to the anterior implants. Uncemented restorations, screw loosening, crestal bone loss, and implant failure risk are increased (Figure 22-13). The "no cantilever" rule for fixed prostheses should especially apply to the molar regions of the mouth.

Additional Implants

Additional implants are used when the bone density is poor or the patient force factors are large. For example, when the bone density is D4 or the patient is a bruxing male, an additional implant is required. Implant number is an excellent method to decrease crestal stresses. As a general rule in this area, one implant is often used for each missing tooth (Figure 22-14). If stress factors are magnified or the ideal implant diameter is reduced, two implants for each missing molar are suggested. Implants should always be splinted together to reduce stresses to the bone, reduce abutment screw loosening, and increase retention for the prosthesis. In general, more implants are indicated in the maxilla compared with the mandible (Figure 22-15).



FIGURE 22-13. A common treatment plan to avoid the maxillary sinus is to place two premolar implants and cantilever to the first molar with the restoration. The bone loss on these two implants is one of the increased risk of this treatment option.



FIGURE 22-14. When the bone density is poor or the patient force factors are moderate to high, one implant per missing tooth is often indicated.

Implant Design

Implant design can increase surface area of support. A threaded design implant has 30% to 200% greater surface area compared with a cylinder implant of the same size. Although more difficult to place, the threaded implant in poorer density bone is strongly encouraged. Biomechanical aspects of thread designs also affect the total increase in the surface area (i.e., thread pitch, shape, and depth).[17]

Roughened surface conditions or hydroxyapatite coating on the implant has been shown to increase the rate of osseous adaptation to implants and provide greater initial rigid fixation. In addition, an increase of surface-to-bone contact and amount of lamellar bone and the relatively greater strength of the coronal bone around the roughened-surface implants occur when compared with machined or smooth titanium implants.[18,19] Therefore, coatings or roughened surfaces on implant bodies are suggested in the compromised D3 or D4 bone density (Figure 22-16).

Dental Contraindications for Implant Treatment

A key to the long–term success of posterior maxillary implants is the presence of adequate anterior teeth or implants. Therefore, the treatment plan should provide for the maintenance or restoration of healthy anterior teeth or division A bone in the premaxilla for implant placement. A minimum of a healthy natural canine tooth or implant abutments in the canine region for each posterior quadrant is required before posterior implants are considered.

A rule in traditional prosthetics is that a fixed prosthesis is contraindicated when the canine and two adjacent teeth are missing. Therefore, when the canine and both premolars are missing, a fixed restoration is contraindicated. A patient missing a first premolar, canine, and lateral is also contraindicated for fixed prostheses. When the patient is missing a canine, lateral, and central incisor, the patient is also contraindicated for a fixed prosthesis.

A removable prosthesis that is completely implant supported and has no movement under function is considered a fixed prosthesis for the implant support. Therefore, the rigid implant overdenture system should follow the rules of treatment planning for a fixed prosthesis in relation to implant number and position. This is important to note because the maxillary sinus usually extends from the premolar region to the posterior wall of the maxilla. Sinus grafts to increase bone height from second premolar to second premolar are very predictable and more predictable than grafting a premaxilla. However, when the patient has only posterior bone for implants, a fixed implant prosthesis is not indicated. Available bone height and width are necessary in the canine region for either a fixed or a maxillary RP-4 (rigid) overdenture. Hence, if an implant cannot be placed in the canine region and only posterior implants are used, there will be an increase in complications of the overdenture.

In summary, the treatment plan of a posterior maxilla should provide for the maintenance or restoration of healthy anterior

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FIGURE 22-15. **A,** Maxillary and mandible full-arch fixed prosthesis. **B,** A panoramic radiograph of maxillary and mandibular fixed restorations. More implants are most often indicated in the maxilla compared to a mandible.



FIGURE 22-16. Implants in the posterior maxilla should have more surface area. The implant on the right has more surface area than the implant on the left. It is longer, has more threads, and has a rougher surface condition.

teeth or adequate bone in the premaxilla for root form implant placement. A minimum of a healthy natural canine tooth or an implant abutment in the canine region is required before posterior implants are considered in the quadrant for either a fixed or a removable restoration.

Abnormal sinus anatomy, pathology, and intraoral conditions may compromise the final outcome of sinus grafting procedures or the survival rates of dental implants placed in the posterior maxilla. Therefore, relative dental contraindications for the posterior maxilla are similar to those reported in cases of standard-implant treatment of edentulous patients and may also include maxillary sinus pathology or the inability to augment the posterior regions with bone.

Treatment History

Literature Review

Over the years, several strategies have been advocated to restore the posterior maxilla and address the deficiency of bone volume and poor bone quality. The various approaches can be categorized as follows.

- Avoid the sinus and place implants anteriorly, posteriorly, or medially.[20–22]
- Place implants and perforate the sinus floor.[23,24]
- Use subperiosteal implants.[25,26]
- Perform horizontal osteotomy, interpositional bone grafting, and endosteal implants.[27,28]
- Elevate the sinus floor during implant placement.[29,30]
- Perform a lateral wall approach sinus graft and simultaneous or delayed implant placement.[29,30]

In the past, implants were inserted in the posterior maxilla without modifying the maxillary sinus topography. Small implants were often placed below the antrum. The decreased surface area compounded by poor bone quality resulted in poor implant stability. Attempts to place larger endosteal implants posterior to the antrum and into the tuberosity and pterygoid plates also resulted in compromised situations. In addition, although feasible from a surgical standpoint, rarely are third or fourth molar abutments indicated for proper prosthodontic support. The pterygoid implant approach often requires three or more pontics between the anterior and posterior implants. A long pontic span results in excessive flexibility of the prosthesis, increased risk of unretained restorations, excess stresses to the abutments, and increased risk of implant failure.

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The thin, porous compact bone often present on the crest of the ridge and on the lateral aspect of the maxilla serves as a poor foundation for subperiosteal implants. Lack of adequate bone height often results in the subperiosteal implant being displaced laterally, off the bony ridge, from occlusal and parafunctional forces.

In the late 1960s, Linkow reported that the blade-vent implant could be blunted and the maxillary sinus membrane slightly elevated to allow implant placement "into" the sinus in the posterior maxilla.[31] This technique required the presence of at least 7 mm of vertical bone height below the antrum. Geiger and Pesch reported that ceramic implants placed through the maxillary sinus floor could heal and stabilize without complication.[23] Brånemark et al. have shown that implants may be placed into the maxillary sinus without consequence if integration occurs between the implants and the bone below the sinus. Yet they also report a higher failure rate (70% success for 5–10 years) for this technique.[24] For long-term predictable results, vertical bone height of at least 10 mm for D3 bone in the posterior maxilla has been clinically determined to be more predictable when the implant diameter is 4 mm or more. Because the posterior maxilla often has D3 or D4 bone, implants of traditional design should have even greater height requirements.

Ashkinazy and others have reported on using tomographic radiographs to determine whether adequate bone exists on the palatal aspect of the maxillary sinus for blade implants.[22] However, Stoler stated that after 25 consecutive computed tomographic scans of the maxillae, adequate bone for implant support was not found on the medial aspect of the maxillary sinus.[32] Thus, it seems that if sufficient bone is present medial to the sinus, it is the rare exception.

In the early 1970s, Tatum began to augment the posterior maxilla with onlay autogenous rib bone to produce adequate vertical bone for implant support.[29,30] He found that onlay grafts below the existing alveolar crest would significantly decrease the posterior intradental height, yet very little bone for endosteal implants would be gained. Therefore, in 1974, Tatum developed a modified Caldwell–Luc procedure for elevation of the sinus membrane and subantral (SA) augmentation.[29,30] The crestal ridge of the maxilla was infractured and used to elevate the maxillary sinus membrane. Autogenous bone was then added in the area previously occupied by the inferior third of the sinus. Endosteal implants were inserted in this grafted bone after approximately 6 months. Implants were then loaded with final prostheses after an additional 6 months.

In 1975, Tatum developed a lateral approach surgical technique that allowed the elevation of the sinus membrane and implant placement in the same surgical appointment.[29,30] The implant system used was a one-piece ceramic implant, and a permucosal post was evident during the healing period. Early ceramic implants were not designed adequately for this procedure, and results with the technique were unpredictable. In 1981, Tatum developed a submerged titanium implant for use in the posterior maxilla.[33,34] The advantages of submerged healing, the use of titanium instead of aluminum oxide as a biomaterial, improved biomechanics, and improved surgical technique made this implant modality predictable.

From 1974 to 1979, the primary graft material for the sinus graft procedure was autologous bone. In 1980, the application of the sinus augmentation techniques with a lateral maxillary approach was further expanded by Tatum with the use of synthetic bone. The same year, Boyne and James reported on the use of autogenous bone for SA grafts.[35] Most of the data published in the 1980s were anecdotal or based on very small sample sizes.

In 1987, the author organized a treatment approach to the posterior maxilla based on the amount of bone below the antrum, and in 1989, he expanded the treatment approach to include the available bone width of the maxillary sinus related to surgical approach and implant design.[36] Since then, minor modifications regarding the graft materials or surgical approach have also been proposed.

In the 1990s, the profession developed a much greater interest in the sinus graft technique.[37] Several reports have flourished in the literature, reporting on minor changes in the technique, different materials used in the graft, different origins for the autogenous portion of the graft, histomorphometric data relative to the graft healing, and other retrospective studies relative to the survival rates of implants placed in grafted sinuses with a simultaneous or delayed approach.[38–62]

Long-term results have been reported by Tatum to be above 95%, with more than 1500 SA augmentations performed.[63] Hence, the sinus graft procedure has been the most predictable method to grow bone height from 5 to 20 mm compared with any other intraoral bone grafting technique, with a graft success rate and an implant survival rate greater than 95%. After the vertical bone height has been improved, an ideal implant number, size, and location may be used to predictably restore the posterior maxilla.

Sinus Graft Options for the Posterior Maxilla

A bone volume classification was published by Misch and Judy in 1987, which followed the bone resorption pattern of edentulous ridges in the maxilla and mandible.[5] The abundant width ridge for available bone was classified as a division A ridge. Since then, the dimensions of this ridge have been slightly modified to greater than 6 mm in width, greater than 7 mm in mesiodistal length, greater than 12 mm in height, and an angulation less than 30 degrees to occlusal load. A residual width of 6 mm was selected for this bone volume because this dimension may adequately support at least a 4-mm-diameter implant, which is the most frequent diameter used as an implant abutment. Division B edentulous ridges are described as 2.5 to 6 mm in width, 7 or more mm in mesiodistal length, greater than 12 mm in height, and an angulation to occlusal load of less than 20 degrees. The decreased width of the bone in all jaw locations primarily occurs from the facial toward the medial aspects of the remaining available bone. Division C–w ridges consisted of inadequate width of 1 to 2.5 mm and greater than 12 mm in height. A C–h ridge is inadequate in height (<12 mm), and a CHS to bone ratio exists greater than 1. A Misch–Judy division D severely atrophic ridge had significant height resorption and the remaining bone had a crown height–to–remaining bone ratio greater than 5 to 1. In the posterior maxilla, the crown height is less affected in division C–h or D ridges because the sinus expands more rapidly than the crestal height of bone is reduced.

A classification based on a treatment option approach to providing additional prosthodontic abutments specific to the maxillary posterior edentulous region was presented by Misch and Judy in 1987,[5] dependent on the available bone height between the floor of the antrum and the crest of the residual ridge in the region of the ideal implant locations[36] (Figure 22-17). This protocol also suggested a surgical approach, bone graft material, and time table for healing before prosthetic reconstruction. In 1998, Cawood and Howell also classified the

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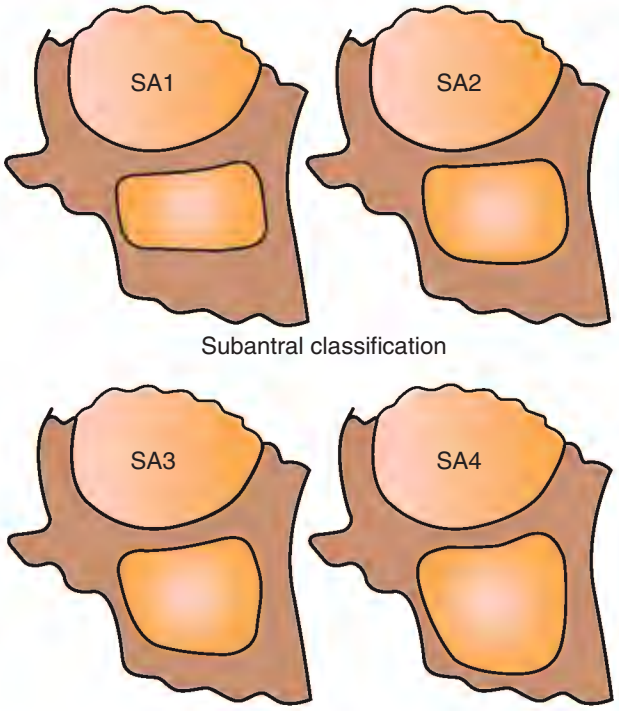


FIGURE 22-17. In 1987, Misch presented four subantral (SA) treatment options based on the amount of bone below the maxillary sinus. SA augmentation category 1 (SA-1) sinus used traditional implant approaches. Category SA-2 used a sinus lift procedure within the osteotomy. For the SA-3 and SA-4 categories, a Tatum sinus graft procedure is performed before implant insertion.

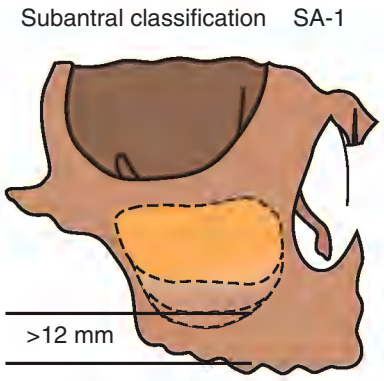


FIGURE 22-18. Posterior maxilla with greater than 12-mm height of bone is placed in subantral augmentation option 1. When more than 5-mm width is present, the ridge is division A and ready for implant insertion; when 2.5 to 5 mm is present, the ridge is division B and should be augmented in width.

edentulous posterior maxilla, which included the loss of bone and pneumatization of the maxillary sinus.[64]

In 1995, the author modified his 1987 classification to include the lateral dimension of the sinus cavity, and this dimension was used to modify the healing period protocol because smaller width sinuses (0–10 mm) form bone faster than larger width (>15 mm) sinuses.[65] Other classifications of the sinus graft procedure have been proposed by Jensen in 1991[66] and Chiapasco in 2003.[67,68]

Misch Maxillary Posterior Classification

Subantral Option 1: Conventional Implant Placement

The first SA treatment option, SA-1, occurs when there is sufficient available bone height to permit the placement of endosteal implants using a usual surgical protocol. In the abundant bone volume (division A), root form implants are used for prosthetic support. The minimum "ideal" bone height is related to implant design and bone density; however, at least a 12-mm implant in height is suggested for a 4-mm-diameter threaded implant (Figures 22-18 and 22-19).

Patients with narrower bone volume (division B) may be treated with osteoplasty or augmentation to increase the width of bone. The insertion of smaller surface area implants is not suggested because the forces are greater in the posterior regions of the mouth, and the bone density is less than in most regions. In addition, the narrow ridge is often more medial than the central fossa of the mandibular teeth and results in an offset load on the restoration, which increases the strain to the bone.

Osteoplasty in the SA-1 posterior maxilla may change the SA category if the height of the remaining bone is less than 12 mm after the bone modification is completed. Augmentation for width may be accomplished with bone spreading, autogenous onlay, or appositional grafts. Larger-diameter implants are often required in the molar region, and bone spreading to place wider implants is the most common approach when the bone density is poor. If less than 2.5 mm of width is available in the posterior edentulous region (division C–w), the most predictable treatment option is to increase width with onlay autogenous bone grafts.[69] After graft maturation, the area is then reevaluated to determine the proper treatment plan classification.

Although a common axiom in implant dentistry is to remain 2 mm or more from an opposing landmark, this is not indicated in the SA region. As long as the antrum is healthy and instruments do not perforate the thin sinus mucosa lining the sinus floor, no contraindications exist to the preparation or placement of implants at the level of or even through the cortical plate of the sinus floor.

Endosteal implants in the SA-1 category are left to heal in a nonfunctional environment for approximately 4 to 8 months (depending on bone density) before the abutment posts are added for prosthodontic reconstruction. Care is taken to ensure that the implants are not traumatized in any way during the initial healing period. Progressive loading during the prosthetic phases of the treatment are suggested in D3 or D4 bone.

Subantral Option 2: Sinus Lift and Simultaneous Implant Placement

The second SA option, SA-2, is selected when 10 to 12 mm of vertical bone is present (0–2 mm less than the minimum height in SA-1) (Figure 22-20). To obtain the 12 mm or more of vertical bone necessary for improved implant survival in ridges of adequate width (division A), the antral floor is elevated through the implant osteotomy (Figure 22-21). This technique was originally developed by Tatum in 1970[29,30] and published by Misch in 1987[36] and many years later by Summers.[70]

The endosteal implant osteotomy is prepared as determined by the density of bone protocol. The depth of the osteotomy is approximately 1 to 2 mm short of the floor of the antrum (Figure 22-22). A cup-shaped osteotome of the same diameter as the final osteotomy is selected.[71] It is of a different end shape than osteotomes used for bone spreading. The osteotome is slightly inserted and tapped firmly in 0.5- to 1-mm increments beyond the initial osteotomy until its final position up to 2 mm beyond the pre-prepared implant osteotomy. This surgical

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FIGURE 22-19. **A,** A panoramic radiograph of posterior maxillae with a subantral option 1 condition. **B,** Root form implants at least 4 mm in diameter and 12 mm long are inserted and one implant for each missing tooth are the treatment of choice for subantral option 1 conditions.

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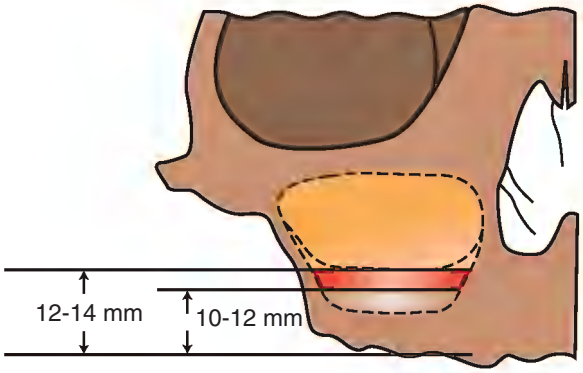


FIGURE 22-20. A posterior maxilla with 10 to 12 mm of vertical height is treated with a subantral option 2. The sinus floor is raised with the implant osteotomy (sinus lift). When the width of bone is greater than 5 mm, treatment follows division A with a sinus lift. A width of 2.5 to 5 mm is division B and should be augmented in width.

approach causes a greenstick-type fracture in the antral floor and slowly elevates the unprepared bone and sinus membrane over the broad-based osteotome.

The implant may be inserted into the osteotomy after the sinus lift and extend up to 2 mm above the floor of the sinus. The implant is slowly threaded into position so that the membrane is less likely to tear as it is elevated. The apical portion of the implant engages the bone below the floor of the sinus, with elevated bone over the apex and hopefully an intact sinus membrane. The implant may extend up to 2 mm beyond the sinus floor, and the 1- to 2-mm bony covering over the apex results in as much as a 4-mm elevation of the sinus mucosa (Figure 22-23).

The autologous bone present above the apical portion of the implant increases the likelihood of new bone formation. The success of the intact sinus membrane lift cannot be confirmed before or at the time of implant placement. Attempts to feel the elevation of the membrane from within an 8-mm-deep implant osteotomy that is approximately 3 mm in diameter may easily cause tearing of the sinus lining.

Four to 6 months after the surgical procedure, a radiograph may be used to indicate the success of the 0- to 2-mm increased vertical height (Figure 22-24). The patient's prosthodontic treatment may proceed similar to that in the SA-1 category. If inadequate bone is formed around the apical portion of an implant after initial healing, a progressive bone loading protocol is suggested.

Some authors have used the SA-2 sinus lift procedure to gain more than 2 mm of implant vertical height or place bone graft materials in the osteotomy site before implant insertion.[53] These blind surgical techniques increase the risk of sinus membrane perforation. When the sinus mucosa is perforated, the graft material may extrude into the antrum and increase the risk of postoperative infection. If a sinus infection occurs, a bacterial smear layer may accumulate on the implant apex. This prevents future BIC and may contribute to future sinus infections.

If sinus membrane perforation occurs during the initial implant placement procedure, increased bone height is not likely. This is the primary reason why no more than 2 mm of additional implant height is attempted with this technique. However, even when membrane perforation occurs or no bone grows around the apical end of the implant, the SA-2 technique is of benefit because the apical end of the implant is often surrounded by denser bone. This enhances rigid fixation during healing and increases BIC, leading to improved loading conditions.

Worth and Stoneman have reported a comparable phenomenon of bone growth under an elevated sinus membrane, called *halo formation*.[72] They observed the natural elevation of the sinus membrane around teeth with periapical disease. The elevation of the membrane resulted in new bone formation after the tooth infection was eliminated.

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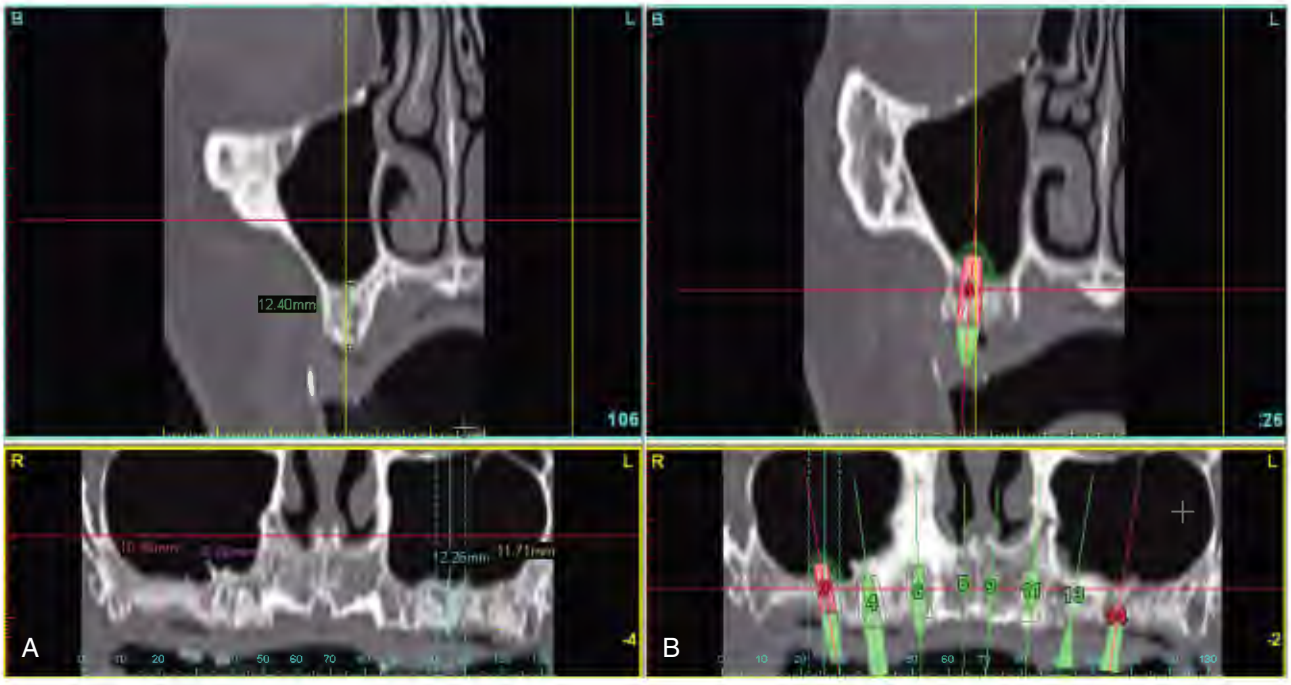


FIGURE 22-21. Treatment plan SA-2 calls for elevation of 0 to 2 mm of the floor of the maxillary sinus at the same time as implant placement. During the treatment plan phase, a computed tomography scan with implant software can be used to visualize the sinus lift and final implant relationship with surrounding bone. (Courtesy S. Caldwell, El Paso, TX.)

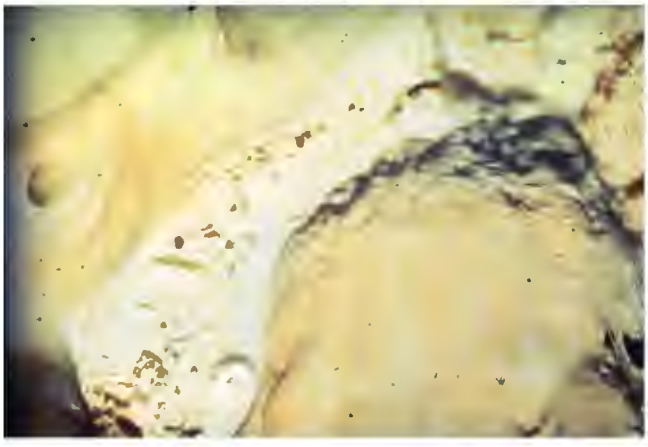


FIGURE 22-22. The implant osteotomy for a sinus lift is prepared 1 to 2 mm below the floor of the sinus.

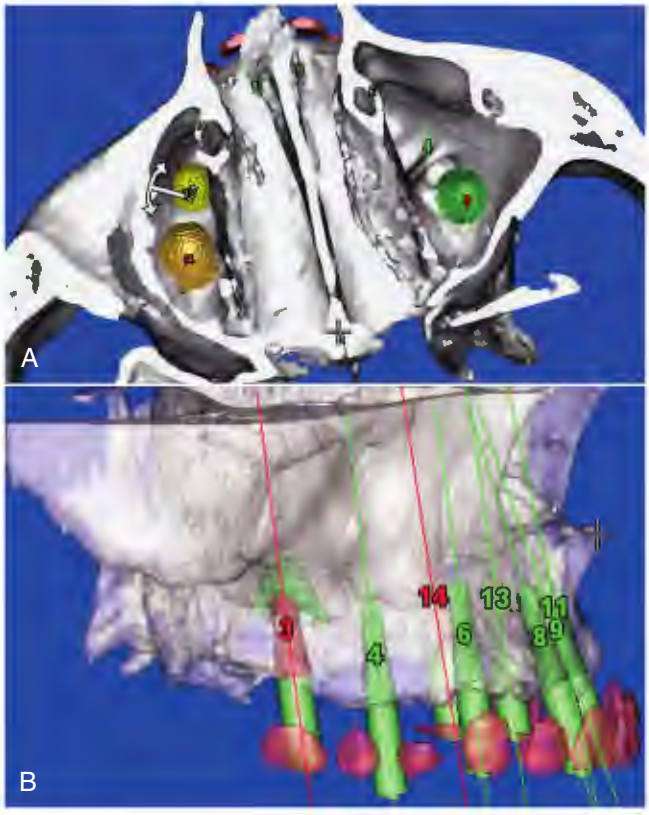


FIGURE 22-23. **A,** A three-dimensional (3D) view of the maxillary sinus illustrates the membrane being elevated only in the vicinity of the implant apex, creating a halolike image. **B,** A 3D view of the maxillary sinus illustrating implant placement during the treatment planning phase along with the proposed final level of the sinus floor after SA-2. (Courtesy S. Caldwell, El Paso, TX.)

Subantral Option 3: Sinus Graft with Immediate or Delayed Endosteal Implant Placement

The third approach to the maxillary posterior edentulous region, SA-3, is indicated when 5 to 10 mm of vertical bone and sufficient width are present between the antral floor and the crest of the residual ridge in the area of a needed prosthodontic abutment (Figure 22-25). A Tatum lateral maxillary wall approach is performed just superior to the residual bone. After the lateral access window and membrane are rotated in and upward to a superior position, a mixture of autogenous bone, alloplast, or allograft material is placed in the space previously occupied by the sinus. When the original ridge is greater than 6 mm in width, the implant may be inserted at the same time as the sinus augmentation under ideal conditions or delayed for a period of

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FIGURE 22-24. After healing, the halo effect at the apex of the implant can be visualized on postoperative imaging.

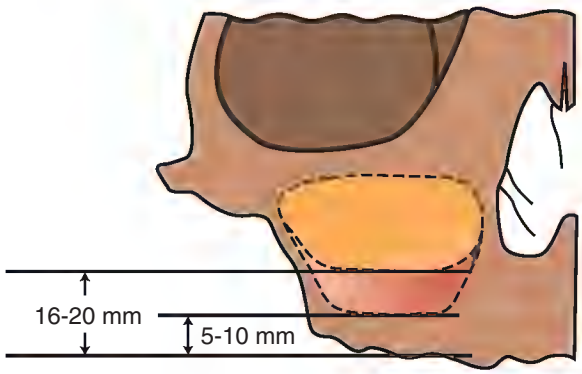


FIGURE 22-25. A posterior maxilla with 5 to 10 mm between the crest of the ridge and sinus floor is placed in subantral option 3. A Tatum sinus graft is indicated before implant insertion. When greater than 5 mm of width is present, the sinus graft converts the ridge to division A. When 2.5 to 5 mm of width is present, the division B ridge should be augmented in width.

2 or more months before implant insertion[17–72] (Box 22-2). The short delay between graft placement and implant insertion ensures the graft is more stable and is healing without compromise related to postoperative sinus infection. When the original ridge width is division B or C–w, an onlay graft in conjunction with the sinus augmentation is a possible treatment option (Box 22-3).

The 5 to 10 mm of initial bone height in an SA-3 posterior maxilla may stabilize an implant that is inserted at the time of the graft and permit its rigid fixation. Therefore, an endosteal implant may be inserted at this appointment and has been advocated for many years (Figure 22-26). However, several conditions should be evaluated and ideal when implants are inserted at the same time. Many of these conditions are specific to a healthy maxillary sinus.

The primary disadvantage of delaying the implant placement at the time of the sinus graft is the need for an additional surgery. If overall treatment time is a significant factor for the patient, the implant may be inserted after 2 months yet reduce considerably the risk of infection related to the sinus graft. Otherwise, 4 months or more is typical for implant insertion after the SA-3 technique with a delayed approach (Figure 22-27).

BOX 22-2 Implant Placement (SA-3I)

When the endosteal implants are inserted at the same time as the sinus graft, several conditions are suggested:
1. >5 mm bone height (D3 or better)
2. >6 mm bone width
3. No sinus pathology
4. No history of sinusitis
5. No relative contraindications
6. No parafunction on RPD transitional
7. No sinus membrane perforation

RPD, Removable partial denture; SA, subantral.

BOX 22-3 No Implant Placement (SA-3)

Implants should not be inserted at the same time as the sinus graft when the following conditions exist:
1. >5 mm bone height (D4)
2. <6 mm bone width
3. Treated sinus pathology
4. History of sinusitis
5. Relative contraindications (smoking, diabetes, periodontal disease)
6. Parafunction on RPD transitional
7. Sinus membrane perforation during surgery

RPD, Removable partial denture; *SA,* subantral.

Subantral Option 4: Sinus Graft Healing and Extended Delay of Implant Insertion

In the fourth option for implant treatment of the posterior maxilla, SA-4, the SA region for future endosteal implant insertion is first augmented. This option is indicated when less than 5 mm remains between the residual crest of bone and the floor of the maxillary sinus (Figure 22-28). There are several reasons to delay the placement of the implant in SA-4 conditions.

1. The individual rate of healing of the sinus graft may be assessed after initial healing while the implant osteotomy is being prepared and the implant inserted. The healing time for the sinus and implant is no longer arbitrary but more patient specific.
2. Postoperative sinus graft infection occurs in approximately 3% to 20% of patients, which is greater than the percentage for implant placement surgery. If the sinus graft becomes infected with an implant in place, a bacterial smear layer may develop on the implant and make future bone contact with the implant less predictable. The infection is also more difficult to treat when the implants are in place and may result in greater resorption of the graft as a consequence. If the infection cannot be adequately treated, the graft and implant must be removed. Therefore, there is also a decreased risk of losing the graft and implant if a postoperative infection occurs with a delayed implant insertion. Reports in the literature indicate a slightly higher failure rate of implants

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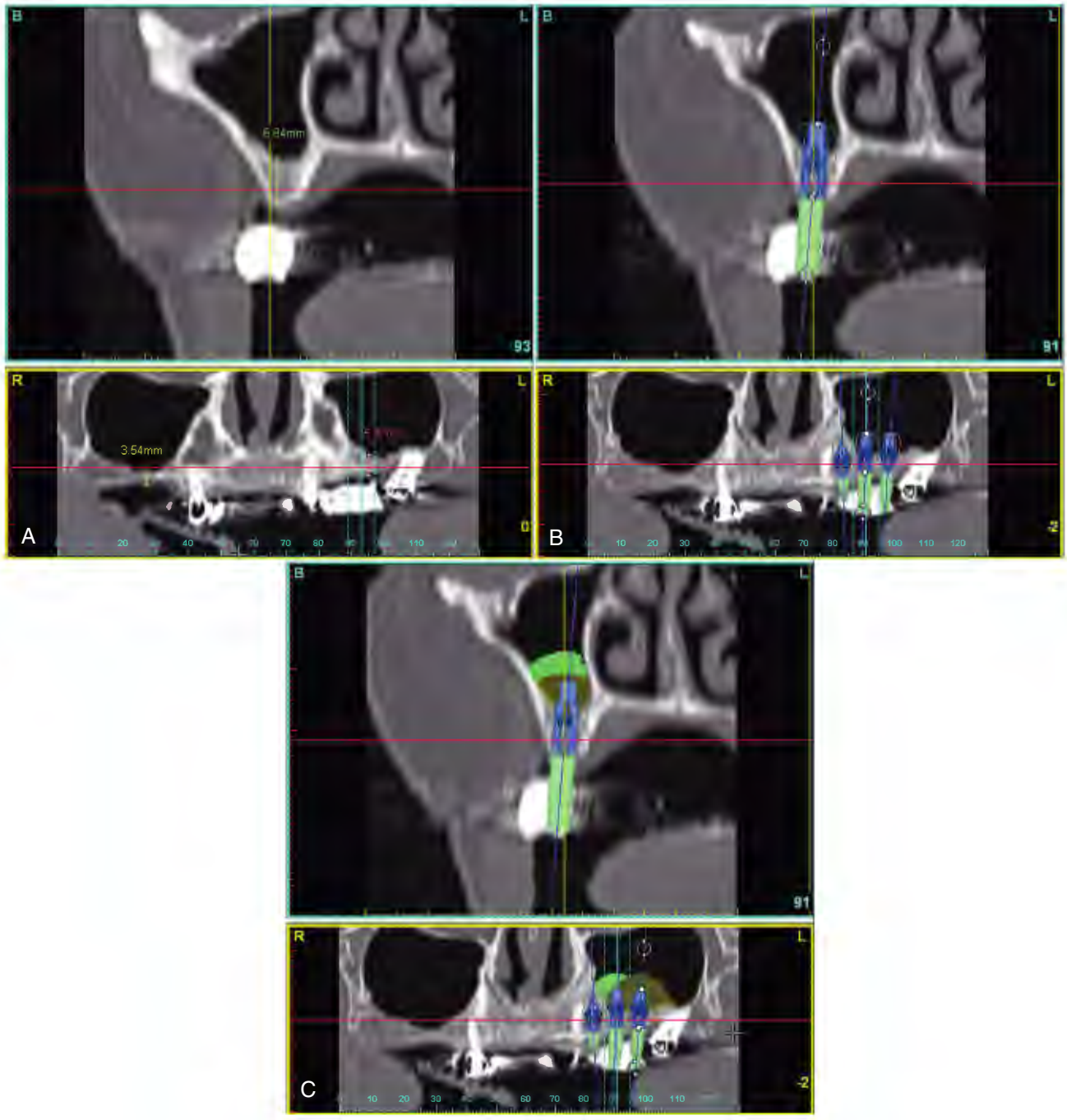


FIGURE 22-26. **A,** A SA-3 posterior maxilla exhibiting only 5 to 10 mm below the floor of the maxillary sinus. **B,** The implant length required in poor-quality bone such as the posterior maxilla is 12 mm or greater. Therefore, a sinus graft to obtain the necessary bone height will be performed before implant placement. **C,** The amount of bone graft necessary can be assessed on computed tomography imaging assisted with a computerized surgery navigation software. (Courtesy S. Caldwell, El Paso, TX.)

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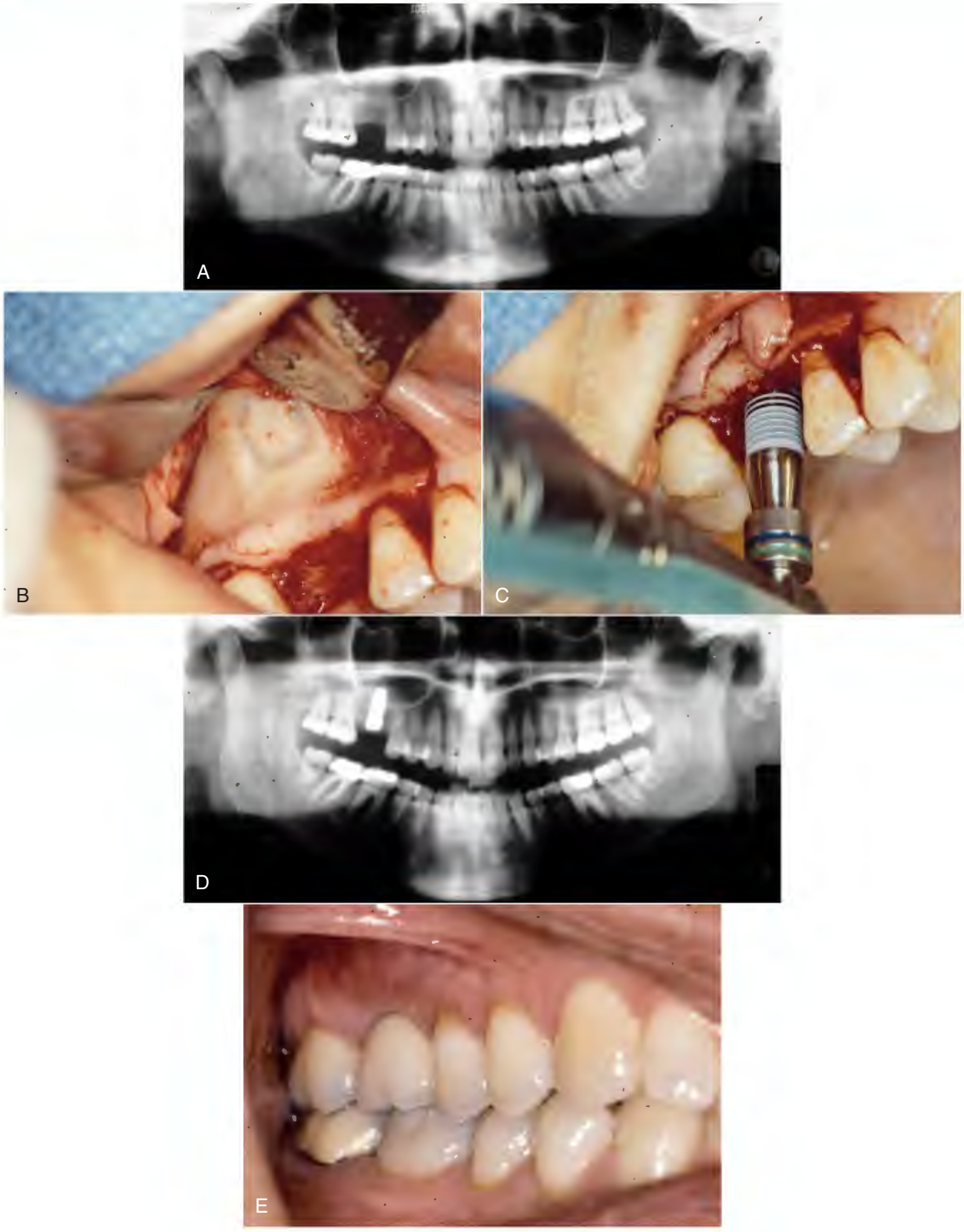


FIGURE 22-27. **A,** A panoramic radiograph of a missing maxillary first molar with 7 mm of bone below the antrum. **B,** A Tatum lateral access window is prepared in the lateral wall of the maxilla. **C,** After grafting, a 5-mm-diameter, 12-mm-long threaded, rough-surface implant is inserted. **D**, A postoperative radiograph of the implant in place with the sinus graft. **E**, The final single implant crown replacing the maxillary right first molar.

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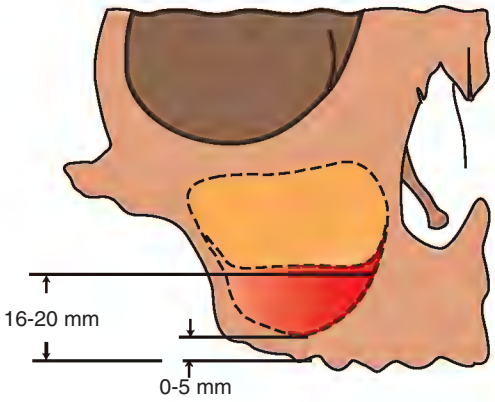


FIGURE 22-28. A posterior maxilla with 0 to 5 mm of bone below the antrum is subantral augmentation option 4. A Tatum sinus graft is placed and allowed to mature before implant placement. After the sinus graft, width of bone 5 mm or greater is placed into division A, and 2.5 to 5 mm is placed into division B and modified into division A before implant placement.

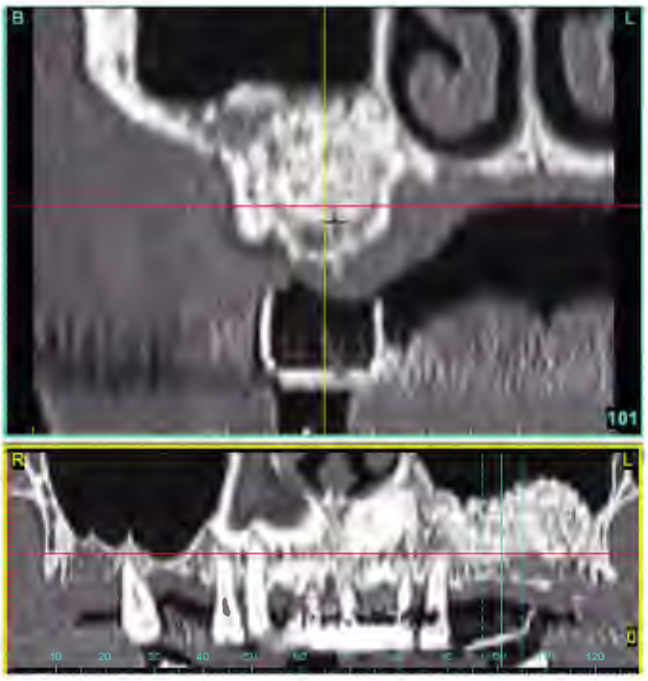


FIGURE 22-29. Computed tomography (CT) scans can be used after the sinus graft (SA-4) before implant placement to verify proper graft placement. (The medial wall was elevated to permit proper bone graft material placement.) This CT scan image illustrates the difference in bone height between an SA-4 site before and after grafting. (Courtesy S. Caldwell, El Paso, TX.)

when inserted simultaneously compared with a delayed approach.[37]

3. Blood vessels are required to form and remodel bone. An implant in the middle of the sinus graft does not provide a source of blood vessels. It may even make vascular supply more troublesome.
4. Bone width augmentation may be indicated in conjunction with sinus grafts to restore proper maxillomandibular ridge relationships or increase the implant diameter in the molar region. Augmentation may be performed simultaneously with the sinus graft. As a result, larger-diameter implants may be placed with the delayed technique.
5. The bone in the sinus graft is denser with the delayed implant placement. As such, implant angulation and position may be improved because it is not dictated by existing anatomical limitations at the time of the sinus graft.
6. The surgeon may access the sinus graft before implant insertion. On occasion, the sinus graft underfills a region, and the lack of awareness of the condition during implant insertion at the same time results in an implant placed in the sinus proper rather than the graft site (Figure 22-29).
7. The SA-4 corresponds to a larger than the SA-2 or SA-3 condition antrum, and it typically exhibits longer mediodistal and lateromedial dimensions, and minimal host bone is present on the lateral, anterior, and distal regions of the graft because the antrum generally has expanded more aggressively into these regions.
8. There is less autologous bone to harvest in the tuberosity, which further delays the bone regeneration in the site. In addition, there are usually fewer septa or webs in the sinus, and these septa increase the bone regeneration.

Therefore, the fewer bony walls, less favorable vascular bed, minimal local autologous bone, and larger graft volume all mandate a longer healing period and slightly altered surgical approach.

The Tatum lateral wall approach for sinus graft is performed as in the previous SA-3 procedure (Figure 22-30). Most SA-4 regions provide better surgical access than the SA-3 counterparts because the antrum floor is closer to the crest compared with the SA-3 maxilla (Figure 22-31).

The augmented region matures for 6 to 10 months before reentry for placement of endosteal implants. The amount of initial healing is related to the antral size (including small, medium, or large lateral-medial size) and the amount of autologous bone used in the inferior third of the antrum.

Typically, the width of crestal bone is wide enough in SA-4 regions for the placement of root form implants after the graft matures. The width of the host site for sinus grafts is most often division A; however, when division C–w to B exists, an onlay graft for width is indicated. When the graft cannot be secured to the host bone, it is often preferable to perform the sinus graft 6 to 9 months before the autogenous graft for width. Then after graft maturation, the implants may be inserted.

The implant surgery at reentry for SA-3 or SA-4 is similar to SA-1 with one exception. The periosteal flap on the lateral side is elevated to directly allow inspection of the previous access window of the sinus graft. The previous access window may appear completely healed with bone, soft and filled with loose graft material, with cone-shaped fibrous tissue ingrowth (with the base of the cone toward the lateral wall), or in any variation states. If the graft site appears clinically as bone, the implant osteotomy and placement follow the approach designated by the bone density.

The time interval for stage II uncovery and prosthetic procedures after implant insertion depends on the density of bone at the reentry implant placement. The most common bone density observed is D3 or D4, and often it is softer than the region in general. Progressive loading after uncovery is most important when the bone is particularly soft and less dense.

Inadequate bone formation after the sinus graft healing period of SA-4 is possible but is an uncommon complication.

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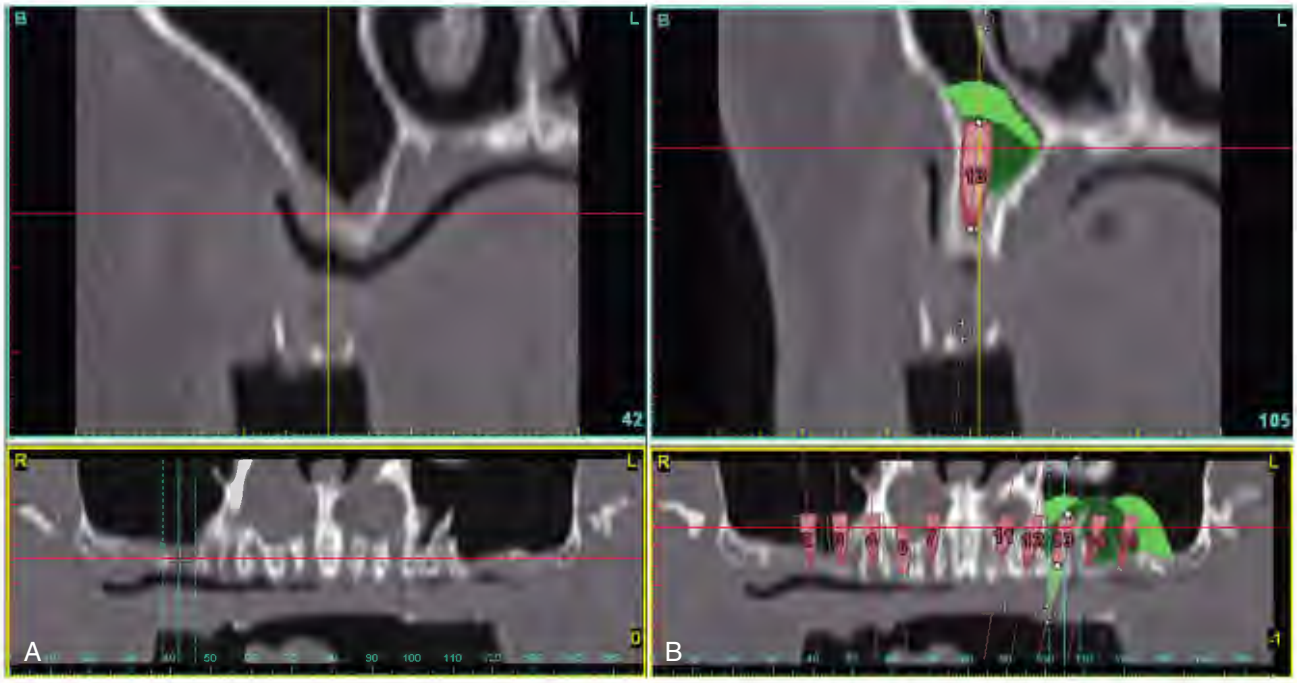


FIGURE 22-30. **A,** When 0 to 5 mm of bone is available between the crest of the ridge and the floor of the antrum, a sinus graft is necessary to restore the bone volume before implant placement. **B,** The use of three-dimensional imaging and implant software allows the visualization of implants at the treatment planning phase. (Courtesy S. Caldwell, El Paso, TX.)

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TABLE 22-1
Healing Times for Treatment Categories

Subantral Augmentation Option	Height (mm)	Procedure	Healing Time (Months): Graft	Healing Time (Months): Implant
SA-1	>12	Division A root form placement	—	4–6*
SA-2	10–12	Sinus lift; simultaneous division A root form placement	—	6–8*
SA-3	5–10	Lateral wall approach sinus graft; delayed division A root form placement	2–4	4–8*
	<5	Lateral wall approach sinus graft; delayed division A root form placement	6–10	4–10*

*Evaluate at implant insertion.

When observed, the SA-3 technique may be used to place additional SA graft before the implant placement surgery.

Summary

In the past, the posterior maxilla has been reported as the least predictable area for implant survival. Causes cited include inadequate bone height, poor bone density, and high occlusal forces. Past implant modalities attempted to avoid this region, with approaches such as excessive cantilevers when posterior implants are not inserted or excess numbers of pontics when implants are placed posterior to the antrum.

The maxillary sinus may be elevated and SA bone regenerated to improve implant height. Tatum began to develop these techniques as early as the mid 1970s. Misch developed four options for treatment of the posterior maxilla in 1987 based on the height of bone between the floor of the antrum and the crest of the residual bone (Table 22-1). These options were further modified to reflect the width of available bone after adequate height was obtained. Root form implants are indicated under these conditions. When the ridge anatomy is too narrow in width for root form implants, these ridges may be treated by osteoplasty or with autogenous grafts. The higher forces and less dense bone often require larger diameter implants.

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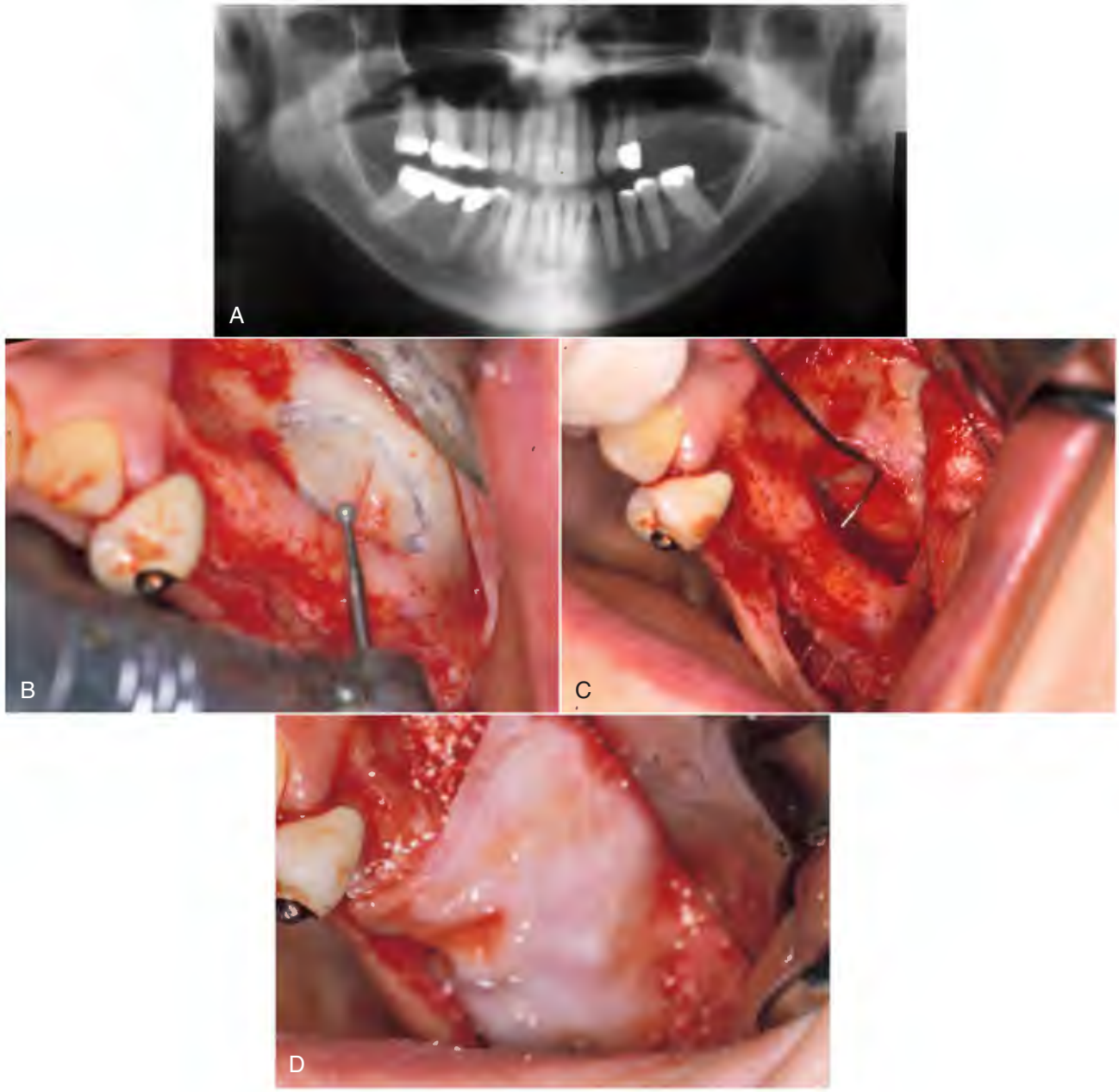


FIGURE 22-31. **A**, A panoramic radiograph of missing maxillary posterior teeth with less than 5 mm below the antrum (SA-4). **B,** A Tatum access window is prepared in the lateral wall of the sinus. **C,** The lateral wall is rotated in and up, along with the sinus mucosa. **D,** A graft is placed and covered with a collagen membrane.

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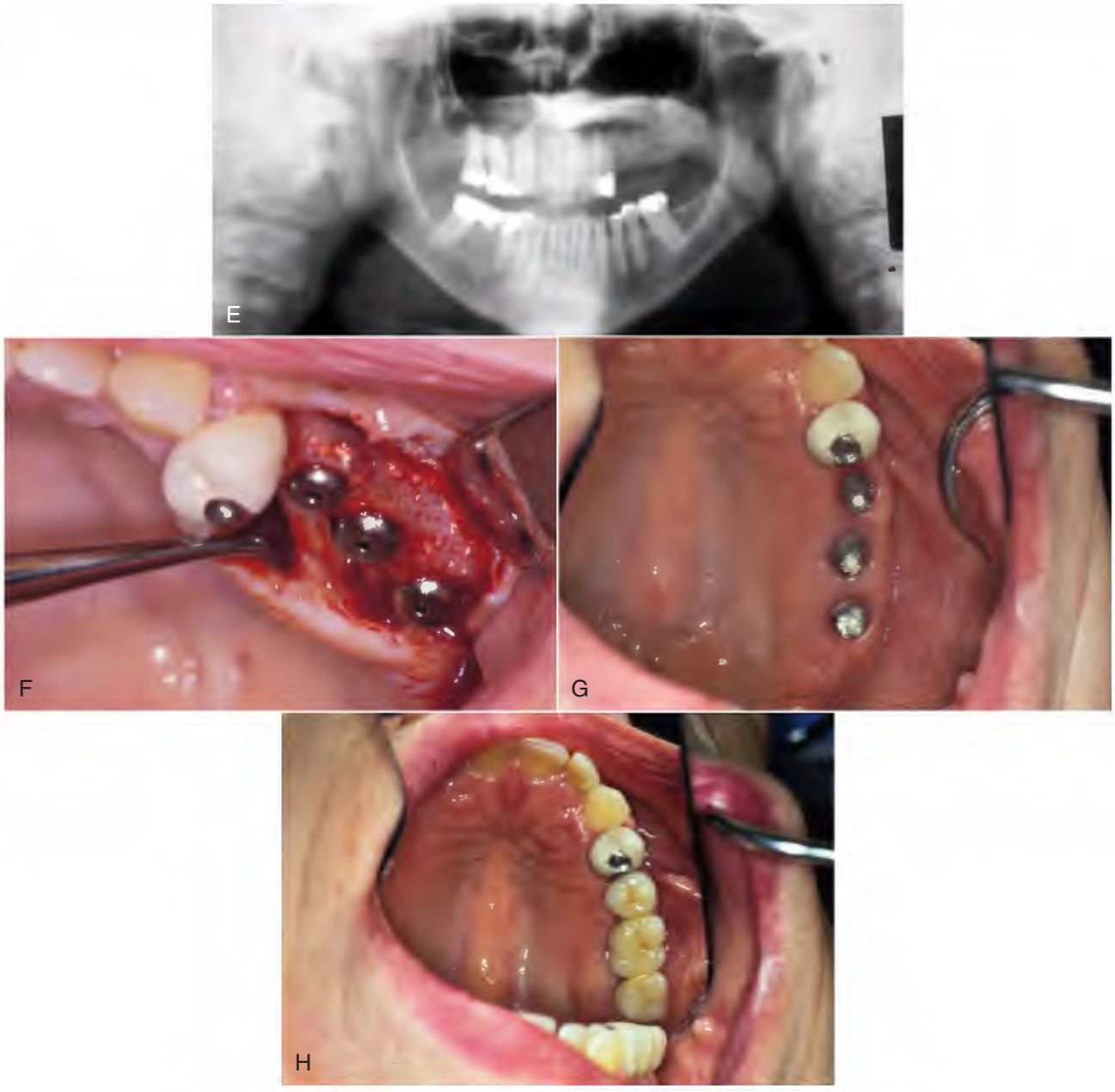


FIGURE 22-31, cont'd. **E,** The graft matures 4 months or more. **F,** Implants are inserted, one for each missing tooth. **G,** After 4 or more months, the abutments are inserted to support the prosthesis. **H,** A three-unit fixed partial denture is cemented to the implant abutments.

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CHAPTER 23

The Edentulous Mandible: Treatment Plans for Implant Overdentures

Carl E. Misch

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The complete edentulous population comprises more than 10% of the adult population and is directly related to the age of the patient. By the age of 70 years old, almost 45% of the population has no teeth in either arch. The vast majority of these patients are treated with complete dentures. Yet the dental profession and the public are more aware of the problems associated with a complete mandibular denture than any other dental prosthesis.

The placement of implants enhances the support, retention, and stability of an overdenture. As a result, edentulous patients are very willing to accept a treatment plan for a mandibular implant overdenture (IOD). There is greater flexibility in implant position or prosthesis fabrication with a mandibular IOD; as a result, it is also an ideal treatment modality to begin an early learning curve in implant surgery and prosthetics. Therefore, one of the most beneficial treatments rendered to patients is also one of the best introductions for a dentist into the discipline of implant dentistry.

An increased awareness from the profession and patients has now rendered the mandibular IOD the treatment of choice in the edentulous patient regardless of most clinical situations, bone densities, and patients' desires to restore an ever-growing number of patients.[1–38] As a consequence, mandibular overdentures have become the minimum standard of care for most completely edentulous mandibles.

Advantages of Mandibular Implant Overdentures

The patient gains several advantages with an implant-supported overdenture prosthesis.[7,8,11] (Box 23-1). The complete mandibular denture often moves during mandibular jaw movements during function and speech. A mandibular denture may move 10 mm during function. Under these conditions, specific occlusal contacts and the control of masticatory forces are nearly impossible. An IOD provides improved retention and stability of the prosthesis, and the patient is able consistently to reproduce a determined centric occlusion.[39]

Bone loss after complete edentulism, especially in the mandible, has been observed for years in the literature.[39–41] Soft tissue abrasions and accelerated bone loss are more symptomatic of horizontal movement of the prosthesis under lateral forces. An implant-supported overdenture may limit lateral movements and direct more longitudinal forces. The anterior implants stimulate the bone and maintain the anterior bone volume.[40–44] The attachment of the mentalis muscle and others are maintained as a result and therefore improve facial esthetics.

Higher bite forces have been documented for mandibular overdentures on implants. The maximum occlusal force of a patient with dentures may improve 300% with an implant-supported prosthesis.[44,45] A study of chewing efficiency compared wearers of complete dentures with wearers of implant-supported overdentures. The complete denture group needed 1.5 to 3.6 times the number of chewing strokes compared with the overdenture group.[38] The chewing efficiency with an IOD is improved by 20% compared with a traditional complete denture.[6,7,46,47]

Mericke-Stern[48] and Mericke-Stern et al.[49] also compared mastication between root overdentures and IODs. Whereas the former was more discriminative, the latter developed slightly harder chewing strokes and tended to masticate more vertically. Jemt et al.[50] showed a decrease in occlusal force when the bar connecting implants was removed, which they attributed to the loss of support, stability, and retention. As a result of improved mastication, patients with IODs can chew significantly better than with their complete dentures[6] (Figure 23-1).

The contraction of the mentalis, buccinator, or mylohyoid muscles may lift a traditional denture off the soft tissue. As a consequence, the teeth may touch during speech and elicit clicking noises. The retentive IOD remains in place during mandibular movement. The tongue and perioral musculature may resume a more normal position because they are not required to limit mandibular denture movement.

The IOD may reduce the amount of soft tissue coverage and extension of the prosthesis. This is especially important for new denture wearers, patients with tori or exostoses, and patients with low gagging thresholds. Also, the existence of a labial

BOX 23-1 Mandibular Implant Overdenture Advantages

- Prevents anterior bone loss
- Improved esthetics
- Improved stability (reduces or eliminates prosthesis movement)
- Improved occlusion (reproducible centric relation occlusion)
- Decrease in soft tissue abrasions
- Improved chewing efficiency and force
- Increased occlusal efficiency
- Improved prosthesis retention
- Improved prosthesis support
- Improved speech
- Reduced prosthesis size (reduces flanges)
- Improved maxillofacial prostheses

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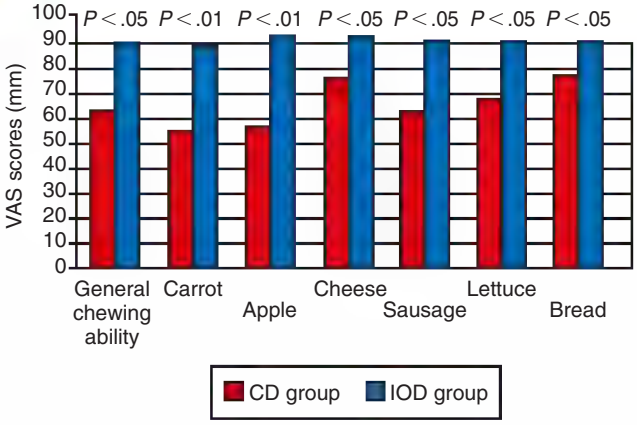


FIGURE 23-1. In a study by Awad et al.,[6] implant overdenture (IOD) patients were able to chew different types of food significantly better than patients with complete dentures (CDs). (Data from Awad MA, Lund JP, Dufresne E, et al: Comparing the efficacy of mandibular implant-retained overdentures and conventional dentures among middle-aged edentulous patients: satisfaction and functional assessment, Int J Prosthodont 16:117-122, 2003.).

BOX 23-2 Implant Overdenture Advantages versus Fixed Prosthesis

- Fewer implants (RP-5)
- Less bone grafting required before treatment
- Less specific implant placement
- Improved esthetics
- Denture teeth
- Labial flange
- Soft tissue drape replaced by acrylic
- Soft tissue considerations
- Improved periimplant probing (follow-up)
- Hygiene
- Reduced stress
- Nocturnal parafunction (remove prosthesis at night)
- Stress relief attachment
- Lower cost and laboratory cost (RP-5)
- Fewer implants (RP-5)
- Less bone grafting (RP-5)
- Easy repair
- Laboratory cost decrease (RP-5)
- Transitional device is less demanding than a fixed restoration

flange in a conventional denture may result in exaggerated facial contours for a patient with recent extractions. Implant-supported prostheses do not require labial extensions or extended soft tissue coverage.

Soft and hard tissue defects from tumor excision or trauma do not permit the successful rehabilitation of patients with traditional denture support. Hemimandibulectomy patients and other maxillofacial patients also may be restored more favorably with an IOD compared with traditional procedures.[51]

An IOD also provides some practical advantages over an implant-supported complete fixed partial denture (Box 23-2). Fewer implants may be required when a RP-5 restoration is fabricated because soft tissue areas may provide additional support. The overdenture may provide stress relief between the superstructure and prosthesis, and the soft tissue may share a portion of the occlusal load. Regions of inadequate bone for implant placement therefore may be eliminated from the treatment plan rather than necessitating bone grafts or placing implants with poorer prognosis. As a result of less bone grafting and number of implants, the cost to treat the patients is dramatically reduced.

When cost is a factor, a two-implant-retained IOD may improve the patient's condition at a lower overall treatment cost than a fixed implant–supported prosthesis.[52] A survey by Carlsson et al. in 10 countries indicated a wide range of treatment options.[53] The proportion of IOD selection versus fixed implant dentures was highest in the Netherlands (93%) and lowest in Sweden and Greece (12%). Cost was cited as the top determining factor in the choice.

The esthetics for many edentulous patients with moderate to advanced bone loss are improved with an overdenture compared with a fixed restoration. Soft tissue support for facial appearance often is required for an implant patient because of advanced bone loss, especially in the maxilla. Interdental papilla and tooth size are easier to reproduce or control with an overdenture. Denture teeth easily reproduce contours and esthetics compared with time-consuming and technician-sensitive porcelain metal fixed restorations. The labial flange may be designed for optimal appearance, not daily hygiene. In addition, abutments do not require a specific mesiodistal placement for an esthetic result because the prosthesis completely covers the implant abutments.

Hygiene conditions and home and professional care are improved with an overdenture compared with a fixed prosthesis. Periimplant probing is easier around a bar than a fixed prosthesis because the crown contour often prevents straight-line access along the abutment to the crest of the bone. The overdenture may be extended over the abutments to prevent food entrapment during function in the maxilla.

An overdenture may be removed at bedtime to reduce the noxious effect of nocturnal parafunction, which increases stresses on the implant support system. In addition, a fixed prosthesis is not desired as often for a long-term denture wearer. Long-term denture patients do not appear to have a psychologic problem associated with a removable restoration versus a fixed prosthesis.[54–62]

In a randomized clinical report, Awad et al.[6] compared satisfaction and function in complete denture patients versus patients with two implant-supported mandibular overdentures. There were significantly higher satisfaction, comfort, and stability in the IOD group (Figure 23-2). A similar study in a senior population yielded similar results.[7] Thomason et al., in the United Kingdom, also reported a 36% higher satisfaction for implant IOD patients than complete denture wearers in the criteria of comfort, stability, and chewing.[8]

The overdenture prosthesis is usually easier to repair than a fixed restoration. Reduced laboratory fees and fewer implants allow the restoration of patients at reduced costs compared with a fixed prosthesis.

In conclusion, the primary indications for a mandibular IOD relate to problems found with lower dentures such as lack of retention or stability, decrease in function, difficulties in speech, tissue sensitivity, and soft tissue abrasions. If an edentulous patient is willing to remain with a removable prosthesis, an overdenture is often the treatment of choice. In addition, if cost is a problem for a patient who desires a fixed restoration, the overdenture may serve as a transitional device until additional implants may be inserted and restored.

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Variable	Conventional denture group Mean (SD)	Overdenture group Mean (SD)
General satisfaction	63.7 (34.7)	89.2 (21.8)*
Comfort	63.6 (36.8)	88.9 (21.4)†
Esthetics	88.9 (17.8)	90.6 (14.9)
Ability to speak	85.2 (20.9)	91.7 (11.8)
Stability	64.5 (36.4)	90.6 (19.8)†
Ability to clean	89.9 (17.8)	91.1 (18.3)

*Significant between-group difference; *t* tests. $P \leq .001$.
†Significant between-group difference; *t* tests. $P < .05$.

FIGURE 23-2. In a study by Awad et al.,[6] the patients with implant overdentures scored significantly higher for general satisfaction, comfort, and stability compared to the conventional complete denture patients. *SD,* Standard deviation. (Data from Awad MA, Lund JP, Dufresne E et al: Comparing the efficacy of mandibular implant-retained overdentures and conventional dentures among middle-aged edentulous patients: satisfaction and functional assessment, *Int J Prosthodont* 16:117-122, 2003.)



FIGURE 23-3. Long-term complete edentulism can result in severe bone atrophy. This cephalometric radiograph demonstrates that the body of the mandible is less 5 mm high and the superior genial tubercle is 10 mm above the crest of the ridge.



FIGURE 23-4. The majority of mandibular overdentures performed by dentists are with two implants regardless of factors such as the remaining bone, the opposing arch, and patient complaints. Although this treatment is an improvement compared with a denture, the posterior bone loss continues, and the anterior implants may experience greater problems than when additional implants are used.

Philosophy for Implants in the Edentulous Mandible

From a bone volume conservation standpoint in the jaws, complete edentulous patients should be treated with enough implants to completely support a prosthesis whether the patient is partially or completely edentulous. The continued bone loss after tooth loss and associated compromises in esthetics, function, and health make all edentulous patients implant candidates. These issues are addressed in Chapter 1. The average denture patient does not see a dentist regularly. In fact, more than 10 years usually separates dental appointments of edentulous patients. As a consequence, patients are unaware of the insidious loss of bone in the edentulous jaw.

During the long hiatus between dental visits after dentures are used to replace the dentition, the amount of resorption from initial denture delivery to the next professional interaction already has caused the destruction of the original alveolar process. The bone loss that occurs during the first year after tooth loss is 10 times greater than in following years. In the case of multiple extractions, this often means a 4-mm vertical bone loss within the first 6 months. This bone loss continues over the next 25 years, with the mandible experiencing a fourfold greater vertical bone loss than the maxilla [35](Figure 23-3). As the bony ridge resorbs in height, the muscle attachments become level with the edentulous ridge.[39,40] The more often a patient wears a denture, the greater the bone loss, yet 80% of denture patients wear their dentures day and night. To the contrary, the anterior bone under an overdenture may resorb as little as 0.6 mm vertically over 5 years, and long-term resorption may remain at less than 0.05 mm per year.[4,35,43]

Therefore, the profession should treat bone loss after tooth extraction in a similar fashion as bone loss from periodontal disease. Rather than waiting until the bone is resorbed or the patient complains of problems with the prostheses, the dental professional should educate the patient about the bone loss process after tooth loss. In addition, the patient should be made aware the bone loss process can be arrested by a dental implant. Therefore, most completely edentulous patients should be informed of the necessity of dental implants to maintain existing bone volume and improve prosthesis function, masticatory muscle activity, esthetics, and psychologic health.

The majority of mandibular overdentures used by the profession are supported by two implants anterior to the foraminae and soft tissue support in the posterior regions (Figure 23-4). Yet posterior bone loss occurs four times faster than anterior bone loss. In a completely edentulous patient, the eventual paresthesia and mandibular body fractures are primarily from posterior bone loss (Figure 23-5). The anterior implants allow improved anterior bone maintenance, and the prosthesis benefits from improved function, retention, and stability. However, the lack of posterior support in two- and three-implant overdentures allows continued posterior bone loss. A primary concern for RP-5 overdentures (soft tissue support in the posterior regions) compared with RP-4 or fixed restorations (restorations completely supported, retained, and stabilized) is the continued bone loss in the posterior regions. The posterior

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bone resorbs faster than the anterior bone, and implant prostheses with posterior soft tissue support may accelerate posterior bone resorption two to three times faster than in a complete denture wearer.[41–43] Therefore, the short-term benefit of decreased cost for RP-5 overdentures may be offset by the accelerated bone loss that is a primary consideration, especially in younger edentulous patients.

Patients wearing fixed implant–supported prostheses show little to no bone loss and usual occurrences of bone apposition.[44,63] For example, studies by Wright et al.[31] and Reddy et al.[40] found prostheses completely supported by implants in the edentulous mandible actually may increase the posterior bone volume (even though posterior implants are not inserted) (Figure 23-6). Therefore, the next progression in the implant philosophy is to convert all mandibular implant and soft tissue–supported restorations to a completely implant-supported prosthesis. As a result, complete implant–supported restorations should be the restoration of choice.

As a consequence of continued posterior bone loss with a two- or three-implant overdenture, the recommendation is to consider a RP-5 prosthesis as an interim device designed to enhance the retention of the prosthesis. These restorations should not be considered an end result for all patients. Instead, a regular evaluation of patients' performance paired with patient education should enable the transformation to a RP-4 or FP-3 (fixed prosthesis) restoration. In addition, reports indicate that RP-5 mandibular IODs may cause a combination-like syndrome, with increased looseness, subjective loss of fit, and midline fracture of the upper denture.[64–68] Although not yet established as a cause-and-effect situation, the condition may be reduced with a proper occlusal scheme.[66]

Financial considerations have been identified as the reason for the selection of a limited treatment, which may consist of two or three implants to support the overdenture.[14,25,34] These RP-5 restorations may be used as transitional devices until the patient can afford to upgrade the restoration. When a partially edentulous patient cannot afford to replace four missing first molars, the dentist often will replace one molar at a time over many years. Likewise, the dental implant team can insert one or two additional implants every few years until finally a complete implant–supported prosthesis is delivered.

The ultimate goal of bone maintenance with a complete implant–supported prosthesis may be designed in the beginning of treatment even though it may take many years to complete. The advantage of developing a treatment plan for long-term health, rather than short-term gain, is beneficial to the patient. As such, if finances are not an issue, the dentist should design a prosthesis that is completely supported, retained, and stabilized by implants. If cost is a factor, a transitional implant-retained restoration with fewer implants greatly improves the performance of a mandibular denture. Then the dentist may establish a strategy for the next one or two steps to obtain the final complete implant–supported restoration.



FIGURE 23-5. A panoramic radiograph of a patient treated with anterior implants and mandibular overdenture 30 years before. The posterior bone has continued to be lost and has partial paresthesia. The maxillary bone has also completely atrophied during this time.

Disadvantages of Implant Overdentures

The primary disadvantage of a mandibular overdenture is related to the patient's desire, primarily when he or she does not want to be able to remove the prosthesis. A fixed prosthesis often is perceived as an actual body part of the patient, and if a patient's primary request is not to remove the prosthesis, an implant-supported overdenture would not satisfy the psychological need of the patient.

The mandible bone may also be a disadvantage for an IOD. The mandibular overdenture treatment plan requires more than 12 mm of space between crestal bone and the occlusal plane (Figure 23-7). When sufficient crown height space (CHS) is lacking, the prosthesis is more prone to component fatigue and fracture and has more complications than porcelain-to-metal fixed prostheses. The 12-mm minimum CHS provides adequate bulk of acrylic to resist fracture; space to set denture teeth



FIGURE 23-6. Wright et al.[31] and Reddy et al.[40] found full arch implant–supported prostheses may prevent posterior bone loss and even may cause some gain in bone volume even though implants are not inserted in the posterior regions. This 25-year-old fixed implant prosthesis have maintained anterior and posterior bone in the mandible.

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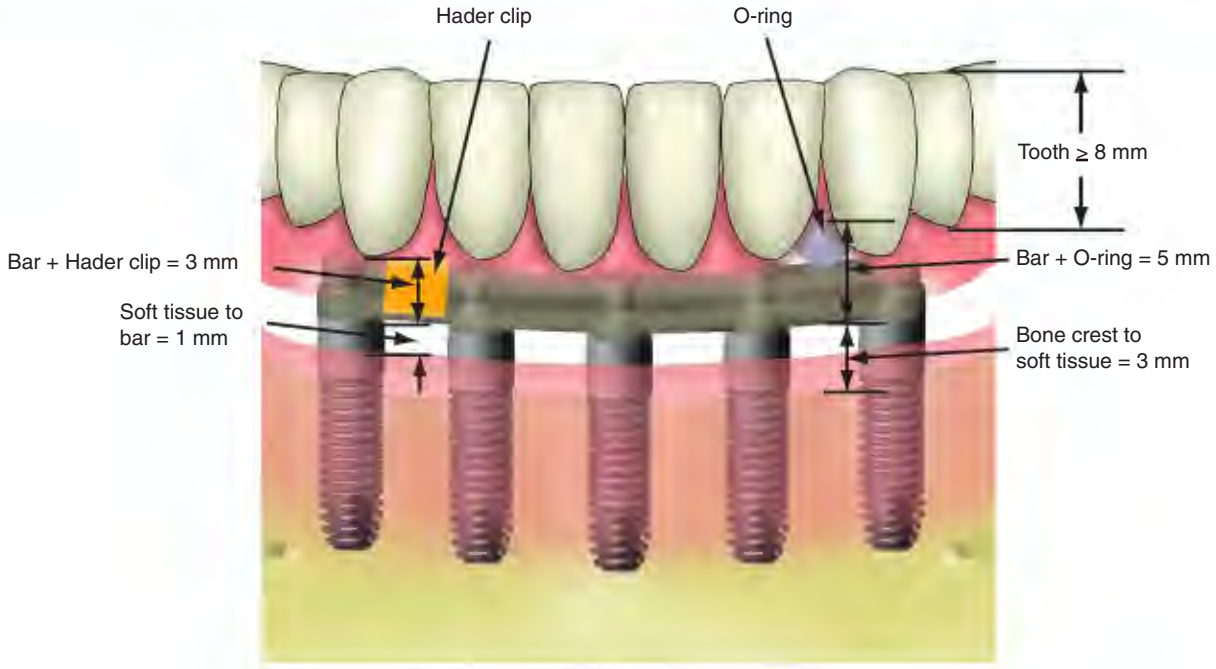


FIGURE 23-7. The mandibular overdenture requires at least 12 mm between the soft tissue and the occlusal plane to provide sufficient space (15 mm from bone level to occlusal plane) for the bar, attachments, and teeth.



FIGURE 23-8. A panoramic radiograph of a patient with abundant mandibular bone and an implant overdenture. The prosthesis fractured several times each year because there was inadequate bulk of acrylic for the restoration.

without modification; and room for attachments, bars, soft tissue, and hygiene. In the mandible, the soft tissue is often 1 to 3 mm thick above the bone, so the occlusal plane to soft tissue should be at least 10 mm in height. An osteoplasty to increase CHS before implant placement is often indicated, especially when abundant bone height and width are present (Figure 23-8). Otherwise, a fixed porcelain–metal restoration should be considered.

Another complication related to the available bone is inclination or angulation of the mandible, especially when the alveolar process has resorbed. The division C–a anterior mandible is angled more than 30 degrees. If the surgeon is unaware of this angulation, the implants may perforate the lingual plate and irritate the tissues of the floor of the mouth (Figure 23-9). If the surgeon places the implants within the bone, they may enter the crest of the ridge at the floor of the mouth and make it almost impossible to restore (Figure 23-10). In a study by Quirynen et al. of 210 computer tomogram images, 28% of the anterior mandibles were lingually tilted −67.6 degrees ± 5.5 degrees.[7] The mandibles with less than −60 degree tilt represent about 5% of the cases.

Although the initial cost of treatment may be less for an IOD, overdenture wearers often incur greater long-term expenses than those with fixed restorations. Attachments (such as O-rings or clips) regularly wear and must be replaced. Replacements appear more frequent during the first year but remain a necessary maintenance step.[18,21,35,69–76] In a study by Bilhan et al. on 59 patients, two thirds of IOD patients had prosthetic-related complications the first year.[77] For example, relines were necessary in 16%, loss of retention in 10.2%, fracture of the IOD in 8.5%, pressure spots in 8.5%, dislodged attachment in 6.8%, and screw loosening in 3.4%.

Denture teeth wear faster on an IOD than with a traditional denture because bite force and masticatory dynamics are

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FIGURE 23-9. An occlusal film of a C–a mandible and five implants perforating the lingual plate of bone. The floor of the mouth would swell up and remain irritated.



FIGURE 23-10. Four anterior implants in a C–a mandible. The implants enter in the floor of the mouth, cause constant irritation, and are difficult to restore.

improved. A new overdenture often is required at 5- to 7-year increments because of denture tooth wear and changes in the soft tissue support. Therefore, patient education of the long-term maintenance requirement should be outlined at the onset of implant therapy.[57]

A side effect of a mandibular IOD is food impaction. The flanges of the prosthesis do not extend to the floor of the mouth in the rest position (to eliminate sore spots caused by elevation of the floor of the mouth during swallowing). However, during eating, food particles migrate and become impacted under the prosthesis during swallowing. A similar condition is found with a traditional denture. However, because a lower denture "floats" during function, the food more readily goes under and then through, but the IOD traps the food debris against the implants, bars, and attachments (Box 23-3).

Review of the Literature

The concept of mandibular implant–supported overdentures has been used for many years. Successful reports were published originally with mandibular subperiostal implants or with immediately loaded and stabilized root form implants in the anterior mandible more than 4 decades ago.[1,2]

BOX 23-3 Overdenture Disadvantages

- Psychological (need for nonremovable teeth)
- Greater abutment crown height space required
- More long-term maintenance required
  - Attachments (change)
  - Relines (RP-5)
  - New prosthesis every 7 years
- Continued posterior bone loss
- Food impaction
- Movement (RP-5)

In 1986, a multicenter study reported on 1739 implants placed in the mandibular symphysis of 484 patients.[2] The implants were loaded immediately and restored with bars and IOD with clips as retention. The overall implant success rate was 94%. Engquist et al.[3] reported a 6% to 7% implant failure for mandibular implant–supported overdentures in 1988. Jemt et al.[4] reported on a 5-year prospective, multicenter study on 30 maxillae (117 Brånemark implants) and 103 mandibles with 393 implants. Survival rates in the mandible were 94.5% for implants and 100% for prostheses.[4] Attard and Zarb followed IOD wearers for 20 years with a success rate of 84% and 87% for prosthesis and implants, respectively.[35]

More recent studies demonstrate even greater implant success rates when used to support a mandibular overdenture. A review of implant literature by Goodacre et al. in 2003 found mandibular implant overdentures have higher implant survival rates compared with any other type of implant prosthesis.[78] Wismeijer et al.[5] reported on 64 patients with 218 titanium plasma-sprayed implants with a 97% survival with overdentures in a 6.5-year evaluation. Naert et al.[15] found 100% implant success at 5 years for mandibular overdentures with different anchorage systems. In Belgium, Naert at al. reported on 207 consecutively treated patients with 449 Brånemark implants and Dolder-bar mandibular overdentures. In this report, the cumulative implant failure rate was only 3% at the 10-year benchmark.[9,10] Similarly, Hutton et al.[12] reported 97% survival rates for mandibular overdentures.

Misch[13] reported less than 1% implant failure and no prosthesis failure over a 7-year period with 147 mandibular

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overdentures (IOD) when using the organized treatment options and prosthetic guidelines presented in this chapter. Kline et al. reported on 266 mandibular implant–supported overdentures for 51 patients, with an implant survival rate of 99.6% and a prosthesis survival rate of 100%.[79] Mericke-Stern et al. reported 95% implant survival with two implant overdentures in the mandible. In a 10-year study of IODs in Israel, with 285 implants and 69 implant overdentures, Schwartz-Arad et al. reported implant survival was 96.1% with higher success rates in the mandible.[42]

In conclusion, many reports have been published over the past 2 decades that conclude that mandibular implant–supported overdentures represent a predictable option for denture wearers.

Overdenture Treatment Options

Traditional overdentures must rely on the remaining teeth to support the prosthesis. The location of these natural abutments is highly variable, and they often comprise past bone loss associated with periodontal disease. For a mandibular implant–supported overdenture, the implants may be placed in planned, specific sites, and their number may be determined by the restoring doctor and patient. In addition, the overdenture implant abutments are healthy and rigid and provide an excellent support system. As a result, the related benefits and risks of each treatment option may be predetermined.

In 1985, the author presented five organized treatment options for implant-supported mandibular overdentures in completely edentulous patients.[13,80,81] The treatment options range from primarily soft tissue support and implant retention (RP-5) to a completely implant-supported prosthesis (RP-4) with rigid stability (Table 23-1). The prostheses are supported by two to five anterior implants for these options. The four RP-5 options have a range of retention, support, and stability. The RP-4 restoration has a rigid cantileverd bar that completely supports, stabilizes, and retains the restoration (Figure 23-11).

The overdenture options err on the side of safety to reduce the risk of failure and complications of bone loss and superstructure loosening. The initial treatment options are presented for completely edentulous patients with division A (abundant) or B (sufficient) anterior bone treated with division A anterior root form implants of 4 mm or greater diameter. Modifications related to posterior ridge support and arch form also are discussed. Following these standardized conditions, anterior bone volume conditions of moderate atrophy (division C minus height [C–h]) are presented.

Overdenture Movement

To develop a treatment plan for a mandibular IOD, the final prosthesis should be determined related to the necessary retention, support, and stability required for the restoration. Retention of the restoration is related to vertical force necessary to dislodge the prosthesis. Support is related to the amount of

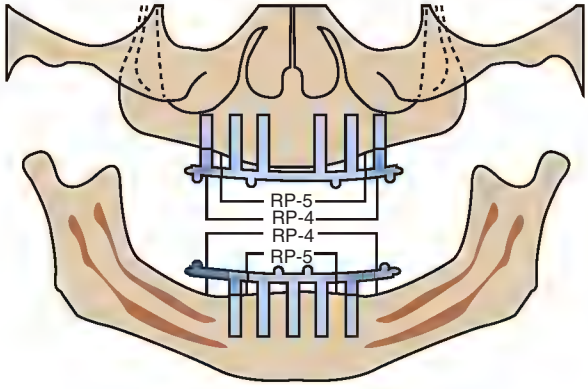


FIGURE 23-11. Five prosthetic options are designed for the mandibular overdentures. Four options are RP-5 (posterior soft tissue support) and one option is RP-4 (prosthesis completely supported by implants and connective bar).

TABLE 23-1
Mandibular Overdenture Treatment Options

Option	Description	Removable Prosthesis Type 5
OD-1	Implants in the B and D positions independent of each other	Ideal denture Ideal anterior and posterior ridge form Cost is a major factor Retention only PM-6
OD-2	Implants in the B and D positions rigidly joined by a bar	Ideal posterior ridge form Ideal denture Cost is a major factor Retention and minor stability PM-3 to PM-6
OD-3A	Implants in the A, C, and E positions rigidly joined by a bar if posterior ridge form is good	Ideal posterior ridge form Ideal denture Retention and moderate stability PM-2 to PM-6 (two-legged chair)
OD-4	Implants in A, B, D, and E positions rigidly joined by a bar cantilevered distally about 10 mm	Patient desires greater retention, major stability, and support PM-2 to PM-6 (three-legged chair)
OD-5	Implants in the A, B, C, D, and E positions rigidly joined by a bar cantilevered distally about 15 mm	Patient has high demands or desires Retention, stability, and support PM-0 (four-legged chair)

OD, Overdenture option; *PM,* prosthesis movement class.
From Misch CE: *Misch Implant Institute manual*, Dearborn, MI, 1984, Misch International Implant Institute.

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vertical movement of the prosthesis toward the tissue. Stability of a prosthesis is evaluated with horizontal or cantilevered forces applied to the restoration. The amount of retention is related to the number and type of overdenture attachments. The stability of the IOD is more related to implant (and bar) position, and support is primarily related to implant number (and bar design in the posterior region). The patient's complaints, anatomy, desires, and financial commitment determine the amount of implant support, retention, and stability required to predictably address these conditions. Because different anatomic conditions and patient force factors influence these factors for an IOD, not all prostheses should be treated in the same manner. In other words, a two-implant overdenture should not be the only treatment plan offered to a patient. One should emphasize that most mandibular overdentures should be designed to eventually result in a RP-4 prosthesis, as previously discussed.

The most common complications found with mandibular implant overdentures are related to prosthetics and an understanding of retention, support, and stability of the prosthesis. For example, when a fixed restoration is fabricated on implants, it is rigid, and cantilevers or offset loads are clearly identified. Rarely will a practitioner place a full-arch fixed restoration on three implants, especially with excessive cantilevers because of implant positioning. However, three anterior implants with a connecting bar may support a completely fixed overdenture, solely because of attachment design or placement. The restoring doctor thinks the three-implant overdenture has less implant support but does not realize that an overdenture that does not move during function is actually a fixed restoration. Therefore, an overdenture with no prosthesis movement (PM) should be supported by the same number, position, and design of implants as a fixed restoration.

Many precision attachments with varying ranges of motion are used in implant overdentures. The motion may occur in zero (rigid) to six directions or planes: occlusal, gingival, facial, lingual, mesial, and distal. A type 2 attachment moves in two planes and a type 4 attachment in four planes. An IOD may also have a range of movement during function. It should be understood that the resulting overdenture movement during function may be completely different from the one provided by independent attachments and may vary from zero to six directions depending on the position and number of attachments, even when using the same attachment type. For example, an "O" ring attachment may allow six directions of movement. However, when four "O" rings are placed on a bar, the prosthesis movement (PM) during function or parafunction may have no directions of movements (Figure 23-12). Therefore, attachment and PM are independent from each other and should be evaluated as such. An important item for the IOD treatment plan is to consider how much PM the patient can adapt to or tolerate on the final restoration.

Classification of Prosthesis Movement

The classification system proposed by the author in 1985 evaluates the directions of movement of the implant-supported prosthesis, not the overall range of motion for the individual attachment; therefore, the amount of PM is the primary concern. An overdenture is by definition removable, but in function or parafunction, the prosthesis may not move. If the prosthesis does not have movement during function, it is designated PM-0 and requires implant support similar to a fixed prosthesis. A prosthesis with a hinge motion is PM-2, and a prosthesis with an apical and hinge motion is PM-3. A PM-4 allows movement in four directions, and a PM-6 has ranges of PM in all directions.



FIGURE 23-12. Prosthesis movement for overdentures is often different than "attachment" movement categories. In this RP-4 overdenture bar, O-rings (a class 6 attachment movement), and Hader clip (a class 2 attachment movement) support a rigid overdenture. The prosthesis movement is PM-0.

Prosthesis Movement

The dentist determines the amount of PM the patient desires or the anatomy may tolerate. If the prosthesis is rigid when in place but can be removed, the PM is labeled PM-0 regardless of the attachments used. For example, O-rings may provide motion in six different directions. But if four O-rings are placed along a complete arch bar and the prosthesis rests on the bar, the situation may result in a PM-0 restoration. A hingelike PM permits movement in two planes (PM-2) and most often uses a hingelike attachment. For example, the Dolder bar and clip without a spacer or Hader bar and clip are the most commonly used hingelike attachments. A Dolder bar is egg shaped in cross-section, and a Hader bar is round. A clip attachment may rotate directly on the Dolder bar. A Hader bar is more flexible because round bars flex to the power of 4 related to the distance and other bar shapes flex to the power of 3. As a result, an apron often is added to the tissue side of the Hader bar to limit metal flexure, which might contribute to unretained abutments or bar fracture. A cross-section of the Hader bar and clip system reveals that the apron, by which the system gains strength compared with a round bar design, also limits the amplitude of rotation of the clip (and prosthesis) around the fulcrum to 20 degrees, thus transforming the prosthesis and bar into a more rigid assembly (Figure 23-13). Therefore, the Hader bar and clip system may be used for a PM-2 when posterior ridge shapes are favorable and soft tissue is firm enough to limit prosthesis rotation.

It should be noted that for these systems to function efficiently, the hinge attachment needs to be perpendicular to the axis of prosthesis rotation, so the PM also will be in two planes (i.e., PM-2). If the Hader or Dolder bar is at an angle or parallel to the direction of desired rotation, the prosthesis is more rigid and may resemble a PM-0 system (Figure 23-14). As a consequence, the implant system may be overloaded and cause complications such as screw loosening, crestal bone loss, and even implant failure. A Hader bar-clip system is an ideal low-profile

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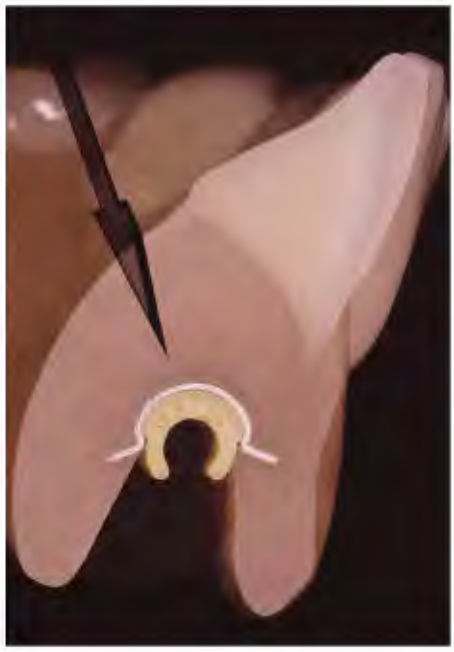


FIGURE 23-13. An implant overdenture with a Hader clip may rotate 20 degrees around a bar when the bar is perpendicular to the midline of the mandible.



FIGURE 23-14. Hader bar clip is a class 2 attachment system. However, when the clips are placed parallel or at an angle to the desired prosthesis movement (PM), the prosthesis is rigid. In this case, two implants are not enough to support a PM-0. Screw loosening, bone loss, and implant failure resulted.

attachment for a RP-4 prosthesis with PM-0. Usually, these clips are placed on the bar in different planes around the arch.

The Hidden Cantilever

The hidden cantilever is the portion of the prosthesis that extends beyond the last implant or connecting bar. If the prosthesis does not rotate at the end of the implant or bar to load the soft tissue, a hidden cantilever exists. For example, if a cantilevered bar extends to the first molar but forces on the second molar of the restoration do not result in movement of the restoration down in the back and up in the front, the cantilever really is extended to the second molar position. Therefore, the cantilever length is measured to the point of PM, not to the end of the bar and attachment system. The teeth on the final

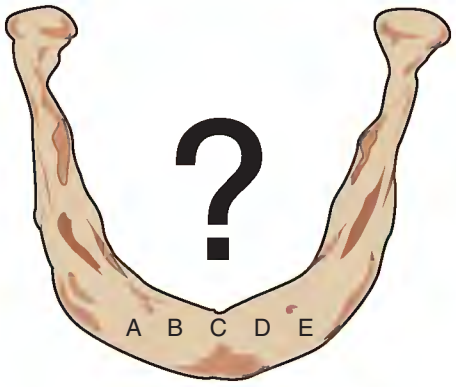


FIGURE 23-15. The anterior mandible is divided into five equal columns of bone between the mental foramens: A, B, C, D, and E.

overdenture restoration usually do not extend beyond the first molar. This helps prevent a hidden cantilever, which may extend beyond this position.

Mandibular Implant Site Selection

Anterior retention and stability for an overdenture prosthesis offer several advantages. Overdentures with posterior movement gain better acceptance than removable restorations with anterior movement. The anterior denture teeth are most often anterior to the edentulous ridge. As a result, horizontal or vertical forces to the anterior teeth cause the prosthesis to rock down in the front (and up in the back). The range of movement is often excessive because there is no bone under the anterior teeth. In the posterior regions, the posterior denture teeth may be positioned over the bone (of the ridge or buccal shelf of bone), which is often parallel to the occlusal plane. As such, when posterior vertical bite forces are applied, the posterior PM is limited to the movement of the tissue.

An axiom in removable partial denture (RPD) design for a class IV Kennedy-Applegate partial edentulous arch (posterior teeth and anterior missing teeth across the midline) is to gain rigid prosthetic support in the anterior region. When the prosthesis has poor anterior and good posterior stability, it rocks back and forth during function. This rocking action applies torque to the abutments and increases stresses on the overdenture components and bone–implant interface. Therefore, whereas anterior forces to the IOD should be resisted by implants or bars, posterior forces may be directed on a soft tissue area, such as the mandibular buccal shelf.

The greatest available height of bone in an edentulous mandible is located in the anterior mandible between the mental foraminae. This region also usually presents optimal density of bone for implant support. Therefore, the implant overdenture treatment options presented are designed for anterior implant placement between the mental foramina because the prostheses' movement will be more limited and the available bone volume and density are more favorable than when implants are inserted more posterior.

The available bone in the anterior mandible (between the mental foramen) is divided into five equal columns of bone serving as potential implant sites, labeled A, B, C, D, and E, starting from the patient's right side[80,81] (Figure 23-15). Regardless of the treatment option being executed, all five implant sites are mapped at the time of treatment planning and surgery. There are four reasons for this treatment approach:

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1. The patient always has the option to obtain additional implants and prosthesis support and stability in the future if all five sites were not initially used for implant support. For example, a patient may receive adequate retention, stability, and support for an implant overdenture with four implants. However, if the patient desires a fixed prosthesis in the future, these four implants may fall short of the new prosthetic requirements. If the implant surgeon did not plan an additional implant site at the initial surgery but instead placed the four implants an equal distance apart, the additional space may not be available without removing one of the preexisting implants.
2. A patient may desire a completely implant-supported restoration (e.g., RP-4 or fixed prosthesis) but cannot afford the treatment all at once. Three implants in the A, C, and E positions and an IOD may be provided now, two implants may be added in the B and D locations later, and a completely implant-supported overdenture or fixed restoration may then be fabricated (Figure 23-16).
3. If an implant complication occurs, the preselected option sites permit repeatable, corrective procedures. For example, if implants were placed in the A, B, D, and E positions and an implant fails to achieve rigid fixation, the failed implant may be removed and an additional implant placed in the C position at the same time. This saves an additional surgery and eliminates the time required for bone grafting and healing before another implant could be reinserted (Figure 23-17).
4. The fourth reason the five implant sites are repeated for each treatment option is for the experience of the restoring dentist.

In overdentures supported by natural teeth, the dentist is forced to choose the best remaining teeth to support the restoration. These remaining teeth have a wide range of clinical conditions and locations. As a consequence, each tooth-supported overdenture is slightly different in regard to retention, stability, and support. In implant dentistry, healthy predictable abutments in preselected locations and the range in the number of implant permit the restoring dentist to obtain more similar clinical results for each treatment option selected. Hence, a more predictable predetermined treatment may be planned for each patient, depending on psychologic need, anatomic conditions, and financial restraints.

Overdenture Option 1

The first treatment option for mandibular overdentures (OD-1) is indicated primarily when cost is the most significant patient factor. However, it is important to note that the patient's desires should also be minimal, and the bone volume in both the anterior and posterior regions should be abundant (division A or B). The posterior ridge form should be an inverted U shape, with high parallel walls for good to excellent anatomical conditions for conventional denture support and stability (Box 23-4). The problem associated with the existing denture relates primarily to the amount of retention. In addition, the opposing arch should be restored with a traditional complete denture.

Under these more ideal intraoral conditions, two implants may be inserted in the B and D positions (Figure 23-18). The implants remain independent of each other and are not connected with a superstructure. The overdenture attachment improves retention. The most common type of attachment used

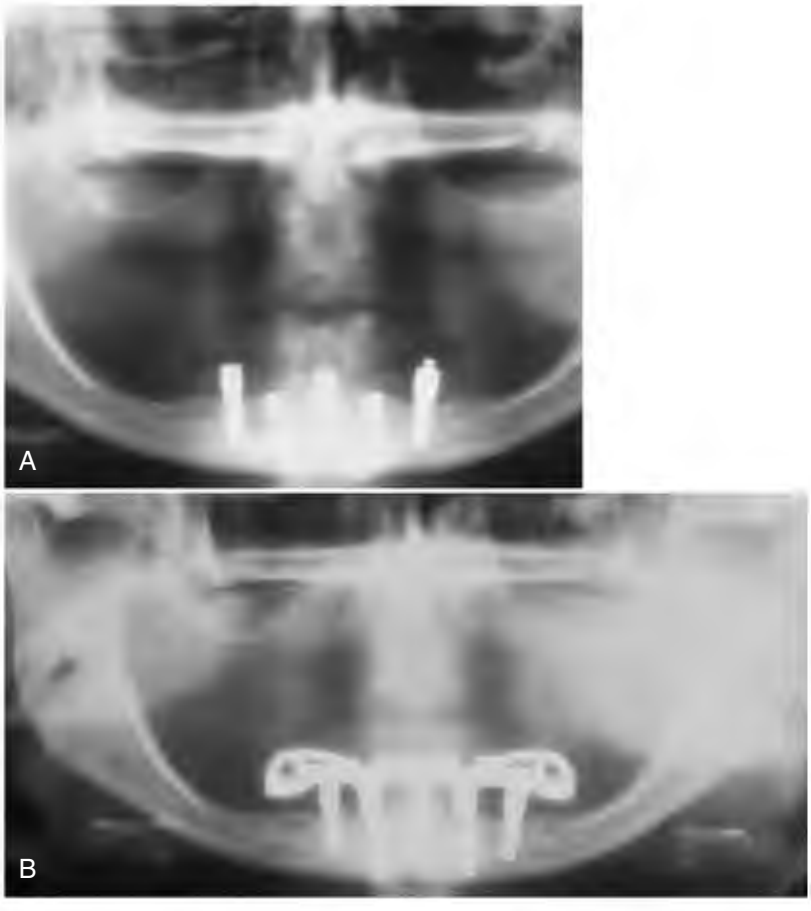


FIGURE 23-16. **A,** This patient wore a three-implant overdenture for several years. She then decided to improve the overdenture support, stability, and retention. The implant sites B and D could be added later because all five implant sites were initially planned. **B,** A hybrid fixed prosthesis was fabricated after the two additional implants were placed (same patient as in **A**).

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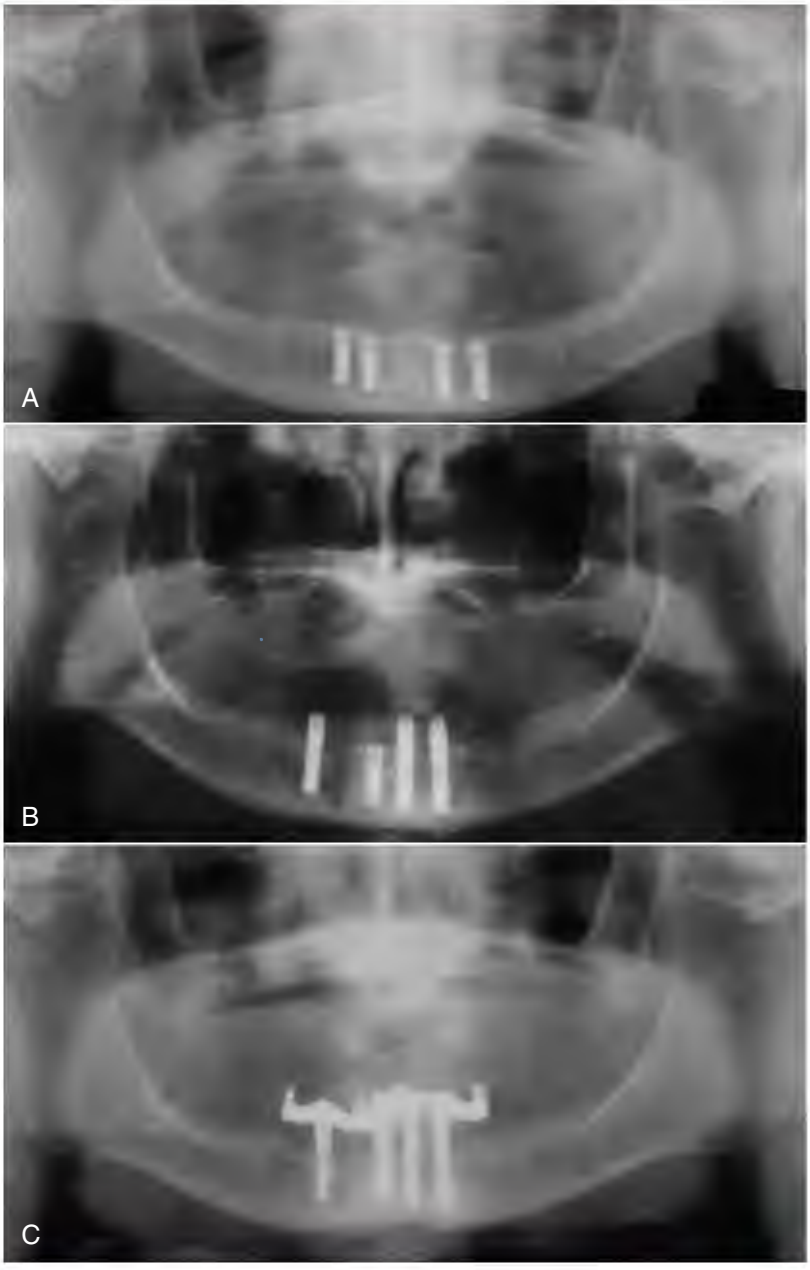


FIGURE 23-17. **A,** A panoramic radiograph of implants in the A, B, D, E position. **B,** A postoperative panoramic radiograph of the removal of implant B and insertion of implant C (and uncover of A, D, E). **C,** An option OD-4 with a RP-5 prosthesis was fabricated.

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BOX 23-4 Patient Selection Criteria: OD-1

- Opposing a maxillary full denture
- Anatomical conditions are good to excellent (division A or B anterior and posterior bone.
- Posterior ridge form is an inverted U shape.
- Patient's needs and desires are minimal, primarily related to lack of prosthesis retention.
- Edentulous ridge, not square with a tapered dentate arch form
- Cost is the primary factor.
- Additional implants will be inserted within 3 years.

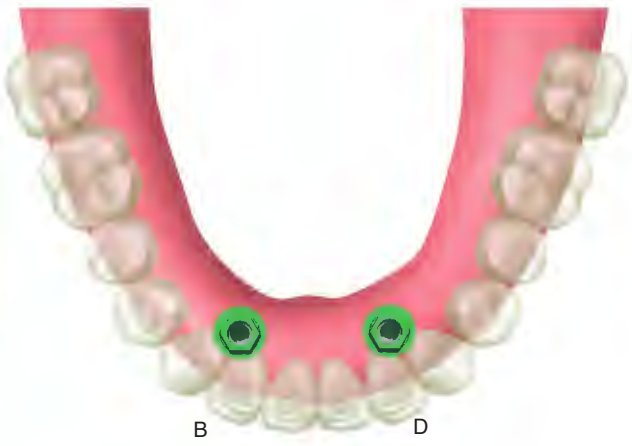


FIGURE 23-18. Overdenture option 1 consists of two independent implants. These are best placed in the B and D positions to limit the forward rocking of the restoration during function.

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in OD-1 is an O-ring or Locator design. The stability of the restoration is improved in the anterior section by the implants and the posterior regions from the ridge form. The support of the restoration is provided primarily from the buccal shelf in the posterior and the ridge in the anterior similar to a traditional denture. The IOD must be RP-5, which means it must be able to rotate and load the posterior soft tissue regions of the mandible (Figure 23-19). The implant support mechanism is poor because stress relief of the attachment is permitted in any plane. In other words, the stability and support of the prosthesis are gained primarily from the anatomy of the mandible and prosthesis design, which is similar to a complete denture.

Positioning of the implants in the B and D position is a much better prosthetic option in OD-1 than positioning in the A and E regions (Figure 23-20). Kennedy-Applegate class 1 patients (with bilateral distal extensions) and anterior missing teeth often are restored with a fixed prosthesis anteriorly and a class 1 RPD. This eliminates the unfavorable rocking leverages that exist when replacement denture teeth are anterior to the fulcrum line.[85] Independent implants in the A and E positions are implant locations in the first premolar region, which is more posterior to the anterior fulcrum line of the anterior teeth and allows a greater amplitude of rocking of the restoration (Figure 23-21). When using B and D implants (which is similar to the natural canine positions), the anterior movement of the prosthesis is reduced.

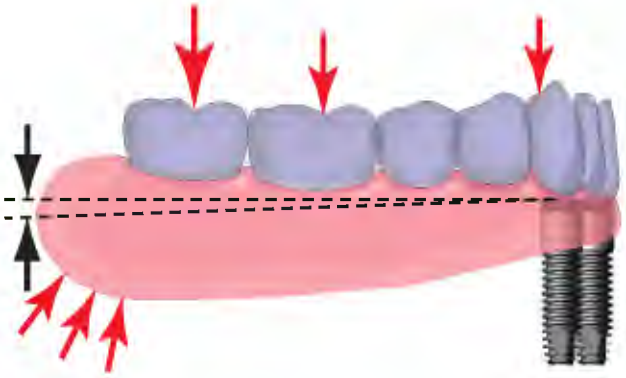


FIGURE 23-19. A RP-5 prosthesis must rotate during function on the anterior implants, so the prosthesis may load the soft tissues of the posterior mandible.

It should be noted that the edentulous ridge may be square, ovoid, or tapering. The dentate arch form is also divided into square, ovoid, and tapering categories and may be different than the ridge form. When a tapered dentate arch form is supported by two independent implants in a square residual ridge form, the anterior teeth are cantilevered anteriorly from the implant retentive system. More implants are required in this dentate–ridge form combination to help stabilize the prosthesis.

The prosthesis may act as a splint for the two B and D implants during anterior biting forces, thereby decreasing some of the stress to each implant. However, most situations do not allow the prosthesis to act as a true splint because a stress relief attachment permits movement in any plane. As a result, only one implant is loaded at a time in most situations, and the restoration is more unstable than when a bar connects the implants.

The patient's primary advantage with treatment option OD-1 is reduced cost. The two implants are usually the fewest implant number, and no connecting bar reduces the prosthetic appointments and the laboratory costs. The existing prior denture may even be adapted with an intraoral rebase and pickup procedure around the implants and attachments. This further reduces the fee. In addition, on occasion, the connecting bar may not be passive, and additional complications may ensue. Because this option does not have a connecting bar, there may be fewer bar-related complications. In addition, hygiene procedures also are facilitated with independent implants.

The disadvantages of the OD-1 prosthesis relate to its relatively poor implant support and stability compared with any of the other options (which have connecting bars and more implants) because of the independent nature of the B and D implants. Jemt et al.[4] demonstrated a decrease in occlusal force when the bar connecting implants was removed from implant overdenture patients. In addition, future bone loss in the edentulous regions of the mandible is not reduced significantly because only two anterior implants are inserted.

The other disadvantages of OD-1 restorations relate to an increase in prosthetic maintenance appointments. For the restoration to be inserted and function ideally, the two implants should be parallel to each other perpendicular to the occlusal plane at the same horizontal height (parallel to the occlusal plane) and equal distance off the midline. If one implant is not parallel to the other, the prosthesis will wear one attachment

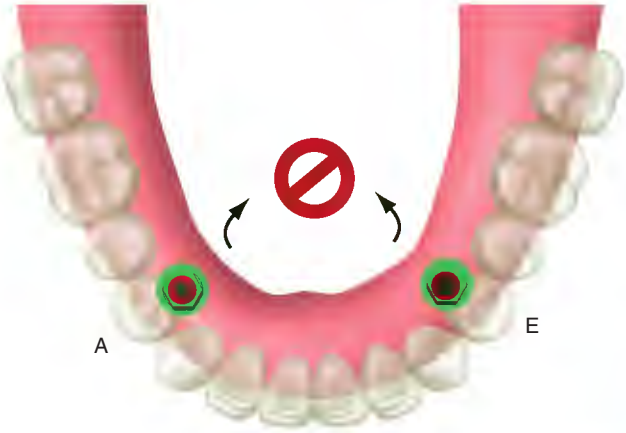


FIGURE 23-20. Independent implants in the A and E positions allow a greater rocking of the restoration and place greater leverage forces against the implants.



FIGURE 23-21. Independent implants in the A and E position are distal to the incisal edge of the anterior teeth. As a result, anterior tipping of the implant overdenture during excising food is common.

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faster because of the greater displacement during insertion and removal than the other. If the angulation difference is severe, the prosthesis may not engage one attachment at all (Figure 23-22).

The implants should be perpendicular to the occlusal plane because the goal is to allow the posterior regions of the overdenture to rock downward and load the soft tissue over the mandibular buccal shelves for support. The hinge rotation should be at 90 degrees to the rotation path; otherwise, one side is loaded different than the other. In addition, because only two implants sustain the occlusal load during function or parafunction, minimization of the forces to the implant components and crestal bone by placing them in the long axis of the implant body and perpendicular to the occlusal plane is ideal.

The two independent implants should be positioned at the same occlusal height parallel to the occlusal plane. If one implant is higher than the other, the prosthesis will disengage from the lower implant during function and rotate primarily on the higher implant (Figure 23-23). This situation will accelerate the wear of the O-ring or attachment on the lower implant. In addition, because the higher implant receives the majority of the occlusal load, an increased risk of complications may occur, including abutment screw loosening, marginal bone loss around the implant, and implant failure.

The implants should be equal distance off the midline. If one implant is more distal (farther from the midline), it will serve as the primary rotation point or fulcrum when the patient occludes in the posterior segments. As such, the more medial implant attachment will wear faster, and the more distal implant will receive a greater occlusal load. When the patient bites in the anterior region, the more anterior implant acts as the fulcrum, and the posterior attachment more rapidly wears.

As a consequence of additional maintenance risks, independent implants should be used less frequently than implants joined together with a bar. Attachments in a connection bar may be placed by the laboratory in similar horizontal, vertical, and axial planes much easier than the surgeon placing the implants.

It is emphasized the available mandibular bone should be division A or B, and the opposing arch for an OD-1 mandibular treatment option should be a traditional complete denture (Figure 23-24).The bite forces are reduced when the patient is completely edentulous before treatment. The maxillary denture has some movement during function and acts as a stress reliever. The instability of the maxillary denture and mandibular OD-1

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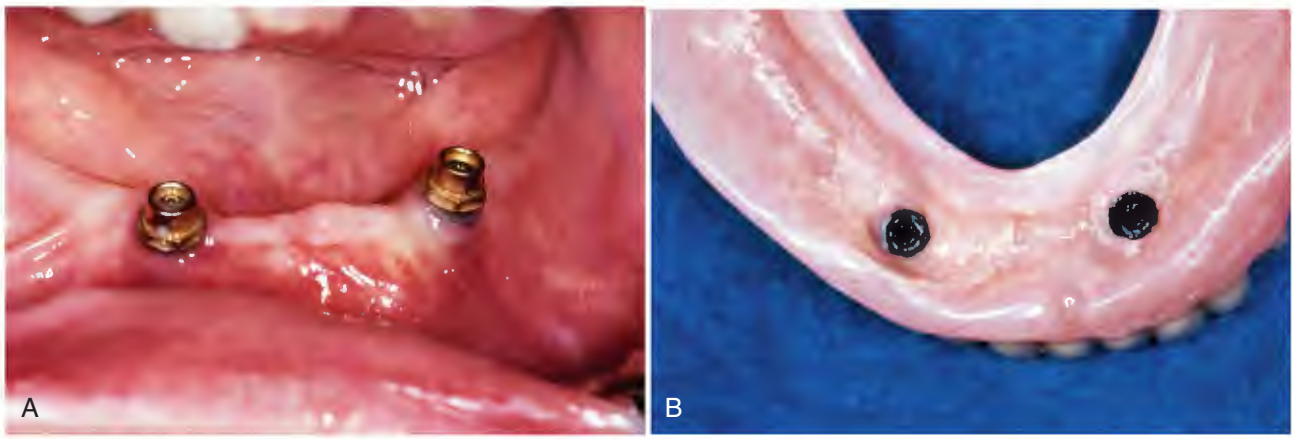


FIGURE 23-22. **A,** When one implant is placed more anterior than the other (as shown), the more distal implant is the fulcrum when chewing in the posterior region and the more anterior implant is the fulcrum for movement when the patient incises food. This causes instability, wearing of the attachments, and loosening of the O-rings from the implant bodies. **B,** When two independent implants are not parallel to each other, equal distance from the midline and at the same occlusal height, the attachments will rapidly wear and need to be replaced more often.

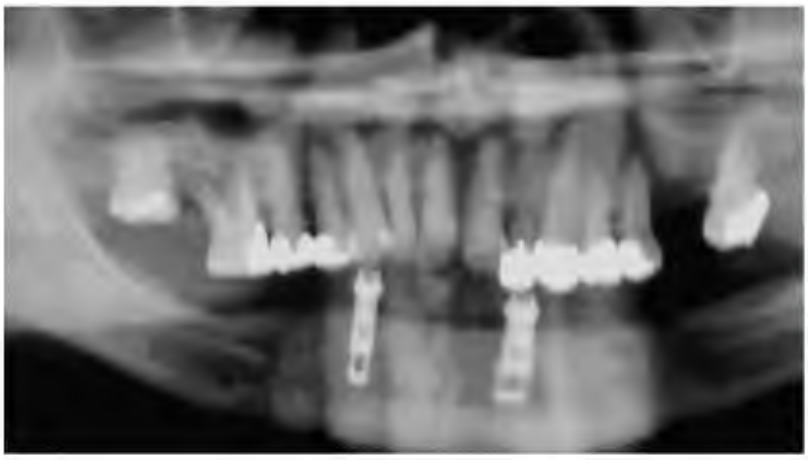


FIGURE 23-23. Two independent implants should be at the same height, equal distance off the midline, and parallel to each other. When the implants are positioned as in this radiograph, one implant (not two) becomes the dominant fulcrum and increases the risk of overload complications. This is especially important when force factors are higher than usual. The patient's occlusal plane also should be modified to allow a bilateral balanced occlusion on a RP-5 overdenture.

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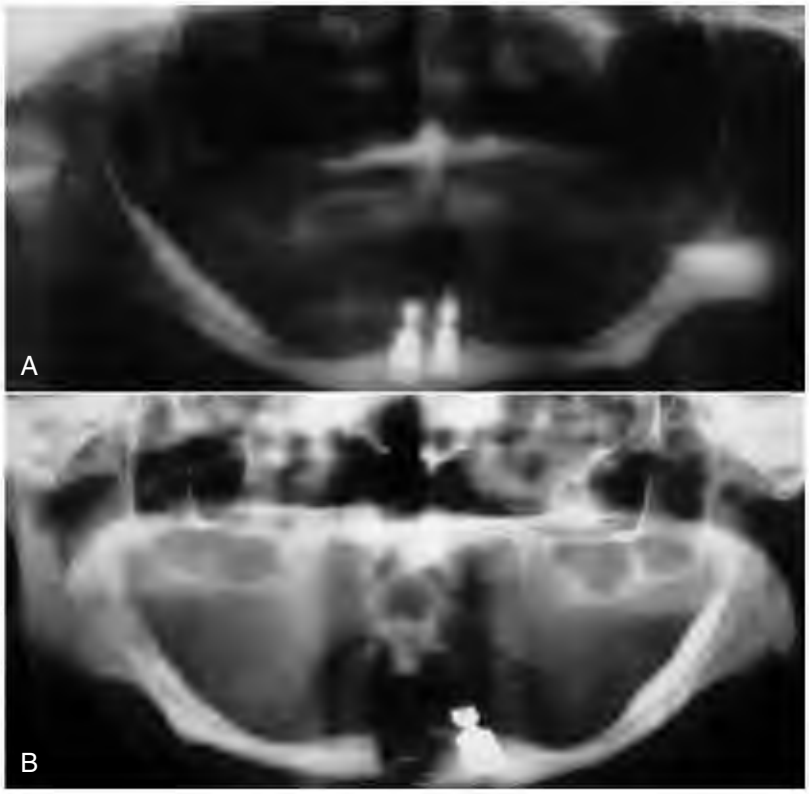


FIGURE 23-24. **A,** A panoramic radiograph of two independent implants in a division D mandible. **B,** One implant failed, and the mandible fractured through the failed implant site.



FIGURE 23-25. A two-mandibular implant overdenture should oppose a complete denture. Otherwise, instability and sore spots are common related to the implant overdenture.

overdenture is shared. The support requirements of the posterior regions of the mandible are reduced when opposing a complete denture (Figure 23-25).

The OD-1 is used as a treatment option when patients understand that a connecting bar and additional implants are beneficial but financial constraints require a transition period of a few years before placing additional implants. The ultimate goal in the treatment plan is to convert OD-1 patients to a RP-4 or fixed prosthesis with more implant support and stability before the loss of the posterior bone in the mandible occurs behind the foraminae. As soon as the patient can afford two more implants, the implants should be placed in the A and E position, and all four ABDE implants should be connected with a bar that may be cantilevered to the posterior and help reduce the posterior bone loss. If an additional implant may be inserted (after the initial two), it may be positioned in the C position, or if bone height and width distal to one mental foramen are adequate, the additional implant may be positioned in one of the first molar regions. With implants in the A, B, C, D, E position or A, B, D, E, and molar position, the connected implants and cantilevered bar will result in a RP-4 or fixed restoration and will help maintain posterior bone. The bar may be cantilevered to provide posterior support because of the greatly improved anteroposterior distance (A-P spread) between splinted implants and the increase in implant number (Figure 23-26).

Overdenture Option 2

The second treatment option for a mandibular overdenture (OD-2) is selected as the initial option more often than OD-1. The anatomic needs and patient desires are similar to the first option, OD-1 (Box 23-5). The implants are also positioned in locations B and D, but in this option, they are splinted together with a superstructure bar without any distal cantilever (Figure 23-27). Reduced loading forces are exerted on two anterior implants when splinted with a bar compared with individual implants.[82–85] The bar is designed to position the attachments an equal distance off the midline parallel to each other at the same occlusal height and in a similar angulation to

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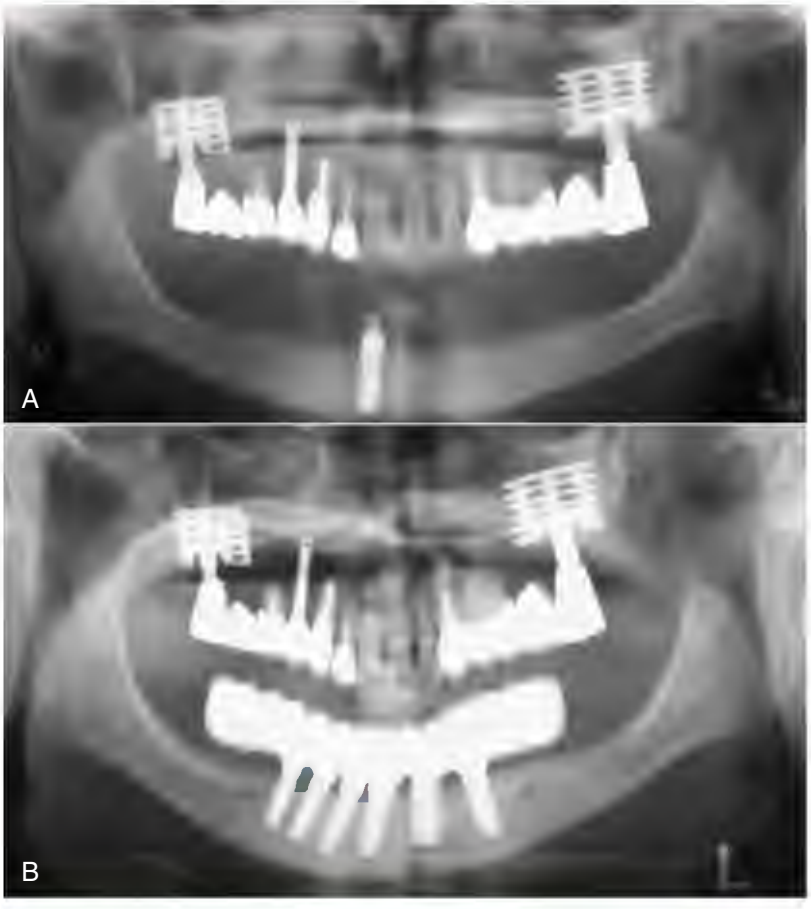


FIGURE 23-26. **A,** A panoramic radiograph of a patient that had two implant overdentures opposing a fixed prosthesis. One implant failed. **B,** Additional implants were eventually inserted and a fixed prosthesis fabricated.

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BOX 23-5 Patient Selection Criteria: OD-2

- Opposing arch is a maxillary denture.
- Anatomical conditions are good to excellent (division A or B bone in anterior and posterior regions).
- Posterior ridge forms an inverted U shape.
- Patient's need and desires are minimal, primarily related to lack of retention.
- Patient can afford new prosthesis and connecting bar.
- Additional implants will not be inserted for more than 3 years.
- Low patient force factors (e.g., parafunction)

provide added retention.[28] (Figures 23-28 and 23-29). The ideal distance between the implants is in the 14- to 16-mm range or B and D positions. However, it should be noted that implants placed closer than the B, D position will result in reduced prosthesis stability during function whether they are connected or independent units. The connecting bar should not be cantilevered to the distal from the two implants (Figures 23-30 and 23-31).

The two splinted implants should not be inserted in the A and E positions (Figure 23-32). There are many reasons why two implants placed in the A and E positions should not be splinted together. The implants in this position are placed just anterior to the mental foraminae and therefore most often in the first premolar positions. This results in a curved arch form anterior to the implant sites. The superstructure that follows the anterior curve of the arch anterior to the first premolars results in an improved lingual contour of the restoration. However, the curve corresponds to an increased length and even greater flexibility of the superstructure. Because the bar is under the anterior teeth but anterior to the implants, a greater moment of force also is created.

Bars that course in a tangential direction do not permit friction-free rotation of the prosthesis around the fulcrum. Excess torsional loading is exerted on the implants and bar resulting in screw loosening or crestal bone loss. The distance between A and E implants represents approximately a span of six teeth. The superstructure flexibility is related to the length. As a result, five times more flexure is observed than if the implants were in the B and D locations.[85] The increase in the connecting bar flexibility may result in loosening of the coping screws. If one screw becomes loose, the other implant supports a cantilever of seven teeth. After this occurs, the remaining attached implant receives a dramatic increase in moment of forces from the long lever arm of the superstructure. As a consequence, bone loss and implant failure risk are increased. This increase in force may result in bone loss, mobility of the implant, and possible fracture of an implant component[85] (Figure 23-33).

Joining A and E implants in the sagittal position with a straight line of the superstructure also causes a problem. If the bar is straight and not bent to follow the arch, it occupies a lingual position relative to the arch. The lingual flange of the denture then extends as much as 10 mm more lingually and 7 mm more vertically to accommodate the attachment, which is connected over the superstructure. Because the teeth are most

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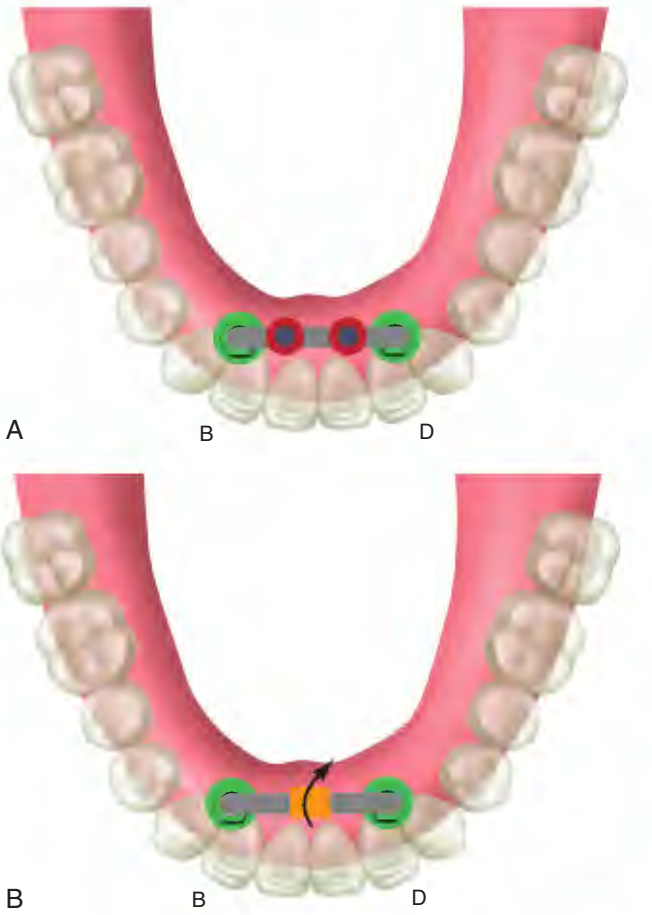


FIGURE 23-27. Treatment option 2 has implants in the B and D positions, and a bar joins the implants. The bar should not be cantilevered off the distal side of the implants. The prosthesis movement will be reduced, and too much force on the bar and implants will increase complications. Attachments such as an O-ring (**A**) or a Hader clip (**B**), which allow movement of the prosthesis, can be added to the bar. The attachments are placed at the same height at equal distances off the midline and parallel to each other.



FIGURE 23-29. **A,** When O-rings are used for OD-2, the attachments are placed parallel to each other and at the some occlusal height. **B,** The O-ring attachments are also positioned equal distance off the midline.



FIGURE 23-28. The implants in B and D are connected with a bar. O-rings are often used for the implant overdenture.

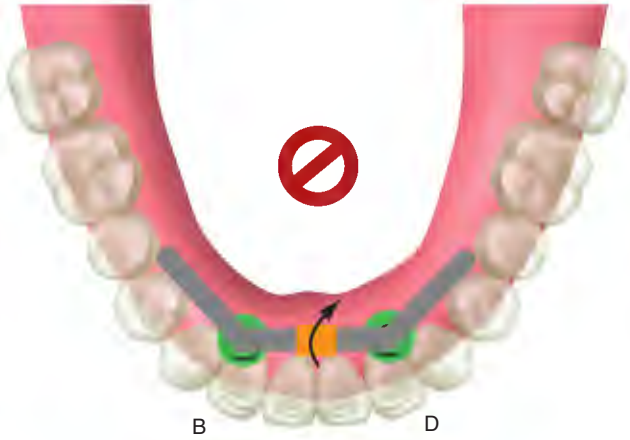


FIGURE 23-30. The connecting bar between implants B and D should not be cantilevered to the distal.

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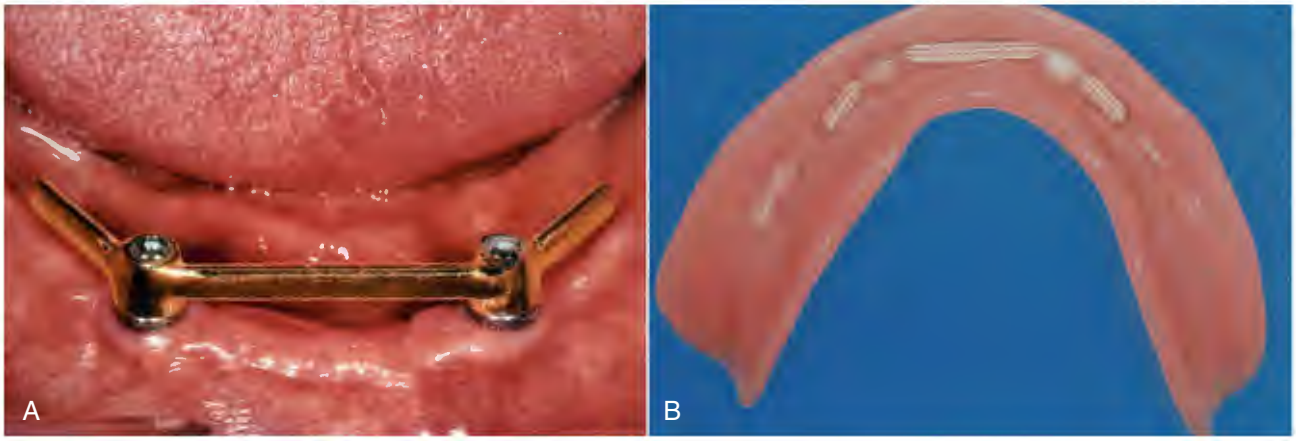


FIGURE 23-31. **A,** Implants in the B and D position and a connecting bar, which is cantilevered to the distal. **B,** The Hader clips in the prosthesis do not allow prosthesis movement. Hence, this is a PM-0 implant overdenture and will cause repeated biomechanical complications.



FIGURE 23-32. Implants in positions A and E should not be splinted together.

BOX 23-6 Disadvantages of A and E Splinted Implants (First Premolar to First Premolar)

- Implants joined with straight bar are lingual to ridge.
  - Difficulty with speech
  - Anterior tipping of overdenture
  - Five times greater bar flexure than B and D positions
- Implants are joined with anterior curved bar.
  - Greater bar flexibility (nine times the B and D positions)
  - Increased screw loosening
  - Increased moment forces on anterior aspect of prosthesis
  - Attachment of curved bar may prevent prosthesis movement
- Bite force is higher than for B and D positions.
- Greater lateral load from prosthesis to implants than B and D positions

often set anterior to the crest of the ridge (anterior to the superstructure bar), rotation and tipping of the restoration are more prevalent. The moment of force on a straight bar connecting implants in the A and E positions is twice that for implants in the B and D locations.[85]

The prosthesis attachment system to the superstructure also may be compromised if Hader and Dolder clips are used for retention. The connecting bar and clips should be perpendicular to the path of rotation. A curved bar often places the clips closer to the implants and prevents rotation of the prosthesis. If the prosthesis rests against the sides of the curved bar, the PM may even be reduced to PM-0. This places a much greater vertical and lateral load on the implant system.

Implants splinted in the A and E positions have greater potential load per surface area compared with implants in the B and D regions because the bite force increases toward the posterior aspects of the mouth. As a result, a greater vertical load is also present, with increased stresses when implants are placed in the A and E positions compared with the B and D positions. This is most important to consider when the patient has parafunctional forces such as bruxism or clenching.

The splinted A and E positions give more lateral stability to the prosthesis than the B and D positions. However, only two implants resist this lateral load. In contrast, the B and D positions increase lateral movement of the prosthesis, which is a patient disadvantage, but the positioning also decreases the lateral forces on the implant system (e.g., coping screws, abutment screws) (Box 23-6).

It should be noted that the A and E positions most often correspond to the first premolar sites. A bar connecting two first premolars is too long for an overdenture and will result in many complications (Figure 23-34). Likewise, splinted implants in the A and E positions may also have biomechanical complications. As a result of these many disadvantages, the placement of only two implants in the A and E positions is strongly discouraged whether the implants are independent or splinted together.

If the surgeon inadvertently inserts the implants in the A and E positions, two options exist. The first is to place at least one additional implant, usually in the C position. The second is to leave the implants independent with O-ring attachments. With the second option, the anatomical ridge form should be good to excellent, and the overdenture should have excellent support and retention independent of the implants. The two implants should not be splinted because they are too far apart. The length of the edentulous span, the position of the connecting bar, the flexure of the metal span, and the additional forces on the implant system create considerable risk for prosthetic

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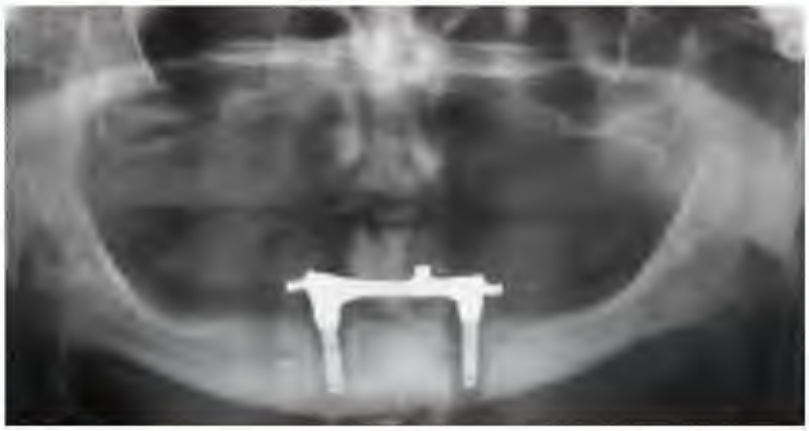


FIGURE 23-33. Implants in the A, E position were splinted together with a bar. The prosthesis screw became loose on the A implant, which resulted in a long cantilever on the E implant, which then failed.



FIGURE 23-34. This patient had an overdenture constructed on the two first premolar teeth. The bar became uncemented in the patient's right side and then acted as a cantilever on the patient's left premolar. This situation is similar to implant positions A and E because the mental foramina are most often between the premolars or distal to the second premolar.

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complications in this treatment option. In other words, the B and D implant positions are closer to the canine positions and are much better suited for force and prosthetic guidelines for either OD-1 or OD-2 treatment options.

Patient selection criteria for OD-2 treatments include the following:

1. The patient's opposing arch is a complete denture.
2. Anatomical conditions for a traditional denture are good to excellent.
3. The posterior ridge form is an inverted U shape and provides good to excellent support and lateral stability.
4. The patient's complaints are minimal and relate primarily to retention.
5. The patient requires a new prosthesis and is willing to invest slightly more time and expense than the patient with the OD-1 option.
6. The mandibular residual arch is square or ovoid and the dentate arch form is ovoid or tapering, but only two implants are used for support.
7. When the patient is unable to insert additional implants within a short time frame (within 3 years), OD-2 is safer than an OD-1 independent implant approach.

Disadvantages

Two-implant overdentures are not indicated in C–h or D bone and are not indicated when opposing anterior or posterior natural teeth. The increase in crown height and the poorer posterior ridge form or the increase in bite forces and rigid opposing arch place additional stresses on the implant system and increase complications. Additional implants should be used to decrease the implant system and prosthetic risks.

Some additional disadvantages of OD-2 treatments compared with OD-1 are possible tissue hyperplasia under the bar, more difficult hygiene under the bar (compared with option 1), and a more expensive initial treatment option compared with option 1 (because a bar and retentive elements are included).

BOX 23-7 Patient Selection Criteria: OD-3

- Opposing arch is a maxillary denture
- Anatomical conditions moderate to excellent
- Posterior ridge forms inverted U shape
- Patient's needs and desires require improved retention, support, and stability
- Cost a moderate factor
- Patient may have moderate force factors (e.g., parafunction)

Overdenture Option 3

The third treatment option may be used when the opposing arch is a denture and the patient has moderate to low anatomic needs. Three root form implants are placed in the A, C, and E positions for the third overdenture treatment option (OD-3) (Box 23-7). A superstructure bar connects the implants but with no distal cantilever (Figure 23-35). In addition, the opposing arch should be a denture to limit the amount of bite force. It should be noted that when the posterior ridge form is poor (C–h or D), the OD-3 is the lowest treatment option suggested. The A-C-E implant and bar position is much more stable than the B-D position for the prosthesis. There are many advantages of splinting A, C, and E implants compared with implants in the B and D positions (Box 23-8).

The additional implant provides a sixfold reduction in superstructure flexure and limits the connecting bar complications previously discussed compared with implants in the A and E positions.[83] Screw loosening also occurs less frequently because three coping screws retain the superstructure rather than two. The risk of abutment or coping screw loosening is reduced further because force factors to each unit are decreased.

Implant reaction forces are reduced with a third implant as compared with two implants. The greater surface area of

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implant-to-bone contact allows better distribution of forces. Three permucosal sites distribute stresses more efficiently and minimize marginal bone loss around the implants. The reduction in the maximum moment of force is twofold with a three-implant system compared with two implants in the A and E regions.[85] Hence, this treatment option is better than OD-1 or OD-2 when the patient has moderate parafunction.

The implants splinted in the A, C, and E positions usually do not form a straight line. The C implant is most often anterior to the more distal A and E implants (in the premolar regions) and ideally directly under the cingulum position of the anterior incisor denture teeth (Figure 23-36). The restoration benefits from direct occlusal load to the implant support in the anterior arch, which reduces tipping and improves stability. As a

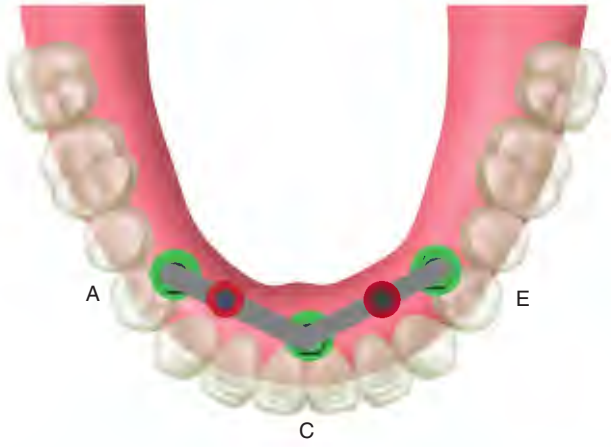


FIGURE 23-35. Overdenture option 3 corresponds to implants in the A, C, and E positions connected with a bar. The attachments should be positioned to allow movement of the distal section of the prosthesis.

BOX 23-8 Advantages of Splinted A, C, and E Implants

- Six times less bar flexure compared with A and E positions
- Less screw loosening
  - Less metal flexure
  - Three implant abutments
- Less stress to each implant compared with A and E implants
  - Greater surface area
  - More implants
  - Greater anteroposterior distance
- One-half moment force compared with A and E implants
- Less prosthesis movement
- One implant failure still provides adequate abutment support

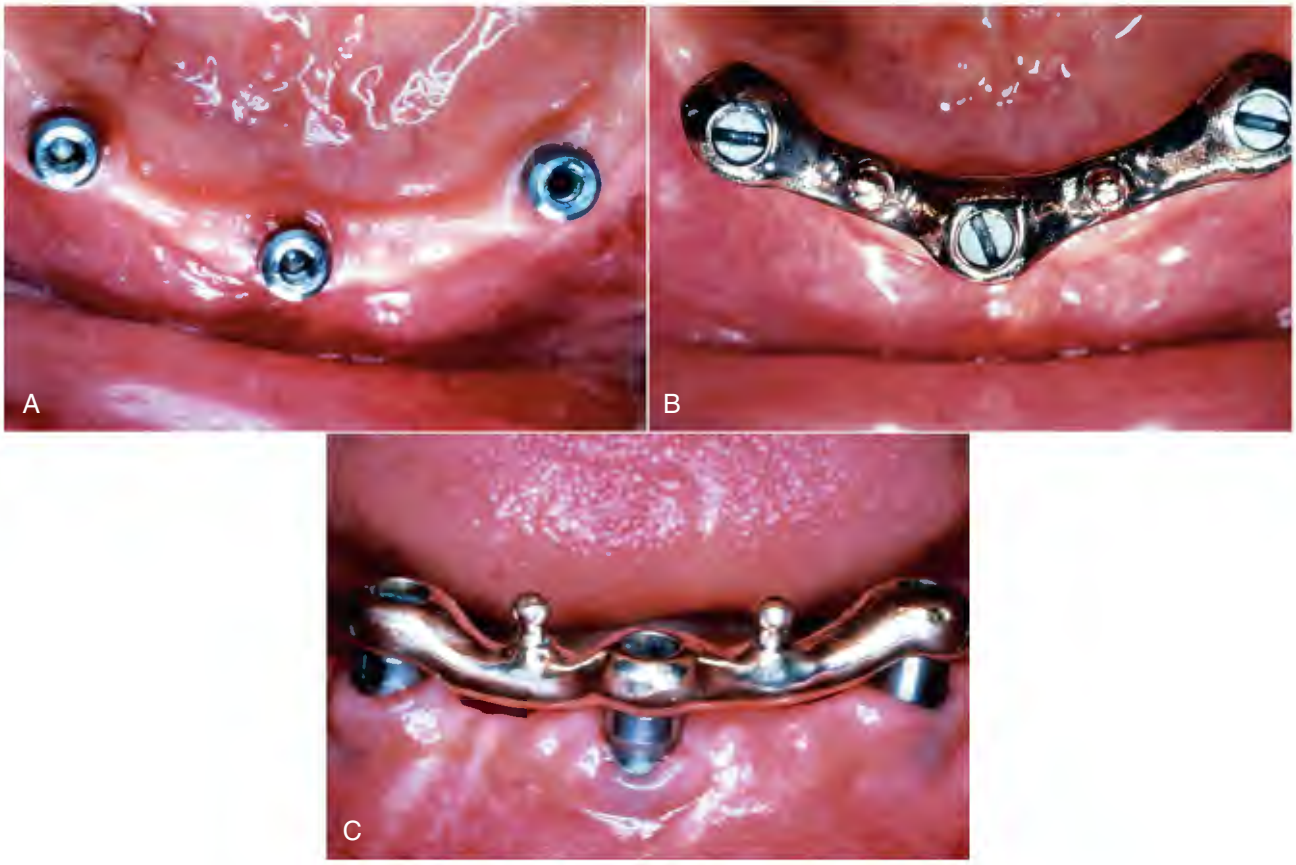


FIGURE 23-36. **A,** A mandible with division A bone and overdenture option 3, with implants in the A, C, and E positions. **B,** The attachments are more distal than the OD-2 and are still equal distance off the midline, parallel, and at the same height. **C,** The C implant is more anterior than the A and E implants, so anteroposterior stability is improved.

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consequence, when more than two implants are in the anterior mandible, a tripod support system may be established.

To determine the amount of benefit of an A-P distance, the distal of the most posterior implants on each side are connected with a straight line. The distance from this line to the perpendicular position of the center implant is called the A-P spread.[85–87] The greater this dimension, the more biomechanically stable the implants are when splinted together. The greater the A-P spread of the A, C, and E implants, the greater the biomechanical advantage of the bar to reduce stress on the implants.

In addition to reduced stresses on the implant system, the lateral stability of the overdenture system is also improved because the implants are in the A and E position and the attachments are more distal than OD-2. As a result, rotation of the prosthesis is more limited compared with OD-1 and OD-2. Therefore, the third implant for OD-3 is a considerable advantage for a mandibular edentulous patient. The IOD option 3 usually does not use a Hader clip for the attachment. Because the two clips do not rotate in the same plane, the prosthesis is usually too rigid (Figure 23-37).

The OD-3 treatment option is usually the first option presented to a patient with minimal complaints who is concerned primarily with retention and anterior stability of the IOD when cost is a moderate factor. The posterior ridge form should be evaluated because it determines the posterior lingual flange extension of the denture, which limits lateral movement of the restoration in this treatment option.[81]

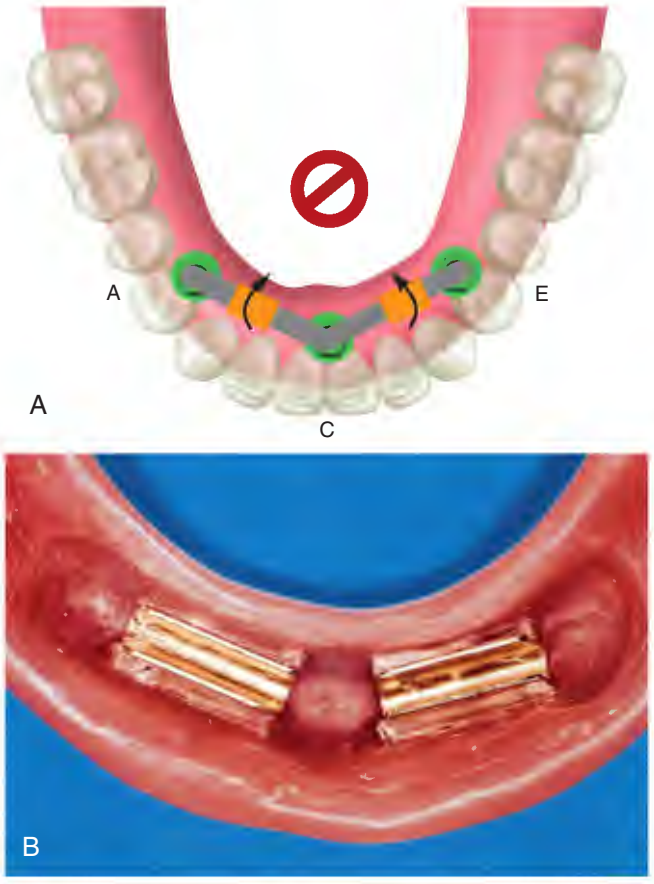


FIGURE 23-37. **A,** An implant overdenture option 3 rarely uses a Hader clip for the attachment system. **B,** The Hader clips rotate in different planes and make the prosthesis too rigid for three implants.

In the future, when the patient can afford additional implants to those in the A, C, and E positions, the next implant placement is in the B and D positions when the posterior bone is inadequate for implants (C–h). When posterior bone permits, the two new implants are positioned with one in a molar region and the other inserted in the contralateral B or D position. A new overdenture bar and prosthesis then permits a RP-4 (or fixed) restoration.

Overdenture Option 4

In the fourth mandibular overdenture option (OD-4), four implants are placed in the A, B, D, and E positions. This is often the minimum number of implants when the patient has opposing maxillary teeth or C–h anterior bone volume with CHS greater than 15 mm. These implants usually provide sufficient support to include a distal cantilever up to 10 mm on each side if the stress factors are low (i.e., parafunction, CHS, masticatory dynamics, and opposing dentition) (Figure 23-38).

The cantilevered superstructure is a feature of the four or more implant treatment options in a completely edentulous arch for three reasons: The first relates to the increase in implant support compared with OD-1 to OD-3. The second is that the biomechanical position of the splinted implants is improved in an ovoid or tapering arch form compared with OD-1 or OD-2. The third is related to the additional retention provided by the fourth implant for the superstructure bar, which limits the risk of prosthetic screw loosening and other related complications of cantilevered restorations.

In considering a distal cantilever for a mandibular overdenture bar, the implant position is the primary local determinant.

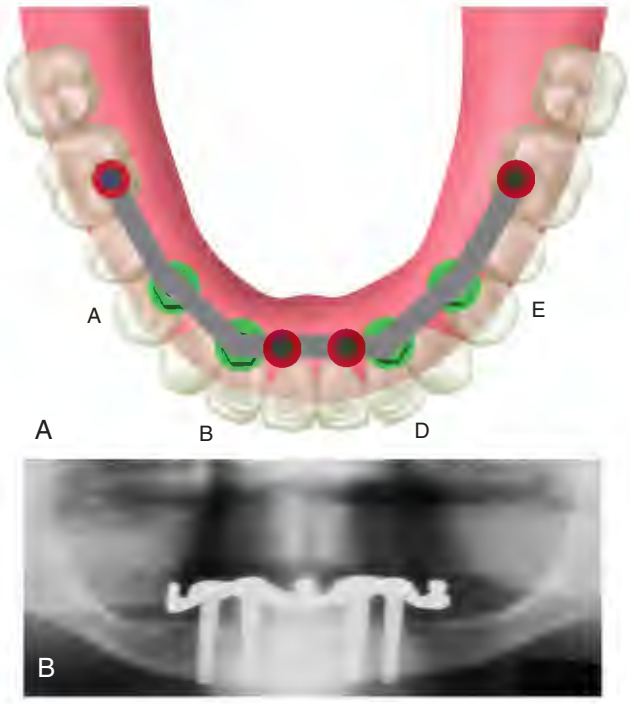


FIGURE 23-38. **A,** In overdenture option 4, four implants are placed in the A, B, D, and E positions. The implants provide sufficient support for a distal cantilever up to 10 mm. **B,** A panoramic radiograph of a mandibular overdenture option 4. In this option, implants in the A, B, D, and E positions are connected with a cantilevered bar (up to 10 mm). The stress-breaking attachments are designed to allow some movement of the prosthesis during function.

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Cantilevers may be compared with a class 1 lever in mechanics. The distal most implant on each side acts as a fulcrum when occlusal forces are applied to the distal cantilever. Therefore, the amount of the occlusal force is magnified by the length of the cantilever, which acts as a lever. For example, a 25-lb load to a 10-mm cantilever results in a 250-lb moment force.

This moment force is resisted by the length of the bar anterior to the fulcrum. Therefore, if the two anterior implants (B and D) are 5 mm from the fulcrum (distal implants A and E), the effect of the posterior cantilever is reduced. If the implants are 5 mm apart, the mechanical advantage of the lever is the 100-mm cantilever divided by the 5-mm A-P spread, which equals 2. Rather than a 250-lb moment force on the distal implant, because it is splinted, a 25-lb distal force is magnified to 50 lb to the anterior implant and 75 lb (50 + 25 = 75) to the distal (fulcrum) implant. As a general rule, the posterior cantilever from anterior implants may be equal to the A-P distance when other stress factors are low to moderate.

The mandibular arch form may be square, tapering, or ovoid. Square arch forms limit the A-P spread between implants and may not be able to counter the effect of a distal cantilever. Therefore, rarely are distal cantilevers designed for square arch forms (Figure 23-39). In a mandibular ovoid to tapering arch form, the A-P spread between implants in the A, E and D, B positions is greater and therefore permits a longer distal cantilever. This A-P spread is usually 8 to 10 mm in these arch forms and therefore often permits a cantilever up to 10 mm from the A and E positions (Figure 23-40).

It may be emphasized that the A-P spread is only one factor to determine the length of the cantilever. When stress factors such as occluding forces are greater, the cantilever is decreased. Parafunction, opposing arch, masticatory dynamics, and CHS affect the amount of force on the cantilever. For example, when the crown height is doubled, the moment forces are doubled. Therefore, under ideal, low-force conditions (crown height less than 15 mm, no parafunction, older female patient, opposing a maxillary denture), the cantilever may be up to 1.5 times the A-P spread for OD-4 overdentures. When the force factors are moderate, the cantilever should be reduced to one times the A-P spread. The amount of distal cantilever is related primarily to the force factors and to the arch form, which corresponds to the A-P spread.

The patient's indications for the OD-4 treatment option as a minimum requirement include moderate to poor posterior anatomy that causes a lack of retention and stability of the IOD, history of recurrent soft tissue abrasions, or difficulty with speech. Remember that the edentulous posterior mandible resorbs four times faster than the anterior mandible. In the C–h posterior mandible, the external oblique and mylohyoid ridges are high (in relation to the residual ridge) and often correspond to the crest of the residual ridge. The muscle attachments therefore are at or near the crest of the posterior ridge. Other conditions that indicate an OD-4 as a minimum treatment option is when the patient's complaints and desires are more demanding than for the previous treatment options (Box 23-9).

The OD-4 prosthesis is indicated to obtain greater stability and a more limited range of prosthesis motion. The overdenture attachments often are placed in the distal cantilevers with an O-ring attachment in the midline. The prosthesis is still RP-5 but with the least soft tissue support of all RP-5 designs. The anterior attachment must allow vertical movement for the distal aspect of the prosthesis to rotate toward the tissue. Clips, which permit rotation, are difficult to use on cantilevered superstructures. To allow movement, the clip must be placed perpendicular to the path of rotation, not along the cantilevered bar, where its only function then is retention (and limits rotation).



FIGURE 23-39. These four implants were placed in a square ridge form and have no anteroposterior dimension. Therefore, no cantilever should be extended from the implants.



FIGURE 23-40. **A,** These four anterior implants (A, B, D, E) are in an ovoid arch form. **B,** The four anterior implants are splinted together with a cantilevered bar approximately 8 to 10 mm. The prosthesis type is RP-5 because the molar region is supported by the soft tissue.

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The patient benefits from the four-implant option because of greater occlusal load support, lateral prosthesis stability, and improved retention. The prosthesis loads the soft tissue over the buccal shelf and the first and second molars and retromolar pad regions. Therefore, the amount of occlusal force on the implant system is reduced (compared with a fixed restriction or RP-4 prosthesis) because the bar does not extend to the molar position, where the forces are greater.

The OD-4 treatment option is the lowest treatment rendered when the patient has maxillary teeth. The greater vertical and horizontal forces to the mandibular IOD require anterior disclusion in excursions to decrease the bite force. As such, more anterior implants are required under these conditions.

The next treatment plan option for the patient with a moderate financial budget is to add an additional implant in the future in one of the first molar positions (preferred) or the C position. Both of these options increase the A-P spread to fabricate a RP-4 prosthesis with an enhanced implant system support. The goal is to convert all patients eventually to a RP-4 or fixed restoration, to prevent posterior bone loss and its associated disadvantages (including esthetics of the posterior facial regions).

Overdenture Option 5

In the OD-5 treatment, five implants are inserted in the A, B, C, D, and E positions. The superstructure is usually cantilevered distally up to two times the A-P spread (if almost all of the stress factors are low) and averages 15 mm, which places it under the first molar area (Figures 23-41 and 23-42). The amount of the distal bar cantilever is related (in part) to the A-P distance. A square ridge form usually has an A-P spread of less than 5 mm and should have a minimum cantilever even with five implants joined together. An ovoid arch has an A-P spread from 5 to 8 mm and a tapered arch form more than 8 mm. In these situations, a cantilever of two times this distance is indicated when force factors are not excessive (Figure 23-43). If any major stress factors (e.g., parafunction) are not favorable, the cantilever should be reduced. Stresses are magnified in direct proportion to the length of cantilever and should be planned carefully based on the patient force factors and the existing anatomy.[87–94]

BOX 23-9 Patient Selection Criteria: OD-4

- Moderate to severe problems with traditional dentures
- Needs or desires are demanding
- Need to decrease bulk of prosthesis
- Inability to wear traditional prostheses
- Desire to abate posterior bone loss
- Unfavorable anatomy for complete dentures
- Problems with function and stability
- Posterior sore spots
- Opposing natural teeth
- C–h bone volume
- Unfavorable force factors (parafunction, age, size six, crown height space >15 mm)

The fifth mandibular overdenture option (OD-5) is designed for two types of patients. Most important, this is a minimum treatment option for patients with moderate to severe problems related to a traditional mandibular denture. The needs and desires of the patient are often most demanding and may include limiting the bulk or amount of the prosthesis, major concerns regarding function (mastication and speech) or stability, posterior sore spots, or the inability to wear a mandibular denture (Box 23-10).

The second patient condition that determines this option is for the treatment of continued bone loss in the posterior mandible. If no prosthetic load is on the posterior bone, the resorption process is delayed considerably and often reversed. Even when no posterior implants are inserted, the cantilevered bar

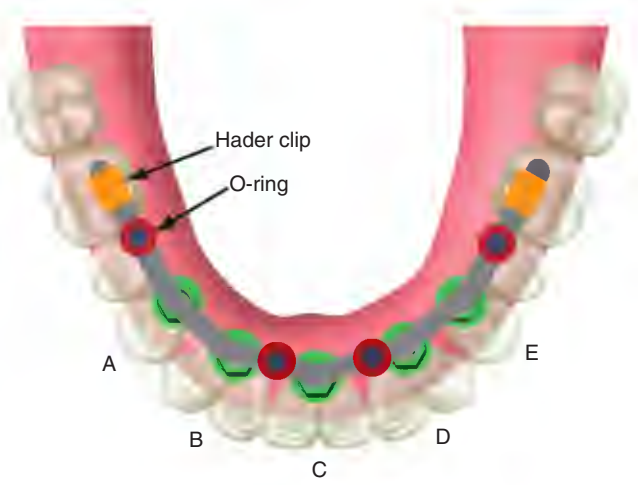


FIGURE 23-41. In the overdenture option 5, implants are placed in the A, B, C, D, and E positions. A bar splints the implants together and is distally cantilevered. The length of the cantilever depends on the anteroposterior distance and the force factors.



FIGURE 23-42. A panoramic radiograph of an option 5 overdenture bar and five implants in the anterior mandible.

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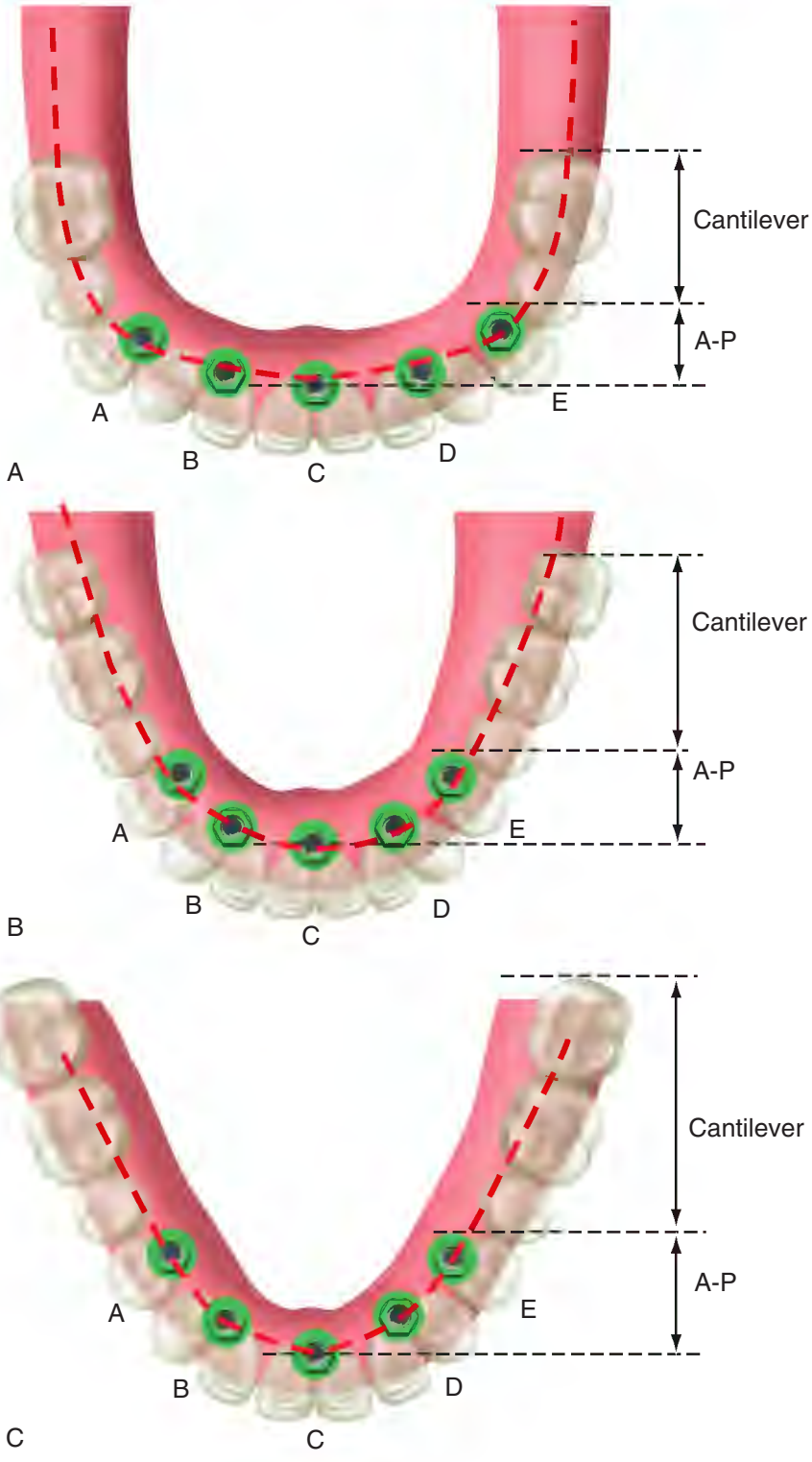


FIGURE 23-43. Arch shape affects the anteroposterior (A-P) distance. **A,** The square arch form is less than 5 mm. **B,** The ovoid arch form often has an A-P distance of 5 to 8 mm. **C,** A tapered arch form has the greatest A-P distance, larger than 8 mm.

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and overdenture avoid load to the posterior residual ridge and often halt its resorption process. Recent evidence shows that completely implant-supported prostheses often increase the amount of posterior bone height even when no posterior implants are inserted.[44,63] However, it should be noted that a better option to prevent this posterior bone loss and increase the A-P spread is the insertion of one or more posterior implants before the bone atrophy has occurred. The OD-5 treatment option is also indicated when the patient desires a RP-4 or fixed restoration, the arch form is square for a RP-5 prosthesis, or the maxillary arch has natural teeth (especially in a young patient or male patient).

The patient force factors are as important as the A-P spread. In a study in which the failure criterion was the failure of the screw joint with arrangements of three, four, five, and six implants with a similar A-P spread submitted to forces from 143 to 400 N, the greater transmitted forces to the prosthetic connection always exceeded the yield strength of the system. This

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study emphasizes the fact that the amount and duration of occlusal load is even more important than the A-P spread to be considered for cantilever length determination.[88]

Challenging Force Factors: Patient and Anatomic Factors

The five treatment options proposed for mandibular implant–supported overdentures provide an organized approach to solving a patient's complaints or anatomical limitations. The prosthesis support and range of motion should be part of the initial diagnosis. The treatment options initially proposed are designed for completely edentulous patients with division A or B anterior bone in desire of an overdenture. These options are modified when the CHS is great (as when the anterior bone is division C–h) and eliminated for division D. The increase in crown–implant ratio and decrease in implant surface area mandate modification of these initial options. In addition, when the patient force factors are greater than usual (parafunction, masticatory dynamics, opposing arch is natural dentition) or the arch form is square (reduced A-P spread), these treatment options must be modified.

For example, under these adverse conditions, one more implant is added to each option, and OD-1 is eliminated completely. Therefore, OD-2 has three implants (A, C, and E positions), OD-3 has four implants (A, B, D, and E regions), OD-4 has five implants (A, B, C, D, and E areas), and OD-5 has six implants, with one positioned behind one of the mental foramina (when possible) (Figure 23-44). If six implants cannot be placed because of inadequate posterior bone, the cantilever length is reduced, and a RP-5 restoration is fabricated.

BOX 23-10 Patient Selection Criteria: OD-5

- Moderate to severe problems with traditional dentures
- Needs or desires are demanding
- Need to decrease bulk of prosthesis
- Inability to wear traditional prostheses
- Desire to abate posterior bone loss
- Unfavorable anatomy for complete dentures
- Problems with function and stability
- Posterior sore spots
- Moderate to poor posterior anatomy
- Lack of retention and stability
- Soft tissue abrasion
- Speech difficulties
- More demanding patient type

Discussion

The doctor and staff can explain to the patient the amount of support each treatment option can provide by comparing them with the support system of a chair. Treatment option OD-1 is similar to a one-legged chair. A one-legged chair can support

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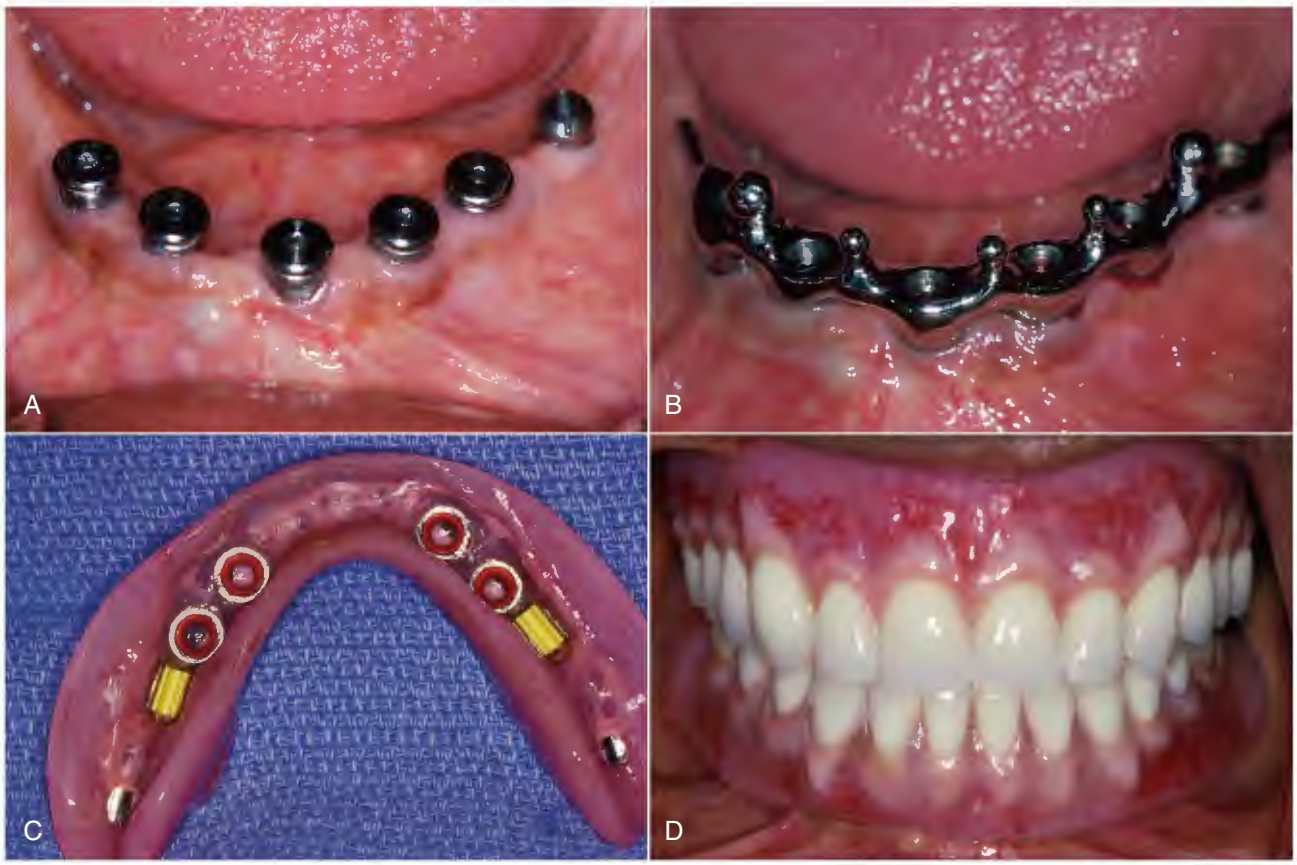


FIGURE 23-44. **A,** Six implants were placed in this edentulous mandible. **B,** The implants are splinted together, and the bar is cantilevered to the molar region. **C,** The implant overdenture (IOD) option is a RP-4 prosthesis. **D,** The maxillary and mandibular IOD in place.

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your weight but provides very little stability. Treatment options OD-2 or OD-3 are similar to a two-legged chair. The prosthesis provides some vertical support but can still rock back and forth and provides limited stability in the posterior regions. Option OD-4 with four implants is compared to a three-legged chair. This system provides improved support and has improved stability. However, it can be rocked one way or the other under lateral forces. A four-legged chair provides the greatest support and stability and is similar to OD-5, which is maximum for prosthesis support and stability because it is a RP-4 design.

Summary

Implant overdentures borrow several principles from tooth-supported overdentures. The advantages of implant overdentures relate to the ability to place rigid, healthy abutments in the positions of choice. The number, location, superstructure design, and prosthetic range of motion can be predetermined and based on a patient's expressed needs and desires and anatomic conditions. The same IOD treatment should not be provided to all edentulous patients. Only two implants placed just anterior to the mental foraminae rarely should be used. This treatment option has more prosthetic complications. The overdenture should be designed to predictably satisfy the patient's desires and anatomical limitations.

The most common overdenture option used by the profession is the two-implant overdenture, with individual O-ring attachments. Yet the only benefits of this approach are improved retention and a reduced initial cost. The bone loss is accelerated in the posterior regions, and the maintenance of anterior bone is limited to the zone around each implant. In addition, more prosthetic complications occur, which is a negative for both the patient and doctor.

An ideal approach for the overall long-term health of the mandible is a complete implant–supported prosthesis (RP-4 or fixed restoration). The bone volume is maintained in the anterior, and the posterior bone loss is significantly reduced or even improved. The occlusal load support is on the implants, not the soft tissues. The stability of the prosthesis is maximal because it does not move during function (mastication, speech). The retention is improved because it may have four to six overdenture attachments.

The patient initially may not be able to afford an OD-5 option (with a RP-4 or fixed prosthetic option). However, an OD-3 may be converted to an OD-4 after several years and eventually to an OD-5 after several more years. If the transition from one option to another is in a short time frame (1 to 2 years), the implants may be independent and use an O-ring system for the short term. This reduces the fee for the transitional prosthesis because no bar is fabricated, and a rebase may be used to modify the prosthesis.

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CHAPTER **24**

The Completely Edentulous Mandible: Treatment Plans for Fixed Restorations

Carl E. Misch

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Twenty million adults in the United States have completely edentulous mandibular arches.[1] Over the past 15 years, many of these patients have been treated with an implant overdenture (IOD), which is a vast improvement compared with a traditional complete denture. The most common treatment option for an IOD is two anterior independent implants (option OD-1) (Figure 24-1). Most often, a fixed prosthetic option is not even presented to the patient. Although these restorations have more retention than a denture, they do not prevent the continued bone loss in the posterior regions of the mouth. This continued bone loss affects esthetics, function, and long-term health. It may eventually cause paresthesia and fracture of the mandible (Figure 24-2). The retention, stability, and support for a complete-arch overdenture are so superior to the other treatment options that almost all implant candidates should eventually have an implant-supported full-arch prosthesis (Figure 24-3). There are many reasons full-arch implant options (including a fixed restoration) should be part of the treatment options presented to an edentulous patient.

Comparing Fixed versus Removable Implant Prostheses

The number and location of implants for an overdenture which is completely implant supported, retained and stabilized by implants and a connecting bar and fixed prosthesis, is most often the same. The laboratory and component costs for a hybrid fixed restoration (denture teeth, acrylic and metal substructure) are often similar to those for a fully implant-supported overdenture (a type 4 removable prosthesis [RP-4]) with a connecting bar and attachments. The chair time required to fabricate an overdenture and bar is similar to that for an implant-supported fixed prosthesis. Therefore, these two restoration types should have a similar fee. Yet because dentures and partial dentures typically cost several times less than fixed restorations on teeth, the doctor often charges half the fee for an IOD and bar compared with a fixed restoration. As a result,

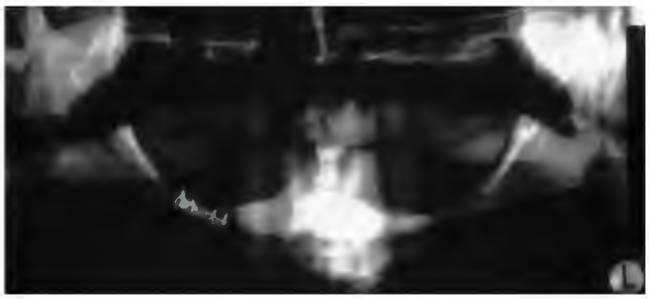


FIGURE 24-2. A panoramic radiograph of a severely resorbed mandible with a fracture and bone plate in the right body region. This patient has bilateral paresthesia of the lower lip.



FIGURE 24-1. A mandibular two-implant overdenture is the most common treatment option offered to a patient with a mandibular denture.



FIGURE 24-3. A mandibular implant overdenture may have complete implant support, retention, and stability from the implant support system (RP-4 prosthesis).

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many patients have preferred a fixed prosthesis but often for financial considerations chose a removable prosthesis. However, implant number, laboratory fees, component fees, and chair time are similar for these two types of prostheses. If the patient fees for these two restorations were similar, most patients would opt for a fixed prosthesis (Figure 24-4).

A fixed restoration provides the psychological advantage over an IOD of acting and feeling similar to natural teeth. An overdenture, even if fully implant supported, remains a removable prosthesis. A common remark heard from patients with implant fixed restorations is, "These implant teeth are better than my own teeth." Patient comments related to IODs most often state, "These overdentures are better than my denture."

Removable IODs require greater maintenance and exhibit more frequent prosthetic-related complications than fixed restorations. For example, Walton and McEntee noted that there were three times more maintenance and adjustments for removable prostheses compared with fixed restorations.[2] IODs often require attachments to be changed or modified every 6 months to 2 years, and denture teeth often wear, requiring a new prosthesis to be fabricated every 5 to 7 years.[2-7] In a review of literature by Goodacre et al., IODs have retention and adjustment problems 30% of the time, relines 19% of the time, clip or attachment fracture 17% of the time, and fracture of the prosthesis 12% of the time.[6] Fixed prostheses need less repair and less maintenance and often last the life of the implant support. Although porcelain fractures with a fixed restoration may occur and be costly to repair, over a lifetime, the implant-supported removable prosthesis is often more expensive.

Unlike the labial flange of a maxillary denture, the labial flange of a mandibular overdenture rarely is required for esthetics. A mandibular overdenture often traps food below its flanges, similar to a denture. Dentures and IODs are border molded to the muscle attachment level to allow the floor of the mouth to raise during swallowing. As a consequence, food accumulates below the denture flange while the muscles are at rest and then is compressed under the restoration during deglutition. The contour of a fixed restoration is less prone to food entrapment. The daily care for a bar IOD (RP-4) may be similar to that for a fixed mandibular restoration because ridge lap pontics are not required for esthetics or speech, as with some maxillary fixed prostheses.

A more recent clinical study by Wright et al. has evaluated posterior mandibular bone loss in IODs (type 5 removable prosthesis [RP-5]) compared with cantilevered fixed prostheses from anterior implants.[8] The annual bone loss index observed in the RP-5 overdentures ranged from +0.02 to −0.05 with 14 of 20 patients losing bone in the posterior regions. On the other hand, the fixed prostheses group had a range from +0.07 to −0.015 with 18 of 22 patients gaining posterior bone area (see Figure 24-3). Reddy et al. also found a similar clinical observation in 60 consecutively treated cantilevered fixed prostheses supported by five to six implants placed between the foramina.[9] The mandibular body height was measured 5, 10, 15, and 20 mm distal to the last implant. The baseline measurements up to 4 years after function increased from 7.25 ± 0.25 mm to 8.18 ± 0.18 mm. Nearly all of the bone growth occurred during the first year of function. Therefore, an important role for the complete implant-supported restoration is the maintenance and even regeneration of posterior bone in the mandible. This is especially important because continued posterior bone loss in this region may lead to paresthesia and even mandibular body fracture (Figure 24-5; Box 24-1).

Too often, the dentist offers overdentures as the only option for edentulous patients rather than including fixed treatment options. The advantages of a fixed restoration over an overdenture warrant almost all edentulous patients to be given an option for a fixed prosthesis. This chapter discusses fixed treatment planning options for the completely edentulous mandibular arches.[10] These same implant location options may also be used for RP-4 restorations in the mandible.



FIGURE 24-4. **A,** A complete-arch implant fixed prosthesis may be hybrid, with denture teeth and acrylic joined to a metal substructure. **B,** A fixed hybrid prosthesis may have a similar implant number and laboratory fee as a full-arch implant-supported mandibular overdenture.

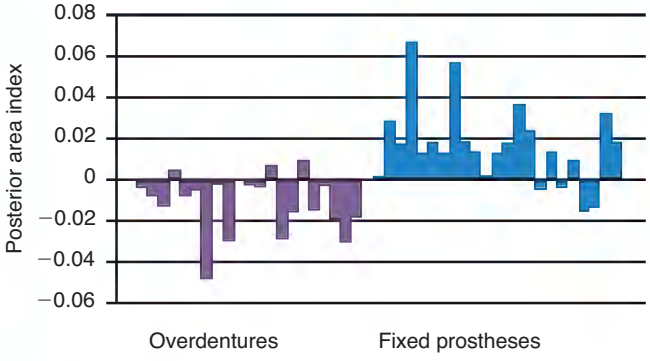


FIGURE 24-5. Implant overdentures with posterior soft tissue support lose bone in the posterior regions almost 75% of the time *(purple bars)*. Fixed prostheses cantilevered from anterior implants gain bone in the posterior regions more than 80% of the time *(blue bars)*.[8]

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BOX 24-1 Advantages of a Full-Arch Fixed Partial Denture versus Overdenture

- Psychological: "feels like teeth"
- Less prosthetic maintenance (e.g., attachments, relines, new overdenture)
- Less food entrapment
- Posterior mandibular bone gain

Force Factors

The amount of force transmitted to an implant-fixed prosthesis is similar to that of a completely implant-supported overdenture (RP-4). In one aspect then, the number of implants to support either prosthesis type should be similar. Mandibular overdentures may be removed at night to decrease the risk of nocturnal parafunctional overload. However, most mandibular edentulous patients also have an edentulous maxilla. Therefore, if the patient is willing to remove the maxillary denture at night, the risk of nocturnal parafunction also may be eliminated for patients with mandibular fixed prostheses. As a consequence, the number of implants required to restore a fixed prosthesis may be similar to that for a fully implant-supported overdenture.

When the patient has natural teeth or implants in the maxilla, more implants usually are indicated for the mandibular fixed prosthesis (compared with patients with an upper denture) to reduce the risk of occlusal overload, or a reduction in cantilever length is necessary. Force factors such as parafunction, crown height, masticatory dynamics, and the bone density of the implanted regions also may modify the implant position, implant number, size, and design for a fixed prosthesis. Increased force factors contribute to uncemented restorations, screw loosening, component fracture, crestal bone loss, and even implant failure. As a result, the fixed prosthesis often may require an improved biomechanical position or greater implant number compared with an IOD support system.

Mandibular Dynamics

Medial Movement

Many reports have addressed the dimensional changes of the mandible during jaw activity as a result of masticatory muscle action.[11-19] Five different movements have been postulated.[18] Medial convergence is the one most commonly addressed.[19] The mandible between the mental foramina is stable relative to flexure and torsion. However, distal to the foramina, the mandible exhibits considerable movement toward the midline on opening.[15,16] This movement is caused primarily by the attachment of internal pterygoid muscles on the medial ramus of the mandible.

The distortion of the mandible occurs early in the opening cycle, and the maximum changes may occur with as little as 28% opening (or about 12 mm).[11] This flexure has also been observed during protrusive jaw movements.[20,21] The greater the active opening and protrusive movements, the greater the amplitude of mandibular flexion. The amount of movement varies among individuals and depends on the density and volume of bone and the location of the site in question. In general, the more distal the sites, the more medial flexure. The amplitude of the mandibular body flexure toward the midline has been measured to be as much as 800 microns in the first molar–to–first molar region to as much as 1500 microns in the ramus-to-ramus sites (Figure 24-6). In a study by Hobkirk and Havthoulas on deformation of the mandible in subjects with fixed dental implant prostheses, medial convergence up to 41 mm was observed.[22]

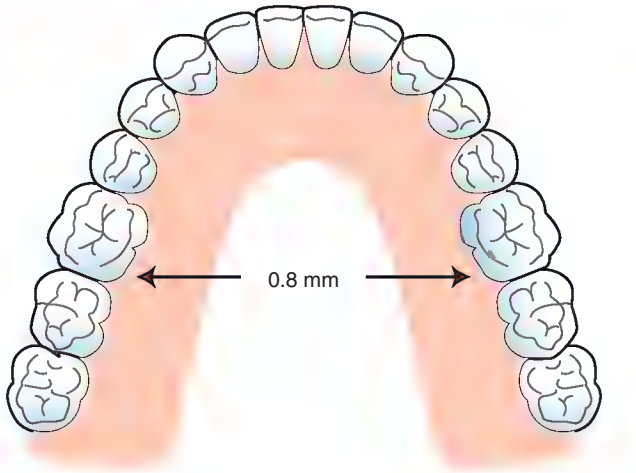


FIGURE 24-6. The flexure of the mandible during opening and protrusive movements occurs distal to the mental foramina. The amount of flexure depends on the amount of the bone volume and the sites in question. The medial movement from the first molar to the first molar region may be 800 microns.

Torsion

Torsion of the mandibular body distal to the foramina has also been documented in both animal and human studies.[23-26] Hylander evaluated larger members of the rhesus monkey family (macaque) and found the mandible twisted on the working side and bent in the parasagittal plane on the balancing side during the power stroke of mastication and unilateral molar biting[26] (Figure 24-7). Parasagittal bending of the human jaw during unilateral biting was confirmed by Marx,[27] who measured localized mandibular distortion in vivo in humans by using strain gauges on screws attached to cortical bone in the symphyseal and gonial regions. Abdel-Latif et al. confirmed that the mandibles of patients with implant prostheses measured up to 19 degrees of dorsoventral shear.[23] The torsion during parafunction is caused primarily by forceful contraction of the masseter muscle attachments (Figure 24-8). Therefore, parafunctional bruxism and clenching may cause torsion-related problems in the implant support system and prosthesis when the mandibular teeth are splinted from the molar to molar regions.

The posterior bone gain in edentulous patients restored with cantilevered prostheses from anterior implants may be a consequence of the mandibular flexure and torsion, which stimulate the bone cells in the region. Because the bite force may increase 300% with an implant prosthesis compared with a denture, the increased torsion may stimulate the posterior mandibular body to increase in size, as reported by Reddy et al.[9] and Wright et al.[8]

Misch has observed the increase in flexure in the posterior mandible is a result of the mental foramen weakening of the facial cortical plate.[10] As such, the mandible flexes and has torsion distal to the foramen. The most common position of the mental foramen is between the first and second premolar teeth. Therefore, when bilaterally splinting teeth distal to the premolar positions, mandibular dynamics should be

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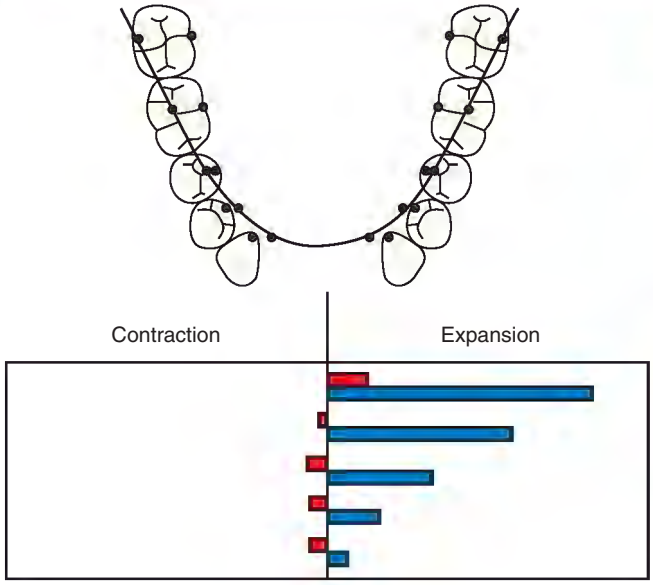


FIGURE 24-7. Unilateral molar biting causes the mandible to undergo torsion with the bottom of the mandible expanding outward and the crest of the mandible rotating medially.[26]

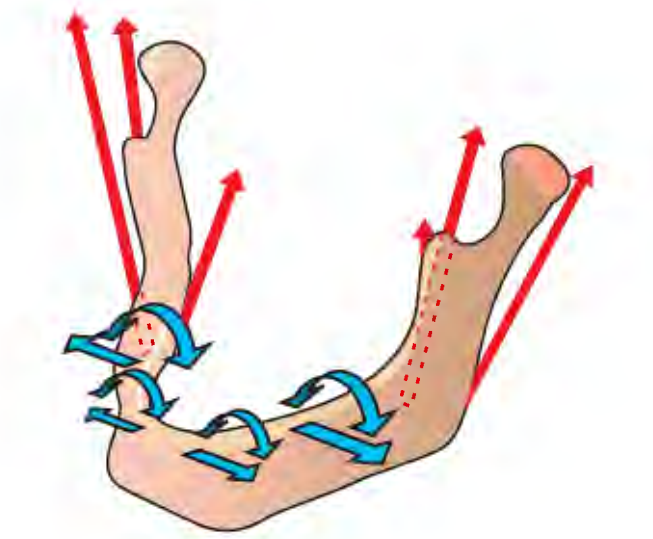


FIGURE 24-8. The mandible flexes toward the midline on opening or during protrusive movements as a result of the internal pterygoid muscle attachments on the ramus. The mandible also torques, with the inferior border rotating out and up and the crestal region rotating lingually. The movement is caused by the masseter muscles during forceful biting or parafunction.

considered.[22] Posterior rigid, fixated implants splinted to each other in a full-arch restoration are subject to a considerable buccolingual force on opening and during parafunction.[22,28,29] A study by Miyamoto et al. identified jaw flexure as the primary cause of posterior implant loss in full-arch splinted mandibular prostheses.[28] The more distal the rigid splint from one side to the other, the greater the risk that mandibular dynamics may influence the implants or prosthesis prognosis. In addition, the body of the mandible flexes more when the size of the bone decreases.[10] As a result, the division C minus height (C–h) or division D mandible flexes or exhibits torsion more than the division A mandible, all other factors being similar.



FIGURE 24-9. Some authors propose that the ideal implant positions to support a mandibular full-arch prosthesis are the bilateral molars and bilateral canines splinted together with a rigid structure. These positions are not ideal because of the mandibular dynamics during opening and function.

The difference in movement between an implant and a tooth has been addressed as a concern for dentists when splinting these objects together. The natural tooth movement ranges from 28 microns apically and 56 to 108 microns laterally. In contrast, the rigid implant has movement up to 5 microns apically and 10 to 60 microns laterally. Yet the mandibular flexure and torsion may be more than 10 to 20 times the movement of a healthy tooth. Therefore, the flexure and torsion of the mandibular body are more critical in the patient evaluation compared with whether an implant should be joined to the natural dentition.

Past authors have suggested four implants in the mandible with a full-arch splinted fixed restoration—two in the first molars and two in the canine regions[30] (Figure 24-9). Additional implants have been used with this full-arch splinted restorative option, with up to four other implants in the premolar and the incisor regions.[31] However, complete cross-arch splinting of posterior molar implants with a rigid, fixated prosthesis should be reconsidered in the mandible. The flexure of the mandible is thwarted by the prosthesis,[22,23,29,32-34] but this introduces lateral stresses to the implant system (cement, screw, crestal bone, and implant–bone interface). These lateral stresses place the molar implants, screws, and bone at increased risk because of the mandibular flexure and torsion previously addressed.

In complete mandibular subperiosteal implants, pain upon opening was noted in 25% of the patients at the suture removal appointment when a rigid bar connected molar-to-molar regions. When the connecting bar was cut into two sections between the foramina, the pain upon opening was immediately eliminated. This clinical observation does not mean that the other 75% of patients did not have flexure of the mandibular arch upon opening. The observation does demonstrate, however, that flexure may be relevant to postoperative complications. Consequences of a treatment plan with cross-arch connection of posterior mandibular implants may include bone loss around the implants, loss of implant fixation, material fracture (implant or prosthesis components), unretained restorations, and discomfort upon opening. Until clinical studies become available and state otherwise, full-arch splinted restorations joining bilateral molar implants in the mandible should not be a treatment of choice.

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Implants placed in front of the foramina and splinted together or implants in one posterior quadrant joined to anterior implants have not shown these complications related to the flexure or torsion of the mandible. Complete implant-supported fixed restorations can halt the posterior bone loss associated with edentulism, improve psychological health, and produce fewer prosthetic complications than removable restorations. Therefore, all edentulous mandibular patients should be given the option of having a fixed prosthesis. However, the increase in forces of mastication, increase in force with patients of greater force factors (e.g., parafunction, crown height space, opposing arch type), or reduced bone density in the implant sites warrants an increase in implant number or implant position in anterior and posterior implant sites.

Five treatment options are used to restore a complete edentulous mandible with a fixed prosthesis. These implant position options also may be considered for implant-supported overdentures. When a mandibular overdenture is completely implant supported and retained and stabilized by a cantilevered bar, it acts similarly to a fixed prosthesis in function and bone maintenance. Therefore, the five treatment options included in this chapter may be used for either a RP-4 overdenture or a fixed prosthesis.

Implant Treatment Options for Fixed Restorations

Treatment Option 1: The Brånemark Approach

Treatment option 1 places four to six implants between the mental foramina, and bilateral distal cantilevers replace the mandibular teeth. The mandible does not flex or exhibit significant torsion between the mental foramina. Therefore, anterior implants may be splinted together without risk or compromise.

The placement of four to six anterior root forms between the mental foramina and a distal cantilever off each side of the most distal implant to replace the posterior teeth was the treatment of choice for clinical reports from 1967 to 1981 with the Brånemark system[35] (Figure 24-10). This treatment approach resulted in an 80% to 90% implant survival for 5 to 12 years after the first year of loading. In a long-term, 18- to 23-year study, Attard and Zarb[36] reported an 84% success rate using this treatment option (Figure 24-11).

The distance from the center of the most anterior implant to a line joining the distal aspect of the two most distal implants on each side is called the *anteroposterior (A-P) distance* or the *A-P spread*[37] (Figure 24-12). The greater the A-P spread, the farther the distal cantilever may be extended to replace the missing posterior teeth. As a general rule, when five to six anterior implants are placed in the anterior mandible between the foramina to support a fixed prosthesis, the cantilever should not exceed 2 times the A-P spread, with all other stress factors being low.

The range of implant and prosthesis survival may be due to the broad application of the same implant position, regardless of crown height, opposing dentition, implant length, A-P position of implants, and parafunction. The arch form, the position of the mental foramina, force factors, and bone density are important criteria when four to six implants are placed only in the anterior segment to replace the entire mandibular arch. The anterior arch form and foramina position affect the position of the distalmost implants. Therefore, a cantilever distance is variable for different patients.

The A-P distance is affected by the arch form. The types of arch forms may be separated into square, ovoid, and tapering. A square arch form in the anterior mandible has a 0- to 6-mm A-P spread between the most distal and most anterior implants (Figure 24-13). An ovoid arch form has an A-P distance of 7 to 9 mm and is the most common type (Figure 24-14). A tapering arch form has an A-P distance greater than 9 mm (Figure 24-15). Hence, whereas a tapering arch form may support a 20 mm cantilever, a square arch form requires the cantilever to be reduced to 12 mm or less.

The position of the mental foramen can affect the A-P spread. The mental foramen is most often found between the root apices of the premolars. However, it may be located as far anterior as just distal to the canine (more common in white women) and as far distal as the mesial of the first molar apex (more often in black men).[38] The farther forward the foramen, the shorter the cantilever length because the A-P spread is reduced.

The A-P spread is only one of the force factors to be considered for the extent of the distal cantilever. If the stress factors are high (e.g., parafunction, crown height, masticatory musculature dynamics, opposing arch), the cantilever length of a prosthesis should be reduced and may even be contraindicated (Figure 24-16). The density of bone is also an important criterion. The softest bone types (D3 and D4) should not have as great of a cantilever than the more dense types (D1 and D2).

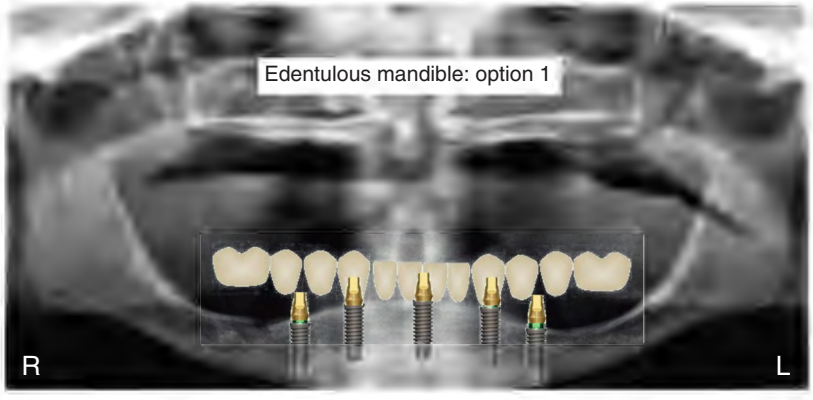


FIGURE 24-10. Option 1 for a full-arch fixed prosthesis uses five or six implants positioned between the mental foramen to support a cantilevered fixed prosthesis. Note the bilateral cantilevered prosthesis and low force factors. Key implant positions are A, B, C, D, and E.

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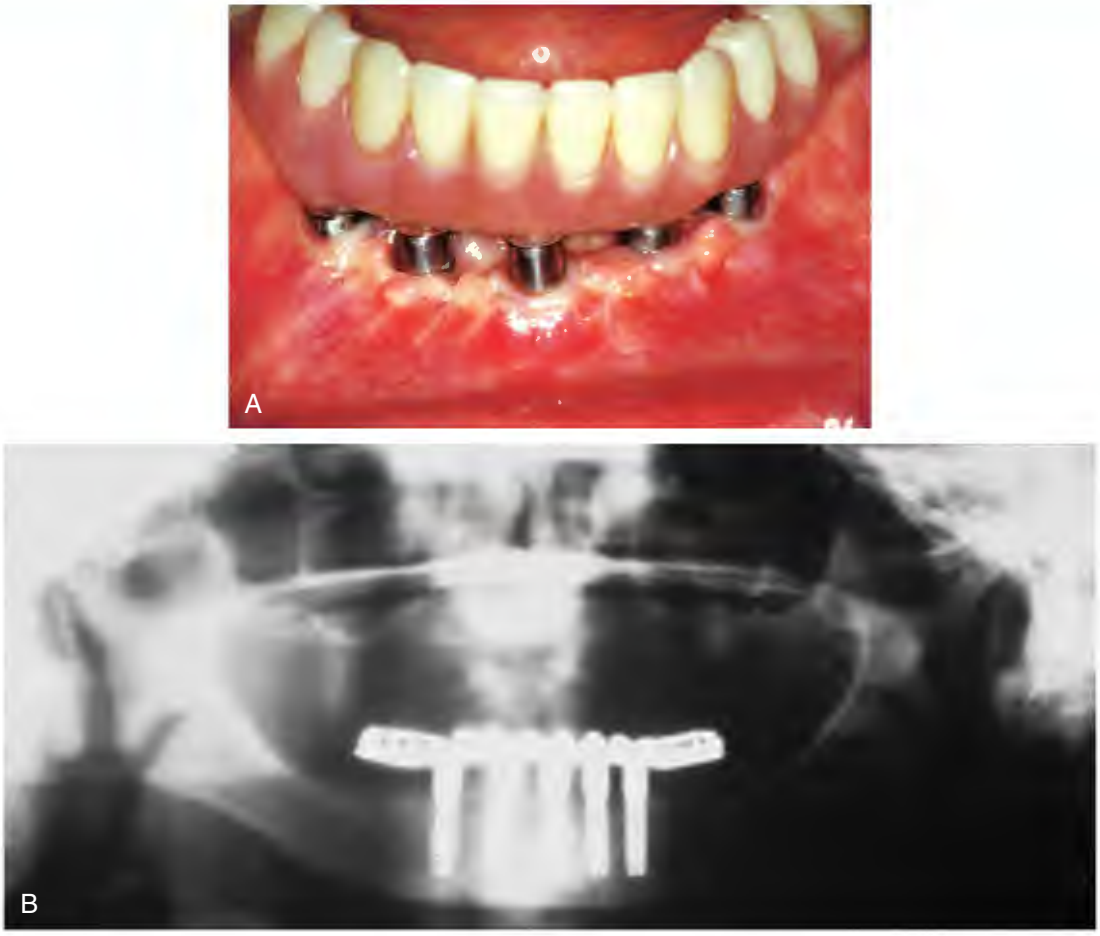


FIGURE 24-11. **A,** A full-arch mandibular implant prosthesis with five implants placed between the mental foramina and a hybrid fixed prosthesis cantilevered to the first molar region. **B,** A panoramic radiograph of a hybrid full-arch fixed prosthesis cantilevered from five anterior endosteal implants positioned between the mental foramina.

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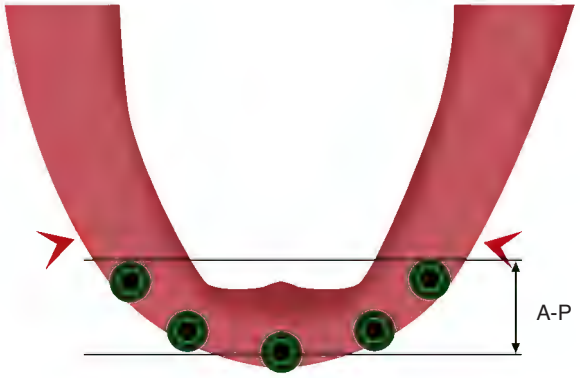


FIGURE 24-12. The anteroposterior (A-P) distance is determined by a line drawn from the distal portion of the distalmost implant on each side of the arch and another parallel line drawn through the center of the anteriormost implant from the cantilever.

Therefore, the length of the posterior cantilever depends on the specific force factors of the patient, of which A-P spread is only one.

The number of implants may also affect the cantilever length. *Stress* equals *force* divided by the *area* over which *force* is applied. The area over which the forces are applied from the prosthesis to the implants can be modified through the number, size, and design of the implants. A cantilever rarely is indicated on three implants even with a similar A-P spread as five implants. The most common number of implants used today in the cantilevered Brånemark treatment option is five (Figure 24-17). This number allows as great an A-P spread as six implants, with greater interimplant distance, so that if bone loss occurs on one implant, the loss would not automatically affect the adjacent implant site. The cantilever can be greater for five implants compared with three or four because of greater implant surface area and greater number of prosthetic components to decrease screw loosening. Often, narrow implants are not designed to support cantilevers, but wider implants can support a greater cantilever.

Treatment option 1 depends greatly on patient force factors; arch form; and implant number, size, and design. As a result, the safest action is to reserve this option for patients with low force factors, such as an older woman wearing an upper denture with abundant anterior bone and crown height less than 15 mm, with a tapered or ovoid mandibular arch, good bone density, and posterior segments of inadequate height for endosteal implant placement. Some patients may be contraindicated for a fixed prosthesis as a result of excessive patient force factors when implants are limited to the interforaminal positions.

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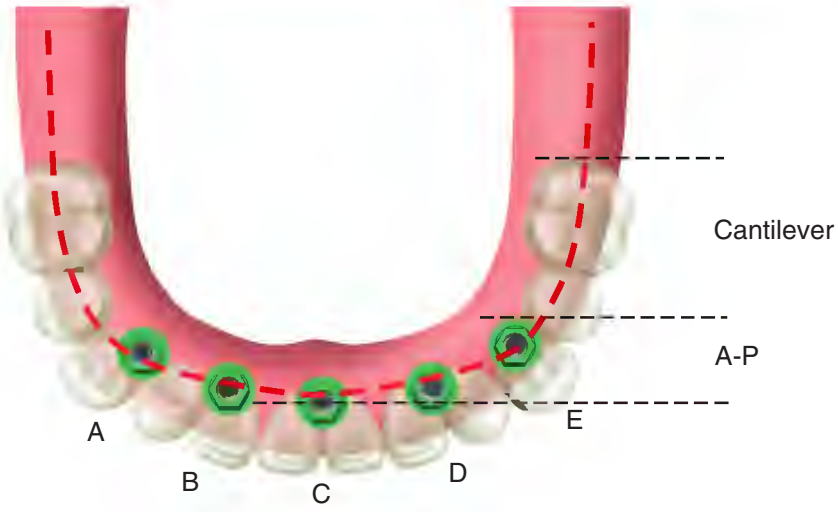


FIGURE 24-13. A mandibular square arch form has an anteroposterior (A-P) distance of 0 to 6 mm. As a result, a cantilever is limited.

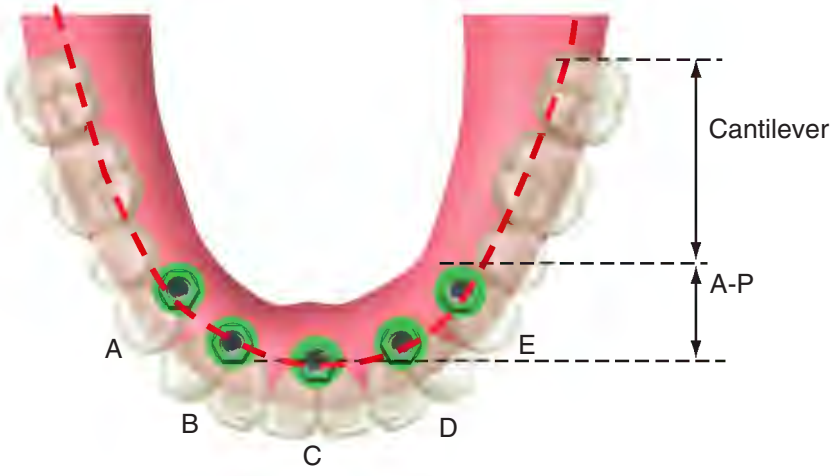


FIGURE 24-14. A mandibular ovoid arch form has an anteroposterior (A-P) distance of 7 to 9 mm and is the most common type. A cantilever may extend to 18 mm with the ovoid-type arch.

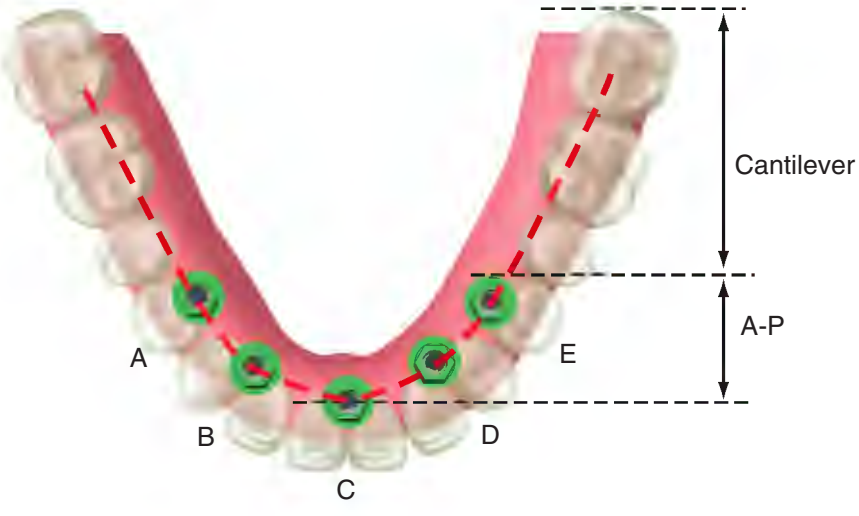


FIGURE 24-15. A mandibular tapered arch form has an anteroposterior (A-P) distance of greater than 9 mm, and is the type least observed. A cantilever is least at risk for this arch form.

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FIGURE 24-16. The length of the distal cantilever should be reduced when opposing an implant prosthesis or when the crown height space is more than 15 mm. A decrease in occlusal awareness causes high bite forces in implant prostheses, and crown height is a force magnifier in the presence of a cantilever. The cantilever in this radiograph should be reduced to decrease the risk of stress-related complications.

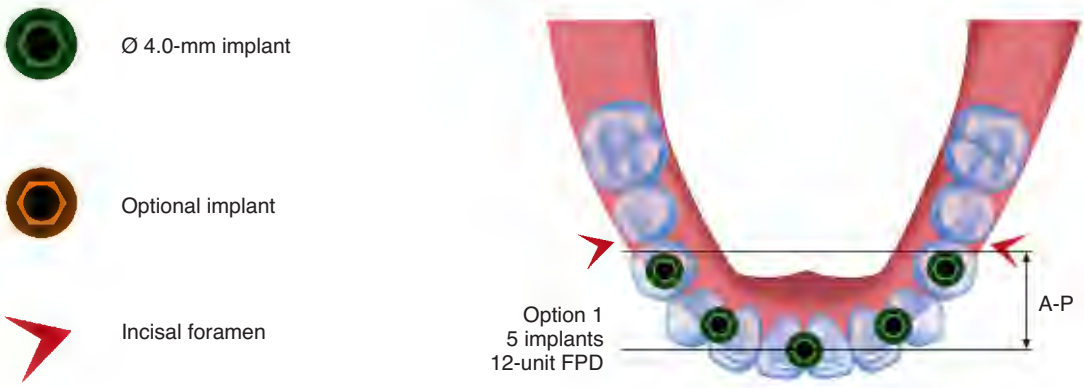


FIGURE 24-17. The most common number of implants between the mental foramina for option 1 is five. These implants provide as great an anteroposterior (A-P) distance as possible between the foramina with sufficient interimplant spacing for treatment of complications. *FPD,* Fixed partial denture.

Treatment Option 2

Bidez and Misch have evaluated dentate and edentulous mandibles and developed a three-dimensional bone strain model of flexure and torsion[10] (Figure 24-18). Studies were performed to evaluate different splinted implant options that would not compromise the prosthetic foundation. As a consequence, a number of implant site options have become available.

A slight variation of the ad modum Brånemark protocol is to place additional implants above the mental foramina because the mandible flexes distal to the foramen (Figure 24-19). An implant above one or both foramina presents several advantages. First, the number of implants may be increased to as many as seven (which increases the implant surface area). Second, the A-P spread for implant placement is greatly increased (usually by 7 mm) even when the total implant number is five (Figure 24-20) The more distal implant position reduces the class 1 lever forces generated from the distal cantilever. Third, the length of the cantilever is reduced dramatically because the distalmost implant is placed one tooth more distal (Figure 24-21).

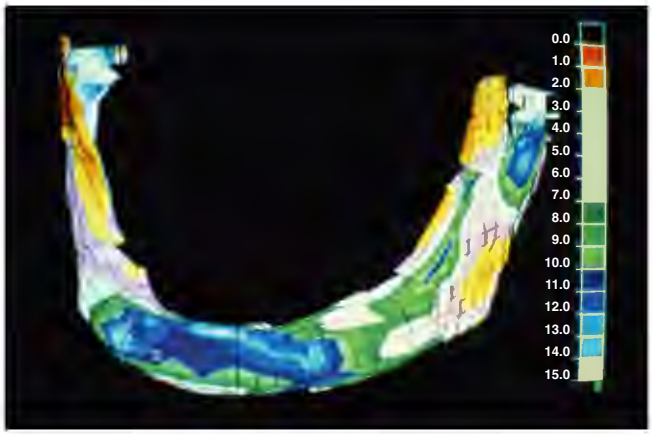


FIGURE 24-18. Studies at the engineering school at the University of Alabama at Birmingham used a dentate and edentulous model to evaluate the bone strain conditions during flexure and torsion. A number of implant site options have become available as a consequence. (Courtesy M.W. Bidez.)

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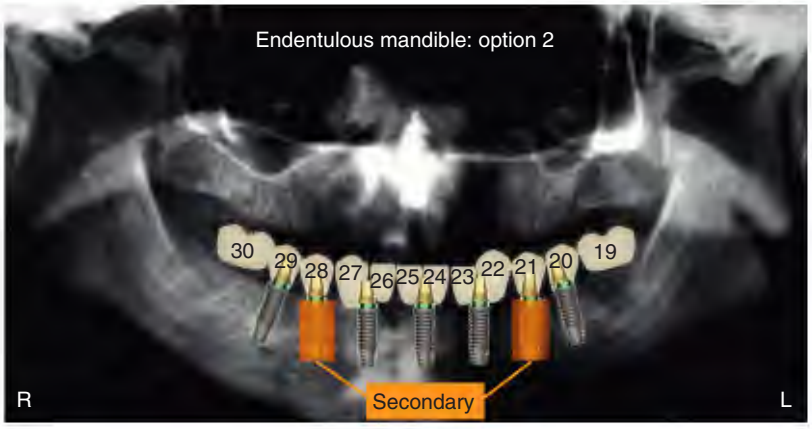


FIGURE 24-19. A panoramic radiograph of a full-arch fixed restoration with seven implants placed after treatment option 2: two implants over the foramina, two implants in the first premolar sites (optional), two implants in the canine positions, and one implant in the midline. Note the bilateral cantilevered prosthesis. Additional force factors require secondary implant sites A and E.

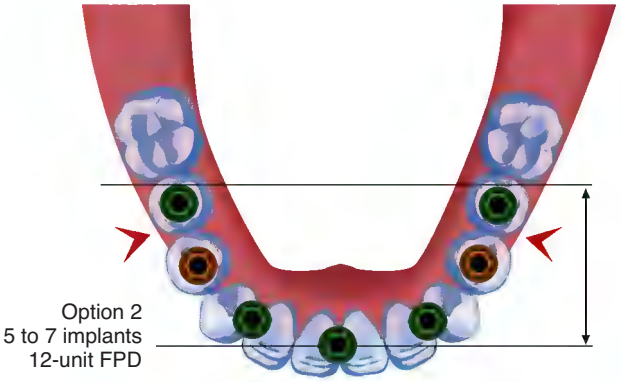


FIGURE 24-20. Treatment option 2 has five key implant positions: two implants placed over the mental foramina, two implants in the canine positions, and one implant in the midline. Secondary implants may be positioned in the first premolar sites. This has a much improved anteroposterior distance and reduces the cantilever length to the first molar. *FPD,* Fixed partial denture.

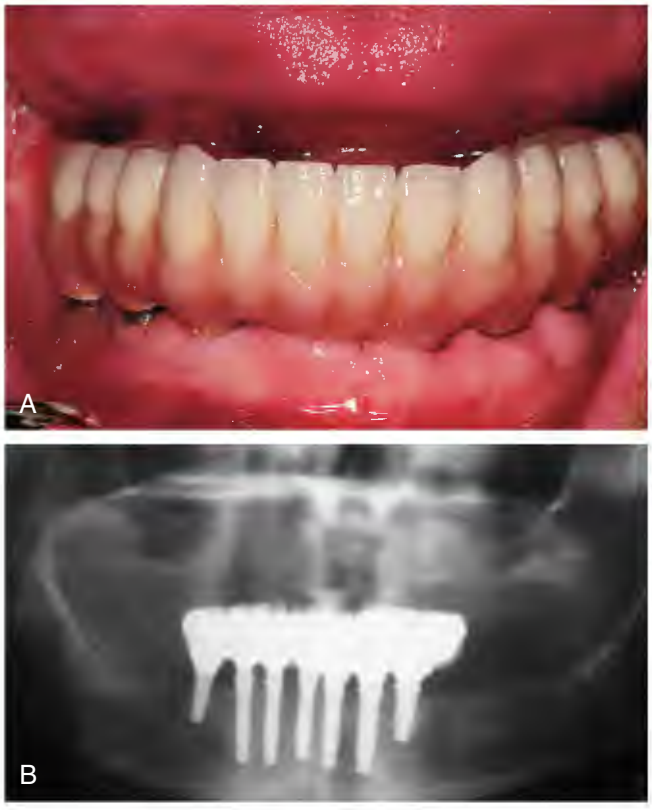


FIGURE 24-21. **A,** An intraoral view of the full-arch fixed prosthesis with option 2. A cantilever to the first molar site is reduced because implants are positioned over the mental foramina. **B,** A panoramic radiograph with option 2: seven implants supporting a full-arch mandibular prosthesis.

A prerequisite for treatment option 2 is the presence of available bone in height and width over one or both foramina. Because the foramen usually is located 12 to 14 mm above the inferior border of the mandible, available bone height is reduced in this location. When available, the foramen often requires implants of reduced height compared with the anterior implants. The most distal implant bears the greatest load when loads are placed on the cantilever (acts as fulcrum); therefore, the greatest forces are generated on the shortest implants. A minimum recommended implant height of 9 mm and a greater diameter or an enhanced surface area design are recommended to compensate for the reduced implant length (Figure 24-22).

The key implant positions in treatment option 2 are the second premolar positions, the canine positions, and the central incisor or midline position. The two optional implant sites are the first premolar sites and are more often indicated when the patient force factors are greater than usual.

Treatment Option 3

The Bidez and Misch strain model of an edentulous mandible indicated that implants in one posterior section may be splinted to anterior implants without compromise. The author has evaluated full-arch fixed prostheses on implants with one posterior segment connected to the anterior region over the past decade and has found no additional complications experienced during this time frame compared with those with independent segments. Therefore, an improved treatment plan option to support a fixed mandibular prosthesis consists of additional implants in the first molar or second premolar position (or both) (Figure 24-23) connected to four or five implants between the mental foramina. Hence, five to seven implants usually are placed in this treatment option.

The key implant positions for treatment option 3 are the first molar (on one side only), the bilateral first premolar positions, and the bilateral canine sites. The secondary implant positions include the second premolar position on the same side as the molar implant and the central incisor (midline) position. On

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FIGURE 24-22. A panoramic radiograph of a full-arch fixed prosthesis in the mandible with option 2 opposing an implant fixed restoration in the maxilla.

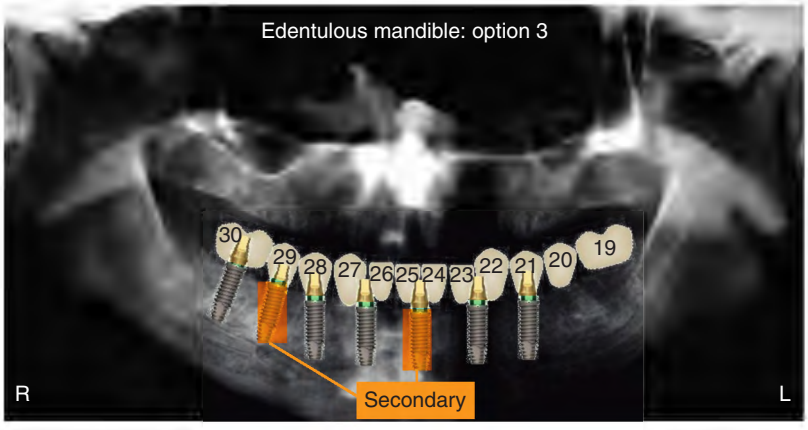


FIGURE 24-23. Treatment option 3 has key implant positions in one first molar site, bilateral first premolar positions, and two canine sites. Secondary implants (orange) may be used in the bilateral second premolar and midline positions. Note the increased force factors and the secondary implants at the second premolar and site C.



FIGURE 24-24. On occasion, option 3 may also include an implant over the foramen on the side of the cantilever and use as many as eight implants.

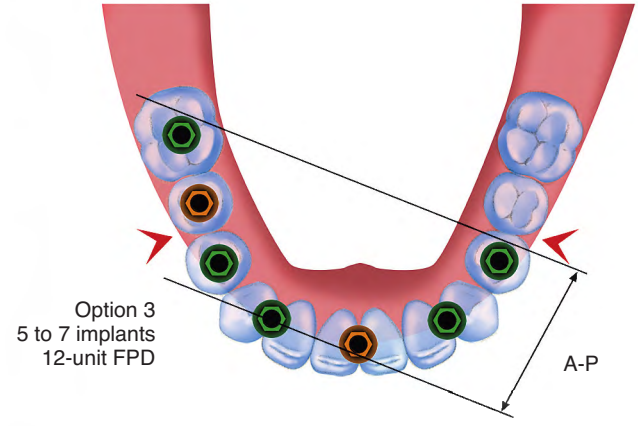


FIGURE 24-25. Five of the seven mandibular implants are positioned between the mental foramina, and two are placed on the patient's right or left side. The anteroposterior (A-P) distance is measured from the two distalmost implants to the anteriormost implant from the cantilever. The placement increases the A-P distance and eliminates the prosthetic cantilever on the patient's left side. *FPD,* Fixed partial denture.

occasion, an additional site may include the position over the mental foramen on the side of the cantilever (Figure 24-24). A one-piece casting can be fabricated, and one cantilever to the opposite side of the molar implant would replace those posterior teeth. Although mandibular movement during function occurs, it has not been observed to cause complications, since the opposite side to the molar implant has no splinted implant(s).

Treatment option 3 is a better option than anterior implants with bilateral cantilevers (option 1 or 2) for several reasons. When one or two implants are placed distal to the foramina on one side and are joined to anterior implants between the foramina, a considerable biomechanical advantage is gained. Although the number of implants may be the same as option 1 or 2, the A-P spread is 1.5 to 2 times greater because on one side, the distal aspect of the last implant now corresponds to the distal aspect of the first molar (Figure 24-25). In addition, only one cantilever is present rather than bilateral cantilevers. When force factors are greater, six to seven implants may be used for this option. Five implants between the foramina and one or two implants distal on one side comprise the usual placement (Figure 24-26).

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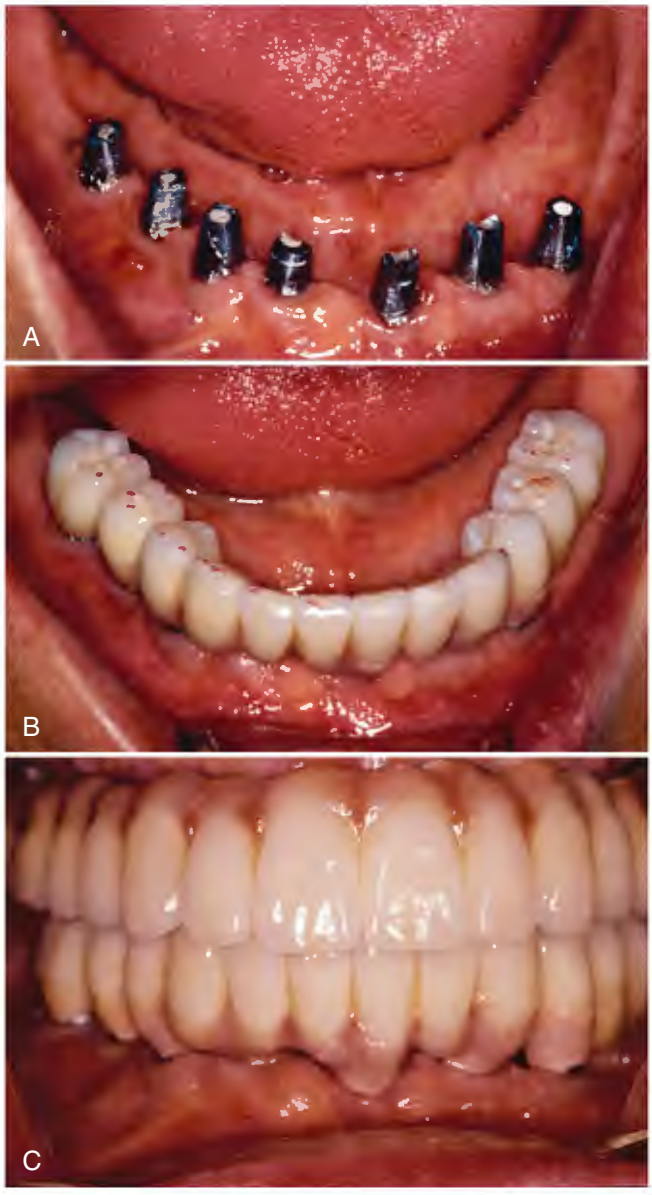


FIGURE 24-26. **A,** Five implants are positioned between the mental foramina and two on the patient's right posterior region. **B,** A fixed mandibular restoration in situ. **C,** An intraoral view of the final maxillary and mandibular fixed implant-supported prostheses.

Over the past 10 years, the author has fabricated more than 55 prostheses with five to seven implants in the option 3 positions. To date, no prosthesis has been replaced, and no implants have failed. In addition, no uncemented prosthesis or abutment screw loosening has occurred. This approach is superior to treatment option 1 or 2 with bilateral cantilevers because (1) the A-P spread is dramatically increased, (2) more implants may be used if desired, and (3) only one side has a cantilever. However, this option requires available bone in at least one posterior region of the mandible (Figure 24-27).

Treatment Option 4

Treatment plan options for fixed full-arch prostheses also may include bilateral posterior implants as long as they are not splinted together in one prosthesis. This option is selected when force factors are great or the bone density is poor. Poor bone quality most often is observed in the posterior maxilla, but on occasion, it is also found in the mandible. This option is also used when the body of the mandible is division C–h and subperiosteal or disk-design implants are used for posterior implant support. Several options for fixed restorations are available when bilateral posterior implants are included.

In treatment option 4, implants are placed in all three segments of the mandible. Key implant positions for this treatment option include the two first molars, two first premolars, and two canine sites. Secondary implants may be added in the second premolars or the incisor (midline) position (or both) (Figure 24-28). All implants in the anterior and one posterior side are splinted together for a nine-unit, fixed prosthesis. The other posterior segment is restored independently with an independent three-unit, fixed prosthesis supported by implants in the first premolar and first molar region as the key positions (Figure 24-29). Three implants (first premolar, second premolar, and molar) are used most often for the smaller segment to compensate for force factors and the alignment of the implants (because they are almost in a straight line). At least six implants typically are used in this option, but seven are more often used, so the smaller segment has three implants (Figure 24-30) Additional implants—as many as nine—may be inserted when force factors are greater or an immediate restoration or loading protocol is selected.

The primary advantage of this treatment option is the elimination of cantilevers. As a result, risks of uncemented restorations and occlusal overload are reduced. Another advantage is that the prosthesis has two segments rather than one. The larger segment (molar to contralateral canine) has an improved advantage because it has implants in three to four different horizontal planes. Because no cantilever is present, weaker cements can be used to install the prosthesis. If the prosthesis requires repair, the affected segment may be removed more easily because only the segment requiring repair needs to be removed. The restoration should exhibit posterior disclusion in excursions to limit lateral loads, especially to the prosthesis supported by fewer implants.

Disadvantages for treatment option 4 include the need for abundant bone in both mandibular posterior regions and the additional costs incurred for one to four additional implants.

Treatment Option 5

Another modification for the completely edentulous mandible is to fabricate three independent prostheses rather than one or two. The anterior region of the mandible may have four to five implants. The key implants are in the two first molar sites, the two first premolar, and two canine regions. Secondary positions are the two second premolar and central incisor (midline) sites (Figure 24-31). With this setup, the posterior restorations extend from first molar to first premolar, and an anterior restoration replaces the six anterior teeth. However, these six implant sites are usually best used in treatment option 4 because the larger segment has improved biomechanical placements. Therefore, when option 5 is indicated, it usually has bilateral implants in the first molars, second premolars, first premolars, and both canine positions. These eight implants may also have a secondary implant in the midline. The fixed anterior prosthesis usually extends from first premolar to first premolar (or less often canine to canine). The posterior restorations are two independent implant prostheses, usually with two units (Figure 24-32).

The advantages of this option are smaller segments for individual restorations in case one should fracture or become uncemented. In addition, if greater mandibular body movement is

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FIGURE 24-27. **A,** A mirror view of seven implants for option 3. **B,** A panoramic radiograph of the previous surgery with the fixed prosthesis in place.

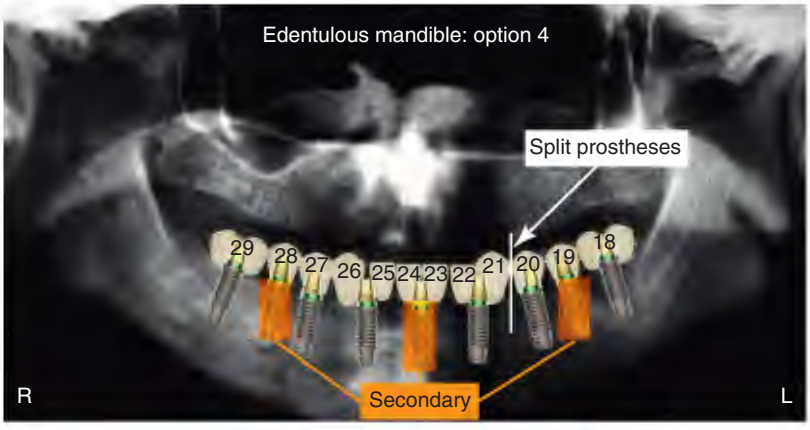


FIGURE 24-28. Treatment option 4 has implants in both molar sites. Other key positions include the two first premolar positions and the two canine sites. Secondary implants may also be positioned into second premolar locations and the midline (orange). Note the additional force factors and secondary implants at the two second premolar and C sites.





FIGURE 24-29. **A,** Eight endosteal implants at stage 2 uncovery with both posterior quadrants of sufficient bone height and width for endosteal implants. **B,** A panoramic radiograph of a full-arch fixed implant prosthesis in the mandible, with option 4 implant support. The prosthesis is separated in two sections between the first premolar and canine sites.

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expected because of parafunction or a decrease in size of the body of the mandible, the independent restorations allow the most flexibility and torsion of the mandible.

The primary disadvantage of option 5 is the greater number of implants required. In addition, the available bone needs are greatest with this treatment option. Nine implants are rarely required to replace the lower teeth, regardless of the bone density or force factors present. Option 5 is the treatment of choice when force factors are severe. However, option 4 may also be used with severe force factors and have a greater A-P spread on the larger restoration.

The most common scenario for option 5 is when the posterior mandible is division C–h bone volume and a circumferential subperiosteal or disk-design implant is used as the second premolar and first molar implant abutment supports. The decrease in the bone volume of the posterior mandible increases the flexure and torsion. As a result, three independent prostheses are more warranted (Figure 24-33).

Long-Term Treatment Planning

There is overwhelming evidence and agreement that a two-implant overdenture (RP-5) is a better option than a traditional denture, but the two-implant overdenture should not be considered a lifetime device. The posterior mandible resorbs four times faster than the anterior mandible. An anterior implant-supported overdenture may accelerate posterior bone loss because the bite force increases, and the patient is more likely able to wear the mandibular prosthesis. When the doctor and patient consider a "lifetime strategy of treatment" rather than a 1-year treatment plan, the overall treatment plan is then treated for a lifetime approach, and both the doctor and patient can benefit.

A mandibular overdenture may be upgraded from a RP-5 prosthesis to a completely implant-supported device (RP-4), a fixed prosthesis (FP-3), or both. If the cost involved to insert two or three implants can be invested every 5 years, within 4 to 10 years almost every patient may have a fixed restoration, provided available bone and force factors are compatible. As a result, the goal of the dentist should be to establish a lifetime strategy of health with the patient's scheduled prosthesis upgrade. For example, if implants are placed in the canine positions at step 1 for an overdenture, the dentist may plan the placement of implants into the left first molar and right first premolar positions at step 2. At step 3, implants can be added to the left first premolar position to reach a goal of a RP-4 or FP-3 restoration.

Summary

Many completely edentulous patients desire a fixed restoration rather than a removable prosthesis. Costs for a fixed implant prosthesis often have been a deterrent but should be more



FIGURE 24-30. Most often treatment option 4 uses at least seven implants, so the smaller segment has three implants.

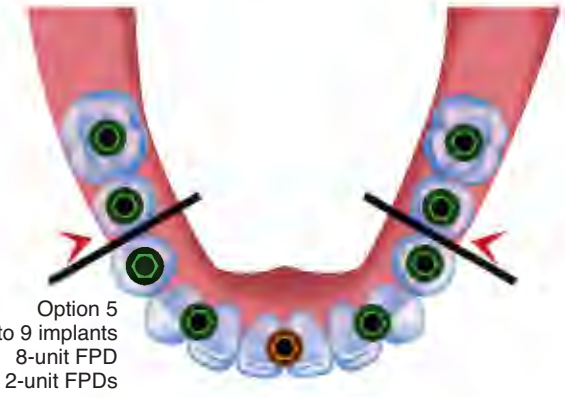


FIGURE 24-32. Option 5 often has a fixed prosthesis from first premolar to first premolar supported by four or five implants. The posterior segments each have two units.

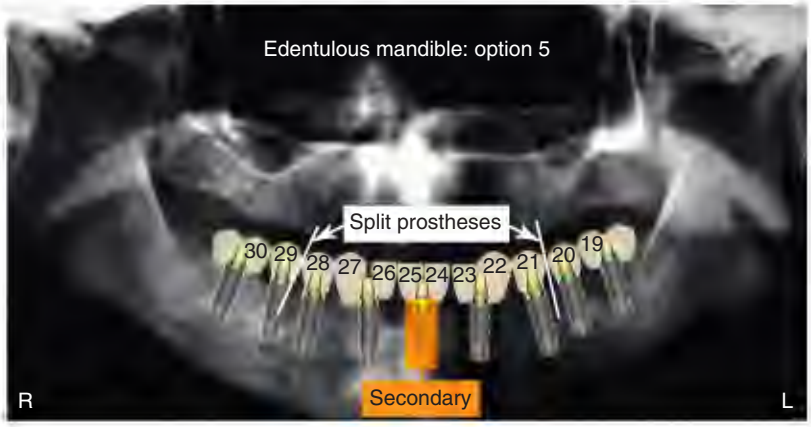


FIGURE 24-31. Treatment option 5 is designed to support three independent prostheses. The key implant positions are usually first molar sites, second premolar sites, first premolar sites, and canine positions. The posterior restorations are usually separated between two premolar sites. This option provides maximum flexure and torsion to the mandibular body during function and parafunction. Note the extreme force factors and the secondary implant site C.

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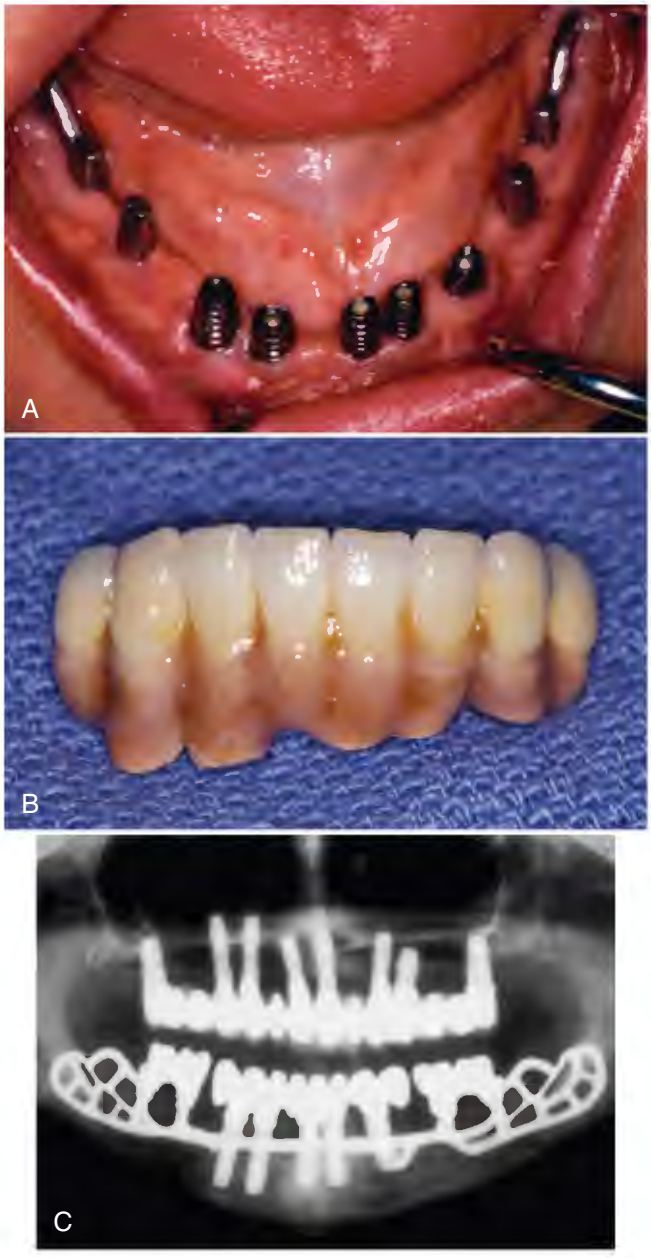


FIGURE 24-33. **A,** An intraoral view of five root form implants positioned between the mental foramina. The posterior quadrants have a subperiosteal implant. This female patient desired maxillary and mandibular fixed prostheses but declined an iliac crest bone graft to the posterior mandible. **B,** The anterior fixed prosthesis is independent of the posterior restorations. This allows maximum flexure of the mandible. This fifth option is more indicated for division C–h bone volume mandibles than division A mandibles. **C,** A panoramic radiograph of the final restorations and implants. The three independent mandibular prostheses permit flexure of the posterior mandible.

similar to a completely implant-supported overdenture. The number and position of implants should be related to the amount of stress transmitted to the bone during occlusion and parafunction and the density of the bone. Other considerations include mandibular flexure and torsion. Five treatment options generally are available for a fixed complete mandibular implant-supported restoration. The primary advantage of treatment option 1 with five anterior implants is cost. Disadvantages include overload situations resulting from bilateral cantilevers. Treatment option 2 is an improved support system, but bilateral cantilevers (which are shorter than option 1) are still a concern. Treatment option 3 is superior to the previous two options but requires posterior bone in one quadrant to place endosteal, subperiosteal, or disk-design implants. The most ideal treatments are options 4 or 5 because they lack cantilevers, and the dentist fabricates two or three separate restorations. These treatment options also accommodate the stronger mandibular bone dynamics without affecting the restoration. However, bilateral posterior bone must be present or obtained through grafting for endosteal implants, or a circumferential subperiosteal or disk-design implant must be used for support in posterior quadrant(s).

Options 4 and 5 increase overhead costs because more implants are used for support of the fixed restoration. However, the fee given to the patient may be similar for all of these options because the time and laboratory fees are similar. The few hundred dollars in additional implant costs to the doctor for options 3 to 5 usually does not warrant a fee increase of several thousand dollars because little additional surgical time is required to place the additional implants.

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CHAPTER 25

Maxillary Arch Implant Considerations: Treatment Plans for Partial and Complete Edentulous Fixed and Overdenture Prostheses

Carl E. Misch

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More than 18 million people in the United States, or 10.5% of the adult population, are completely edentulous.[1] Maxillary dentures usually are tolerated better by patients than their mandibular complete denture. As such, many treatment plans initially concentrate on the problems associated with the mandibular prosthesis (Figure 25-1). However, after the patient obtains an implant prosthesis in the mandible that is a stable and retentive (and perhaps a fixed mandibular prosthesis), often the patient's attention is brought to the inadequacies of the maxillary restoration.

In addition to the edentulous segment of the population without any teeth, 7% of the employed adult population wears a maxillary denture opposing some remaining mandibular teeth.[2] These people routinely have more problems with their upper denture because their opposing arch is fixed and the plane of occlusion is often compromised. This means a total of 17% of the U.S. adult population (30 million people) have no natural maxillary teeth.

The first chapter of this book addressed the esthetic and psychological consequences of the loss of maxillary teeth. After patients become aware of the anatomical and esthetic consequences of multiple missing anterior teeth (as a result of continued bone loss), there is an increased desire for implant restorations. In addition, traditional fixed or removable prostheses accelerate the loss of additional teeth. As a result of continued patient and doctor education related to the consequences of the loss of several adjacent teeth, implant restoration of the edentulous maxilla will become even more prevalent in the future.

Partially edentulous patients missing multiple maxillary anterior teeth are not unusual. Failed fixed partial dentures (FPDs) often result in additional tooth loss. Car accidents and other sources of trauma also result in multiple anterior teeth missing (Figure 25-2). Less often are the effects of periodontal disease affecting only anterior teeth. Most of the partially edentulous patients prefer a fixed prosthesis to restore their dentition. There are many advantages to restore missing teeth with a fixed implant restoration, independent from the remaining natural teeth.

Edentulous Anterior Maxilla

Treatment Limitations

In a 20-year review of the literature compiled by Goodacre et al., restorations associated with the edentulous maxilla have the highest early loading implant failure rate compared with any



FIGURE 25-1. Implant treatment plans for the completely edentulous patient often address the mandible because it is the least stable unit. The maxilla is often restored with a traditional denture. This patient has a maxillary denture opposing a mandibular fixed implant supported prosthesis.



FIGURE 25-2. Multiple adjacent anterior teeth may be lost from trauma and less likely from periodontal disease.

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other dental prostheses.[3] For example, overdentures in the maxillary arch averaged 19% implant failure, and complete arch fixed prostheses in the edentulous maxilla have an early implant failure of 10%. In comparison, mandibular overdentures and partial or mandibular full-arch fixed restorations demonstrated a 3% implant failure rate. When 10% to 20% of implants fail in an edentulous maxillary prosthesis, the number of restorations affected may be more than half of the patients. For example, if four implants are used to support a prosthesis (fixed or removable) and 25% of the implants fail (one per patient), all of the final restorations would be affected because three remaining implants cannot predictably support a maxillary full-arch restoration.

Anatomic Limitations

Several factors affect the condition of the edentulous maxilla and may result in a decrease in implant survival or an increase in prosthetic complications. The facial cortical plate of the premaxilla is thin over the roots of the teeth and may be resorbed from periodontal disease or is often fractured during the extraction of these teeth (Figure 25-3). In addition, the facial cortical plate rapidly resorbs during initial bone remodeling, and the anterior ridge loses more than 25% of its width within the first year after tooth loss and 40% to 50% over 1 year, mostly at the expense of the labial plate. As a result, the residual available bone migrates to a more palatal position.[4–7]

The patient is more likely to wear and functionally accommodate to a maxillary complete denture compared with its mandibular counterpart. The greater retention, support, and stability compared with the lower denture are well documented. As such, the patient often is able to wear the maxillary removable prosthesis for many years before complications arise. During this time, from a patient's perspective, the need to replace the maxillary denture is more related to a desire to improve esthetics or for a fixed restoration as the motivating factor. By the time the patient notices problems of stability and retention caused by resorption of the premaxilla, the maxillary bone often has advanced atrophy and may be division C–h or D in volume (Figure 25-4). Therefore, unlike the anterior mandible (in which denture complications occur before advanced bone atrophy), in the completely edentulous maxilla, the anterior bony ridge is often inadequate for ideal endosteal implant insertion even though few denture complications exist. It is the doctor's responsibility to inform the patient about the continued bone loss in the maxilla before complications arise.

To achieve predictable esthetics for a maxillary anterior or full-arch fixed prosthesis, the hard and soft tissue, volume, and character should be adequate in most aspects. Available bone should be evaluated closely for implant insertion in esthetic regions because of its influence on the soft tissue drape, implant size, implant insertion (angulation and depth), and the final prosthetic result. Bone loss after maxillary anterior tooth loss is rapid and has considerable consequences. Therefore, most multiple maxillary anterior edentulous sites in the esthetic zone require at least some bone and soft tissue augmentation before or during implant insertion and/or at implant uncovery.

As the bone resorbs from division B to C–w in the anterior edentulous mandible, the cross-section of the residual ridge is triangular (with a wide base). As a consequence, an osteoplasty removes the narrower crestal bone and the residual ridge becomes wider, often converted to a division A bone volume. In the maxilla, however, the division B to C–w crest often remains narrow almost to the floor of the nose. An osteoplasty to gain bone width results in a division C–h to D ridge (Figure 25-5). The implant dentist often has difficulty inserting implants in the correct position when augmentation does not restore the region prior to implant insertion (Figure 25-6). Therefore, bone augmentation is more often required to increase



FIGURE 25-4. The patient may not complain about a maxillary complete denture until advanced bone atrophy has occurred.



FIGURE 25-3. The bone in the edentulous anterior maxilla often is narrow because the labial plate is thin over the roots and often fractures during extractions or resorbs soon after tooth loss.



FIGURE 25-5. The anatomy of the edentulous premaxilla is often not conducive to osteoplasty procedures to gain ridge width because the opposing plates of bone are often parallel to each other.

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FIGURE 25-6. Ideal implant placement in the premaxilla is often more difficult than other regions of the mouth because the bone is often narrower than most other regions of the mouth.

BOX 25-1 Premaxilla Compromised Biomechanical Conditions

- Narrow ridge is common in anterior maxilla and often uses narrow implants. Ridges reduced in height use shorter implants
- Esthetics require facial cantilevers
- Oblique centric contacts against a thinner cortical plate
- Increased moment loads with lateral forces during mandibular excursions
- Direction of force in excursion is outward
- Reduced trabecular bone density
- Absence of thick cortical plate
- Crown height space often greater than ideal
- Maxillary arch opposing teeth or implant restoration in the mandible

bone width in the anterior maxilla compared with the anterior mandible.

In general, the premaxilla requires the most varied surgical approaches to improve success and is the most critical region for esthetics and phonetics. Initially, the anterior maxilla has less bone height than the anterior mandible and may compose only one third of the vertical dimension. Bone grafting is much more predictable for width gains rather than increases in height. Surgical options for division B and C–w bone more often require bone augmentation rather than osteoplasty, as often advocated in the mandibular anterior region. Division B bone grafting may use a synthetic bone component for the graft; division C–w often requires at least some autologous bone as a donor.

In some C–h premaxillae, implants may be inserted for a fixed prosthesis FP-3 or overdenture prosthesis. It should be noted that the opposing landmark is the floor of the nose, and this structure may be modified slightly by nasal elevation of 1 to 2 mm to improve implant support. However, when the premaxilla is less than 7 mm in height and when a D edentulous maxilla is present, this condition requires height augmentation before implant insertion. As a result, the dentist often must resort to the iliac crest or other extraoral donor sites for large volumes of bone. As such, the maxillary completely edentulous patient should understand that the surgical rehabilitation is much more complex and extensive because the volume of bone needed to reconstruct the atrophic maxilla increases. Therefore, notifying patients of their continued maxillary bone loss is even more important than in the anterior mandible rather than waiting until problems with their removable restoration develop.

Biomechanical Limitations

From a biomechanical perspective, the implant-restored anterior maxilla is often the weakest region of the mouth compared with other sections of the mouth. Compromised biomechanical conditions and their consequences include the following (Box 25-1):

1. Narrow ridges form soon after tooth extractions. Bone augmentation is often necessary and may mandate the need for smaller diameter implants. Their use results in increased stress concentrations in the implant and contiguous interfacial tissues, particularly at the crestal region.
2. In the premaxilla, esthetics and phonetics dictate that the replacement teeth be placed at or near their original position. The teeth are often cantilevered from the implants and the residual ridge, which usually is resorbed palatally and superiorly. The use of facial cantilevers results in increased moment loads at the implant crest and often leads to localized crestal remodeling bone loss and soft tissue recession. The cantilevered forces are also applied to the cement or screw that retains the restoration and the abutment screws that connect the implant components. This increases the risk of partially unretained restorations (Figure 25-7).

   The farther forward the maxillary anterior crowns are positioned from the implants, the greater the moment force leverage on the implants, bone–implant interface, abutment screws, and prosthetic components. Yet many dentists attempt to do plastic surgery with plastic, hoping to eliminate vertical lines in the lip by bulking out the labial flange of an overdenture and positioning the teeth farther forward than the natural tooth position. Patients who desire to eliminate wrinkles in the lips from bone loss should have plastic surgery and bone augmentation, not the teeth positioned more labially for the maxillary prosthesis.

   The facial position of the lip relative to esthetics is an important criterion to evaluate at the onset of treatment before the placement of the implants. This is even more important when the patient desires a fixed prosthesis. Bone and soft tissue augmentation is usually required to restore the natural appearance of the face without the help of a labial denture flange when a fixed restoration is planned. This criterion alone may indicate an overdenture rather than a fixed prosthesis or an onlay graft to position the implants more labial.
3. The arc of closure of the mandible is anterior to the maxillary residual ridge and is usually at an angle of 15 degrees or more. An angled load to an implant crown increases the force by 25.9% when it is 15 degrees off axis. As a consequence, the moment force is greater against the maxillary anterior crowns supported by implants compared with any other position in the mouth. Oblique centric contacts result in potentially harmful, off-axis load components. The force is also directed against the thinner facial bone (Figure 25-8).
4. All mandibular excursions place lateral forces on the maxillary anterior teeth, with resulting increased stress on the implant system, including the prosthesis and crestal bone of the supporting implants, especially on the labial aspect.

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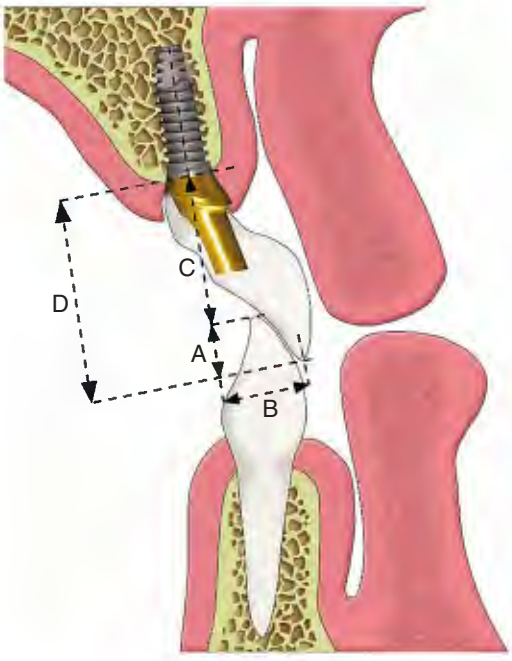


FIGURE 25-7. There are often facial cantilevers on anterior implants (points *A* and *B*). The crown height is also larger than the natural tooth (*C* in centric occlusion and *D* in protrusive).

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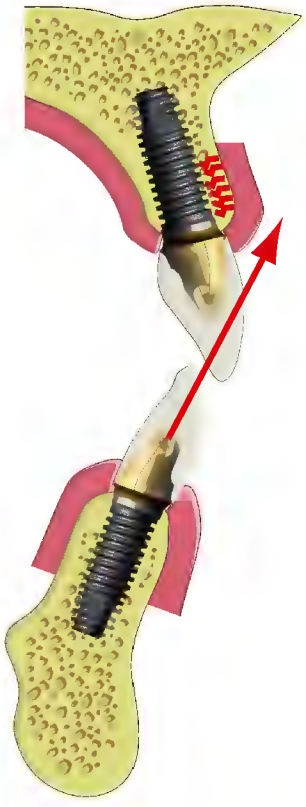


FIGURE 25-8. The arc of mandibular closure is anterior to the maxillary ridge; as a result, increased forces of the maxilla are applied to the thinner facial cortical plate.

These lateral loads in excursion further increase the moment loads applied to the implant system (Figure 25-9).

5. A mandibular arch receives a load from the outside of the arch toward the center. An arch is constructed for this force direction. A maxillary arch receives a force from within the arch to the outside of the structure, especially in mandibular excursions. An arch is not as effective to resist this type of force (Figure 25-10).
6. In most patients with available bone, the bone is less dense in the anterior maxilla than in the anterior mandible, where a dense cortical layer surrounds coarse trabeculae of adequate bone strength to provide implant support. In contrast, the maxilla presents thin porous bone on the labial aspect, very thin porous cortical bone on the floor of the nasal and sinus region, and more dense cortical bone on the palatal aspect.[8,9] The trabecular bone of the maxilla is usually fine and is less dense than the anterior region of the mandible. The trabecular bone of D3, often found in the maxilla, is 45% to 65% weaker than the trabecular bone of D2, usually found in the anterior mandible.[10] Reduced trabecular bone density of the maxilla results in compromised bone strength and a weaker implant–bone interface.
7. Absence of thick cortical plate at the crest of the premaxilla results in loss of high-strength implant support and less resistance to angled loads.
8. Crown height space (CHS) is often greater than ideal and is a force magnifier to any angled or cantilevered force. An increase in crown height further magnifies the effect of the anterior cantilever.
9. Whereas the maxillary arch restored with implants almost always opposes a fixed dentition or implant prosthesis, many



FIGURE 25-9. Mandibular excursions place lateral forces on maxillary anterior implants, which increase the resultant stresses.

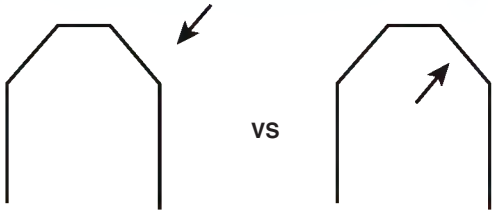


FIGURE 25-10. During function, the forces from the maxilla are directed against and within the mandibular arch form, which is designed to reduce stresses *(left)*. In the maxilla, forces from the mandible are directed outside the arch form *(right)*. An arch is much less effective against outward forces than inward forces.

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mandibular implant prostheses oppose a complete maxillary denture. As such, the bite forces and parafunction are more often contributory to complications with the maxillary implant prostheses and implants.

As a consequence of these biomechanical factors, not only is implant failure more common, but prosthetic complications are also more often found in maxillary restorations.

Treatment Options

The treatment options for the restoration of a complete or partially edentulous patient with multiple maxillary anterior teeth missing include a removable partial or complete denture, an implant-supported overdenture, or an implant-supported fixed prosthesis. Most traditional maxillary dentures have adequate retention, stability, and function, and soft tissue sore spots are rarely a problem. Therefore, less benefit is perceived with an implant overdenture (IOD) compared with the situation in an edentulous mandible.

A major disadvantage of a maxillary complete denture is most often the psychological aspect of removable teeth, especially when the mandibular arch is natural teeth or a fixed prosthesis. In contrast, a fixed prosthesis presents significant benefits for maxillary denture patients. In fact, after 3 years of function, most patients feel the maxillary fixed prosthesis is as good as or better than their natural teeth. On the other hand, an IOD is always considered by the patient as a removable prosthesis.

An independent, fixed implant-supported restoration has become the treatment of choice for most patients with complete or partial edentulism. A fixed prosthesis presents several advantages over a removable partial denture or an overdenture for a maxillary edentulous patient. However, when one or two canine teeth or implants are missing in addition to two or more adjacent teeth, it is contraindicated for a fixed prosthesis, regardless of how many teeth (or implants) are splinted together, unless two or more implants are used to replace the teeth[11,12] (Figure 25-11). Additional contraindications for a FPD include long edentulous spans, poor abutment support, and inadequate edentulous bone for proper prosthetic contour.

The primary reason for a conventional maxillary removable denture is economic reasons or because a patient is unwilling to undergo bone grafting or implant surgery. However, the easiest interim treatment prosthesis for the replacement of several anterior teeth during implant-submerged healing is a removable restoration. If bone augmentation is necessary, this prosthesis may need to be used for longer than 1 year before delivery of the final implant restoration.

Sequence of Treatment Planning

Maxillary Labial Lip Position

The maxillary anterior region with multiple adjacent teeth missing often is restored with an overdenture or a fixed restoration that replaces teeth and the soft tissue drape (FP-3 prosthesis) (Figure 25-12). Whether a denture, an overdenture, or a fixed prosthesis is being fabricated, a full-arch or anterior edentulous maxillary reconstruction begins with the determination of the facial position of the maxillary incisal edge. Its modification at a later step may alter all other determinants of a reconstruction. A baseplate and wax rim (or the patient's existing denture) may determine the facial support necessary for the labial contour of the maxillary lip. Most often the facial surfaces of the central incisors are 12.5 mm from the most posterior aspect of the incisive papilla.[13,14] The wax rim is initially positioned with this in mind. The farther forward the labial flange and teeth position, the higher the resting position of the lip and the greater the incisal edge exposure. The philtrum of the lip should have a visible depression in the midline under the nose. If the philtrum is too flat, the lip is extended too far, and wax should be removed from the labial aspect of the wax rim.

The position of the maxillary lip also may be determined by the position of the lower lip and chin with the face at the proper vertical dimension. A horizontal line, represented by the Frankfort plane, may be drawn from the highest point of the auditory meatus (top of the tragus) to the lowest point on the margin of the orbit, with the patient's head in a vertical position. Ideally, a vertical perpendicular line drawn from the Frankfort plane to the lower lip should have the maxillary lip anterior to this landmark 1 to 2 mm and the chin 2 mm posterior to this line[15] (Figure 25-13).

The labial position of the lip in relationship to the premaxillary bone is the primary criterion to determine whether a fixed restoration, a bone graft and fixed restoration, or a maxillary overdenture is indicated. When the labial position of the wax rim is forward of the residual ridge more than 5 mm, a bone graft before implants or a hydroxylapatite graft on the labial plate is required to support the lip for a fixed restoration,

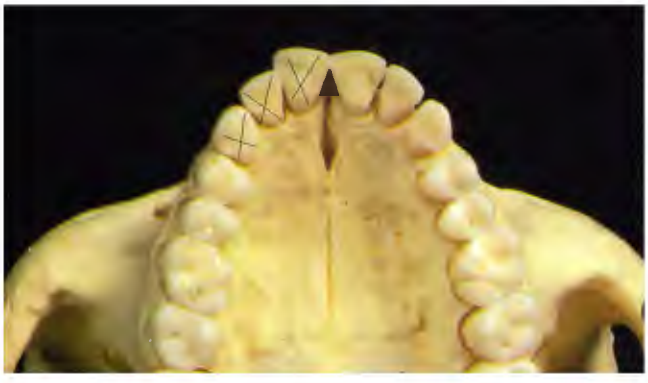


FIGURE 25-11. When the patient is missing a canine and two adjacent teeth, it is contraindicated for a fixed prosthesis unless two implants (or more) are used to replace the teeth.



FIGURE 25-12. A fixed prosthesis to replace multiple adjacent maxillary anterior teeth most often also replaces the soft tissue drape with the restoration (a FP-3 prosthesis).

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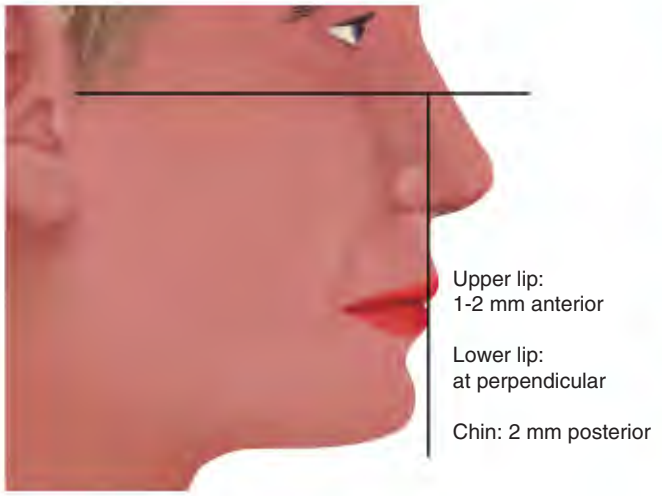


FIGURE 25-13. A perpendicular line to the Frankfort plane at the position of the lower lip should be 1 to 2 mm behind the upper lip and 2 mm in front of the chin.

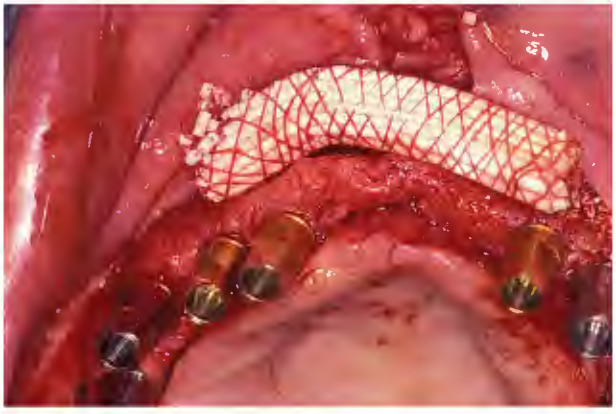


FIGURE 25-14. When the labial position of the teeth needed to support the upper lip is more than 5 mm anterior to the residual ridge, a bone graft or hydroxyapatite graft on the facial of the residual ridge is required to support the upper lip for a fixed prosthesis. Another method to support the maxillary lip is an implant overdenture with a labial flange.

or a maxillary overdenture with a labial flange is considered (Figure 25-14).

Key Implant Positions

After the prosthesis type and labial tooth position are determined, the key implant positions are then determined for the maxillary restoration.[16,17] An important parameter in treatment planning is to provide adequate biomechanical position and surface area of support for the load transmitted to the prosthesis. Four guidelines are presented in Chapter 9 for key implant positions in an implant prosthesis. For the edentulous maxilla, these four guidelines may be slightly modified and summarized as no posterior cantilever, no posterior three adjacent pontics, the canine rule, and the first molar sites.

In addition to these four key implant position guidelines, the complete edentulous maxilla should further reduce the increased biomechanical risks by adding a fifth guideline, the five-sided arch[12] (Box 25-2).



FIGURE 25-15. This maxillary restoration had anterior teeth cantilevered from the anterior implants and posterior teeth cantilevered from the posterior implants. Because the maxilla is at an increased biomechanical risk compared with the mandible, the posterior cantilever should usually be eliminated by placing implants in the molar region.

BOX 25-2 Key Implant Positions: Edentulous Maxilla

1. No cantilever
2. No posterior three adjacent pontics
3. Canine rule
4. First molar site
5. Five-sided arch

Guideline 1: No Posterior Cantilever

The premaxillary teeth may be cantilevered forward from the implants for esthetics and phonetics. Hence, it is more important to place posterior implants connected to anterior implants to increase the anterior-posterior (A-P) distance and counter this affect. There should be little to no posterior cantilever in a complete edentulous maxilla (Figure 25-15).

Guideline 2: No Posterior Three Adjacent Pontics

When the posterior teeth are included in a prosthesis, there should not be three (or more) adjacent pontics.[11] Under those conditions, the adjacent abutments must support five or more adjacent teeth, the amount of the force is greater in the posterior regions, and the metal of the restoration flexes 27 times more than a one pontic prosthesis. In addition, the bone density to support the implants is often less in the posterior maxilla, hence the strength of the bone is reduced (Figure 25-16). This further increases the overload risk to the implants.

When all six anterior teeth are missing, at least one implant should usually be positioned between the canine implants in the maxillary arch. However, the "no three pontic" rule may be modified in the front of the mouth because the force is less in the anterior region compared with the posterior region In addition, a lateral incisor is the smallest maxillary tooth, so the length of the span is reduced (compared with the posterior regions).

Guideline 3: The Canine Sites

A fixed prosthesis replacing a canine tooth is at greater risk than almost any other tooth in the mouth. The adjacent maxillary

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FIGURE 25-16. When three or more adjacent pontics are used in a prosthesis, the adjacent abutments are bearing the load of five or more teeth. The maxillary posterior bone is usually weaker than any other region, which further increases the overload risk to the implants.



FIGURE 25-17. A patient missing a canine, lateral, and central incisor requires at least two implants to restore these teeth.



FIGURE 25-18. A patient missing a second premolar, first premolar, and canine requires at least two implants to restore these three missing teeth.

lateral incisor is the weakest anterior tooth, and the first premolar is often the weakest posterior tooth. A traditional prosthodontic axiom indicates that a fixed prosthesis is contraindicated when a canine and two or more adjacent teeth are missing.[11] Therefore, if a patient desires a fixed restoration, implants are required whenever the following adjacent teeth are missing: (1) the first premolar, canine, and lateral incisor; (2) the canine, lateral incisor, and central incisor (Figure 25-17); and (3) the canine, first premolar, and second premolar (Figure 25-18).

When any of these three missing teeth combinations are present, a fixed restoration is contraindicated because of the length of the span (three pontics), the amount of force on the abutments (forces greater in the canine region compared with the anterior and the force on the abutments includes the three missing teeth), the direction of the force on the abutments (angled forces to the canine region), the proprioawareness of the canine site, and the need to establish posterior disocclusion of the teeth in excursions (Box 25-3).

BOX 25-3 Canine and Two Adjacent Teeth Missing (Contraindicated for Fixed Partial Dentures)

1. Length of span (three teeth)
2. Amount of force (canine and posterior teeth have greater force than anterior teeth)
3. Direction of force (nonaxial load with mandibular teeth in centric and excursions)
4. Proprioawareness of canine is missing
5. Anterior guidance to disclude posterior teeth is necessary in implant restoration.

A tooth-supported prosthesis is less at biomechanical risk than an implant-supported restoration when the canine and two adjacent teeth are missing. Teeth are more mobile than implants; therefore, the stress relief mechanism of the periodontal–ligament complex reduces the flexure, force, and effect of an angled force. Despite this, it is contraindicated for patients with natural teeth to use three pontics in a fixed prosthesis whenever the natural canine and two adjacent teeth are missing. Therefore, under these conditions with implant treatment plans, at least two implants are indicated to support an independent fixed restoration (usually in the terminal positions of the span to eliminate cantilever forces) (Figure 25-19).

Using the missing canine and two adjacent natural teeth guideline, a fixed prosthesis is obviously contraindicated when either (or both) canine(s) and anterior four incisors are missing. For example, when a right canine, right lateral incisor, right central incisor, left central incisor, left lateral incisor, and left canine are missing, the condition is contraindicated for a fixed restoration. Yet in some underengineered treatment plans, implants are placed in each posterior maxillary quadrant, and a fixed restoration with five or six pontics is fabricated to replace the anterior teeth (Figure 25-20). The anterior cantilever from the first premolar sites in this treatment option is more detrimental than a posterior cantilever because of all of the biomechanical issues of the premaxilla. Apparently, the rationale for violating the prosthetic guidelines established in the literature for teeth are the following:

1. To augment a complete premaxilla, autologous bone grafts are often necessary, but synthetic materials can be used to predictably graft in the posterior maxillary sinus. The large volumes of autograft required for the complete premaxilla may require advanced bone graft procedures (which patients do not want, and few doctors are properly trained for) (Figure 25-21).

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FIGURE 25-19. **A,** The patient is missing the canine, first premolar, and second premolar. An implant was inserted in the terminal tooth positions. **B,** A three-unit FPD is cemented to the two implant abutments.



FIGURE 25-20. **A,** A panoramic radiograph of a fixed prosthesis with five adjacent pontics, including a canine. This prosthesis is undersupported, especially because it opposes natural dentition in a younger patient. **B,** It is contraindicated to replace three adjacent teeth, which include a canine. This implant prosthesis has at least five adjacent pontics that include a canine.

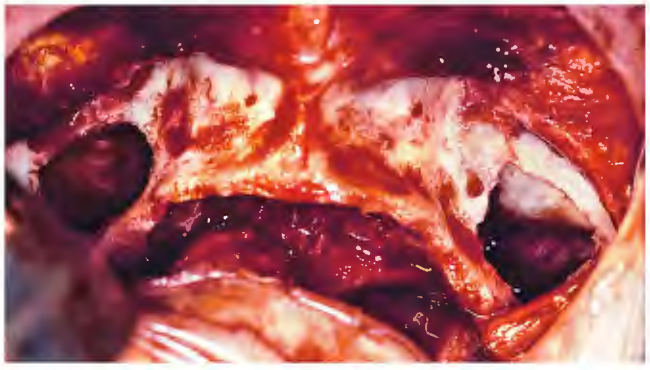


FIGURE 25-21. The maxillary edentulous arch with both lateral walls of the maxilla rotated medially for sinus grafts with allogenic or synthetic grafting material. Similar graft materials used in the premaxilla are not as predictable to gain bone height and width.

2. The impression is that implants are more rigid and therefore stronger than natural roots. However, this is false security. The fact that implants are more rigid than teeth makes the three or more adjacent pontics and canine position guidelines more important to follow when the abutments are implants. The rigid abutments magnify the problem of flexibility of the metal and the direction of force applied to the prosthesis. Therefore, the canine is an especially important implant site when the anterior six teeth are missing. When available bone is not present, a bone graft in the canine position is indicated before implant insertion, or an implant in both the lateral incisor and first premolar site is indicated to compensate for the missing canine.

Guideline 4: The First Molar Site

The first molar is an important abutment position in an edentulous maxilla. The bite force in this region increases to 200 lb compared with half this amount in the premolar sites. As a consequence, the first molar natural tooth surface area is more than two times greater than the premolars. In addition, the bone density in the molar region is often poorer than the premolar regions of the jaws. As a result, larger diameter implants or more implants are suggested, not a cantilevered force applied in the molar regions.

An anatomical problem for implant treatment in the posterior maxilla is the rapid expansion of the maxillary sinus after tooth loss. As a result, the edentulous posterior maxilla rarely has enough bone height without sinus grafting. Therefore, a treatment option to cantilever the posterior missing teeth from anterior implants is used to eliminate sinus grafting. Posterior cantilevers from anterior maxillary implants are less predictable than cantilevers from anterior mandibular implants for all the reasons addressed previously in this chapter. In addition, when first molar implants are not present, the A-P distance of the splinted implants is reduced, and the anterior cantilever from

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the most anterior implants is more of a biomechanical risk (Figure 25-22). Instead of a posterior cantilever, sinus grafting and larger diameter implants (or two smaller diameter implants instead of one larger diameter) are indicated in the first molar region and render improved overall implant success rates and, as important, fewer prosthetic-related complications.

Guideline 5: Five-Sided Arch

The dental arch may be divided into five different components related to their direction of movement (Figure 25-23). The posterior regions (first premolar, second premolar, first and second molars) each move in lateral directions to the midline. The canine positions move in two different oblique directions, and the anterior teeth (laterals and central incisors) move in an A-P direction. When three or more different components of an arch are splinted together, the different force directions are blended together, and the splint has less movement. In addition, when the three or more sections are splinted together, an A-P dimension is present, which also resists lateral forces. The more sections of the arch splinted together, the greater the A-P distance and the more resistant the splint is to any lateral force or cantilever.

In the maxilla, most often at least one implant should be placed in each of the five sections missing teeth and then splinted together when replacing multiple adjacent teeth. This means at least three implants usually are required to replace the anterior six teeth in the premaxilla: one in each canine position and one in any of the four incisor positions[16,17] (Figure 25-24). Previous studies by Bidez and Misch have shown that the force distributed over three abutments results in less localized stress to the crestal bone than two abutments.[17,18] When these three implants are splinted around an arch, connecting at least three segments creates a tripod effect and provides an A-P distance (A-P spread) with mechanical properties superior to a straight line and with greater resistance to lateral forces.

When anterior and posterior teeth are missing, additional posterior implants are usually required (Figure 25-25). Because the premaxillary prosthesis has many biomechanical conditions that increase forces (both in centric and excursions), it may be considered a cantilever from the implant support system. When the implants in all five sections are splinted together, they act as one side of the class I lever with the most anterior implants in the position of the fulcrum, and the incisal edge of the prosthesis as the cantilever length of the lever. The A-P distance of the implants for the anterior cantilever in the premaxillary restoration corresponds to the distance between the center of the most distal implants on each side (in the splint) and the anterior aspect of the most anterior implant. Hence, an implant in the most distal missing tooth position greatly improves the A-P spread and reduces the forces of the premaxilla to the implant system (Figure 25-26).



FIGURE 25-22. A fixed prosthesis with anterior and posterior cantilevers. An implant in the first molar position would eliminate the posterior bite force on a cantilever and increase the anteroposterior distance between implants to counter the effect of an anterior cantilever.



FIGURE 25-23. The maxillary arch may be treated as an open pentagon, with five straight-line segments. When teeth are missing in multiple segments, at least one implant is required in each section.



FIGURE 25-24. A panoramic radiograph with six maxillary anterior teeth missing. Three implants are indicated, one in each section of the five-sided pentagon missing teeth.

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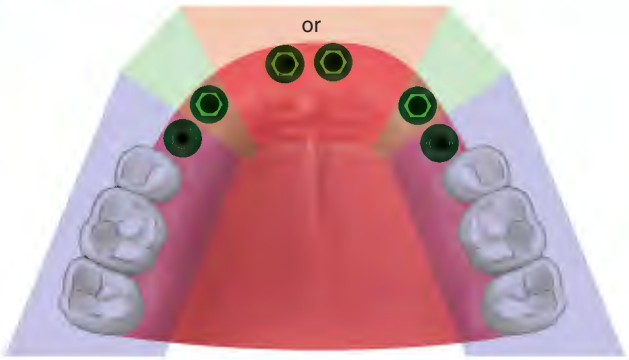


FIGURE 25-25. When eight anterior teeth (first premolar to first premolar) are missing, implants should be placed in each segment of the five-sided arch to provide adequate support. Therefore, at least five implants are ideally indicated.

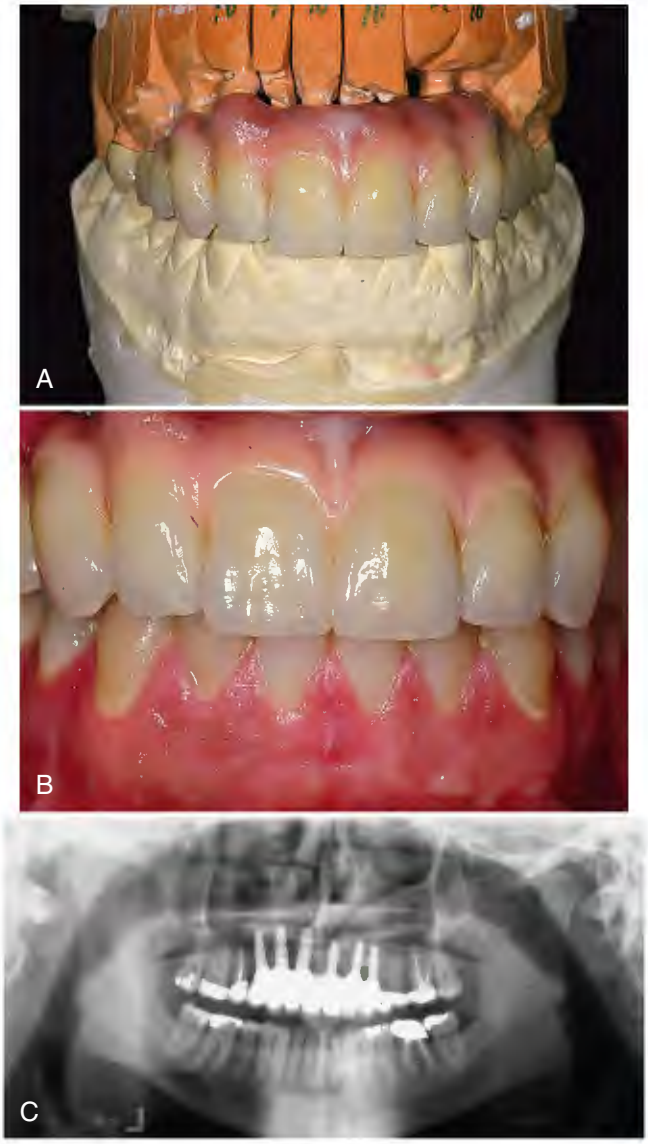


FIGURE 25-26. **A,** The dentate arch form may be different than the residual bone form as the ridge resorbs apically and away from the original tooth position. In such cases, the prosthesis is designed to restore the proper tooth contour and lip support. **B,** The fixed FP-3 prosthesis replaces eight adjacent anterior teeth and is supported by six implants. **C,** Panoramic radiograph of the same patient.

Premaxilla Arch Form

The arch form of the maxilla influences the fixed prosthesis treatment plan of the edentulous premaxilla. Three typical dentate arch forms for the maxilla are square, ovoid, and tapering. The dental arch form of the patient is determined by the final teeth position in the premaxilla and not the arch shape of the residual ridge. There are also three edentulous bone arch forms. As a consequence of bone resorption, the edentulous ridge arch form may be different from the dentate arch form. A residual ridge may appear square because of resorption or trauma. However, the final teeth position may need to be cantilevered facially with the final prosthesis. In other words, a dental ovoid or tapering arch form may be needed to restore a residual edentulous square arch form (Figure 25-27). The number and position of implants are related to the arch form of the final dentition (restoration), not only the existing edentulous arch form.

The dental arch form in the anterior maxilla is determined by the distance from two horizontal lines. The first line is drawn from one canine incisal edge tip to the other. This line most often bisects the incisive papilla regardless of the dentate arch form.[13,14] The second line is drawn parallel to the first line along the facial position of the anterior teeth[16] (Figure 25-28). When the distance between these two lines is less than 8 mm, a square dental arch form is present. When the distance between these two lines is 8 to 12 mm, an ovoid dentate arch form is present—the most commonly observed. When the distance between the two horizontal lines is greater than 12 mm, the dentate arch form is tapering[12,17] (Table 25-1).

In a dental square arch form, lateral and central incisors are not cantilevered very much facially from the canine position. Therefore, mandibular excursions and occlusal forces exert less stress on the canine implants. As a result, implants in the canine position to replace the six anterior teeth may suffice when the force factors are low (parafunction, masticatory dynamics, CHS) and if they are splinted to additional posterior implants (Figure 25-29). The four pontics between the canines may counter rule 2 of key implant positions (no three adjacent



FIGURE 25-27. The residual ridge form is square, and the dentate arch form is tapered. As a result, the anterior teeth are cantilevered from the implants. Because posterior implants were not used to replace the posterior teeth, they are also cantilevered in the restoration. The reduced anteroposterior distance makes this restoration more at risk of biomechanical complications.

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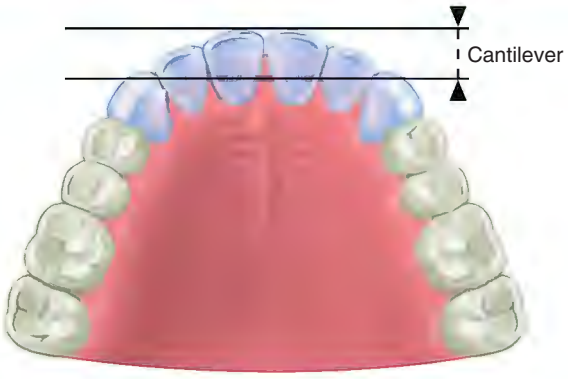


FIGURE 25-28. Two horizontal lines are drawn. The first line bisects the incisive papilla and connects the tips of the canines. The second line is parallel and along the facial position of the central incisor. The distance between these lines determines whether the dentate arch form is square, ovoid, or tapering.

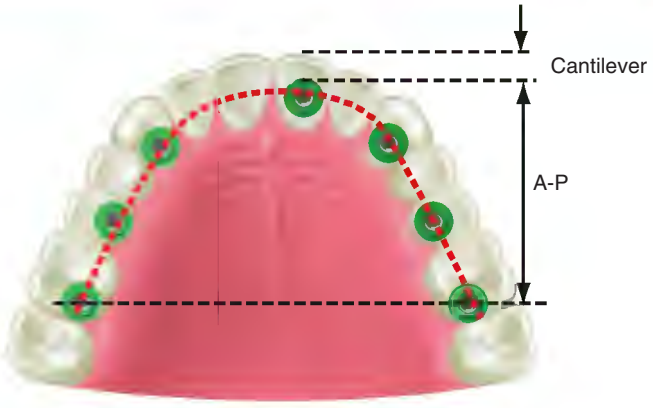


FIGURE 25-30. In an ovoid dentate arch form, three implants should be planned in the premaxilla, one in each canine position and one additional anterior implant. In addition, at least four posterior implants should be splinted to form an arch in an edentulous maxilla. *A-P,* Anteroposterior distance.

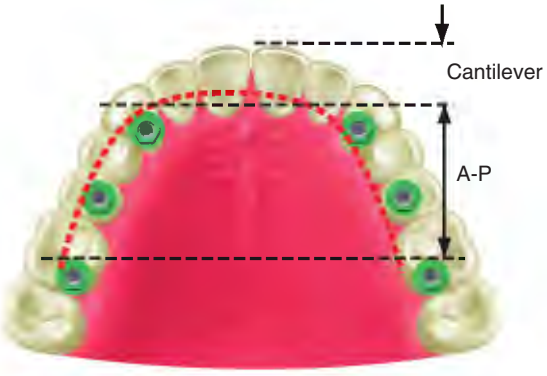


FIGURE 25-29. When force factors are low, a square dentate arch form may use two implants in the canine positions when additional implants are used in the posterior regions. A total of six implants for a fixed or RP-4 prosthesis may be used in an edentulous square dentate maxilla. *A-P,* Anteroposterior distance.

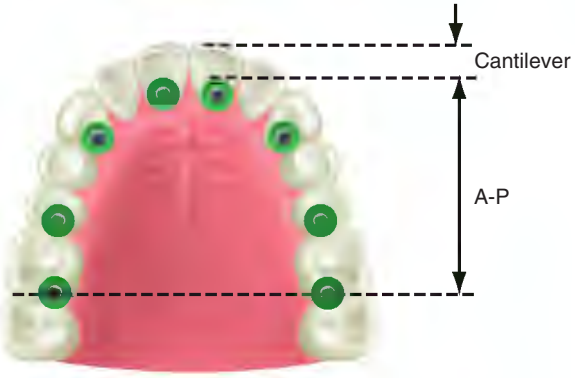


FIGURE 25-31. In a tapered arch form, the anterior cantilever is greater and should be supported by more implants in the premaxilla. At least four posterior implants should also be added to restore the completely edentulous arch. *A-P,* Anteroposterior distance.

TABLE 25-1
Treatment Plan for Edentulous Premaxilla

Arch Form	Anterior Cantilever (mm)	Number of Implants	Implant Position
Square	<8	Two	Canines
Ovoid	8–12	Three	Two canines and one incisor
Tapering	>12	Four	Two canines and two incisors

pontics) because (1) the forces are lowest in the incisor region and (2) in a dentate square arch form in the maxilla, minimal cantilevers are placed on the canines.

If the final teeth position is an ovoid arch form, at least three implants should be inserted into the premaxilla: one in each canine and one between the canines (preferably one in a central incisor position) (Figure 25-30). The central incisor position increases the A-P distance from the canine to central and provides improved biomechanical support to the prosthesis. In long-term edentulous maxillae, this most likely will require bone augmentation before implant insertion. When patient force factors are low to moderate, the anterior implant may be positioned in a lateral incisor site, when anterior implants are connected to molar implants and the A-P distance is increased. These three anterior implant positions resist the additional forces created in this arch form, enhance prosthesis retention, and reduce the risk of abutment screw loosening.

The restoration of a tapered dental arch form places the greatest forces on anterior implants, especially during mandibular excursions when the residual bone is an ovoid or square ridge form. The anterior teeth create a significant facial cantilever from the canine position. As such, four implants should be considered to replace the six anterior teeth (Figure 25-31). The bilateral canine and central incisor positions represent the best option. These positions are preferred when other force factors are greater, such as CHS, parafunction, and masticatory muscular dynamics. When more than six anterior teeth are missing, additional posterior implants also should be splinted to the anterior segment. The farther posterior the implants are splinted to anterior implants, the greater the A-P distance.

The worst-case scenario for biomechanical complications is a patient requiring restoration of a dental tapered arch form with a square residual ridge form. Not only are four anterior implants then ideally required to compensate for the anterior cantilevered tooth position, but these implants should also be connected to additional posterior implants, preferably to

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include implants as far distal as the second molar sites (Figure 25-32). The second molar implant positions increase the A-P spread to counter the anterior forces (note that the first molar implants are also included).

When one canine region cannot be used to place an implant in the edentulous premaxilla, one implant on each side of the missing canine is suggested to compensate for this vital position (a first premolar and lateral incisor implant). A central incisor implant and canine position in the contralateral section can be splinted to these other two implants to act as abutments for the fixed or overdenture restoration.

When force factors are greater than usual, four implants to replace the anterior six teeth are suggested. The four implants in the premaxilla should be splinted together and share any lateral forces during excursions. In the presence of these greater forces (e.g., moderate to severe bruxism), larger-diameter implants also should be used in the canine positions (which have increased load angulation in excursions and higher bite forces). In other words, in most instances, the completely edentulous anterior maxilla is restored with three or four implants splinted together to replace the anterior six teeth.

Ideally, posterior cantilevers should not be placed on maxillary anterior implants (rule 1 in key implant positions). If posterior teeth also are being replaced in the prosthesis, additional implants are required. Seven to 10 implants often are inserted to restore a completely edentulous maxilla with a fixed prosthesis or a rigid overdenture (RP-4), especially when opposing natural dentition or a fixed restoration.

It should be noted that most full-arch maxillary prostheses are FP-3 fixed restorations or RP-4 overdentures. In either scenario, the mesiodistal implant position does not have to strictly correlate with tooth position. In other words, the faciopalatal position is often more important than the mesiodistal tooth site because the gingival aspect of the restoration separates the clinical crown from the implant site. As such, the implant site is determined more for biomechanics, interimplant spacing, or available bone rather than a strict tooth site position (as in a FP-1 prosthesis). Therefore, when implants are positioned in the canine and lateral incisor position, they can be 3 mm apart (or more) and not compromise the cervical esthetics or hygiene of the restoration.

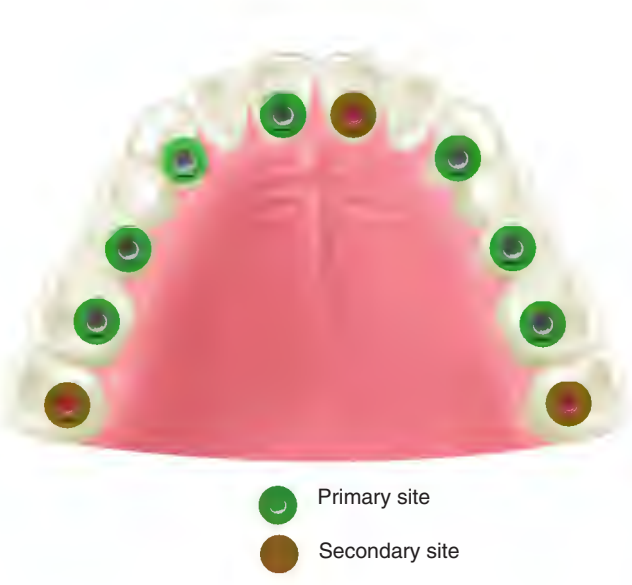


FIGURE 25-32. Moderate force factors usually require four implants in the premaxilla, splinted to additional posterior implants. Implants in the second molar position compensate for an anterior cantilever because the anterior-posterior distance is increased.

Premaxillary Edentulous Treatment Plans

Multiple Adjacent Implant Diameters

A FP-1 implant restoration attempts to restore only the missing tooth crown, so the restoration is similar to a crown on a natural tooth. To do this, the bone and soft tissue drape should be almost ideal. When conditions are within recommended guidelines, the implant diameter may affect the initial and long-term esthetic success of the restoration. Several conditions should be considered for the proper implant diameter, including tooth size, distance from an adjacent tooth, interimplant distance, facial bone dimension, and loading forces.

A primary factor for implant size is the necessary distance from an adjacent tooth root or implant. The horizontal dimension of a wedge-shaped bone defect around an implant at the crest of the ridge from the biological width, implant design, or occlusal overload ranges from 0.5 to 1.4 mm.[19,20] Initial vertical bone loss around an implant during the first year of loading varies and ranges from 0.5 to more than 3 mm. When the implant is closer than 1.5 mm to an adjacent natural root, the wedge-shaped vertical defect may evolve into a horizontal defect, creating bone loss on the adjacent tooth root. This is of importance because the interseptal bone height in part determines the incidence of complete fill or partial fill of the interdental papillae space between the teeth or implants, as well as the incidence of probing depth greater than 5 mm.[19] As a consequence, whenever possible, an implant should be at least 1.5 mm or more from the adjacent teeth (Box 25-4).

When implants are placed adjacent to each other and an ideal soft tissue drape is desired, a minimum distance of 3 mm is suggested to accommodate eventual crestal bone loss and maintain interseptal bone levels.[21] Tarnow et al. have observed that the horizontal dimension of a crestal defect next to an implant measures almost 1.5 mm.[19] As such, if two implants are closer than 3.0 mm, a vertical angular defect on each implant may result in horizontal bone loss between the two implants. This bone loss in turn may favor the proliferation of anaerobic bacteria in the sulcular environment, or the tissues may shrink and compromise the interdental or implant soft tissue contours in a highly esthetic area (Figure 25-33). Degidi and Misch have found the vertical defect width next to an implant may be as small as 0.5 mm rather than 1.3 mm, depending on implant design, and would permit implants to be placed closer together.[21] However, the 3-mm guideline is an ideal safety factor for an interimplant distance. It is also more predictable to form interimplant papilla when 3 mm or more is present between the implants. Although the implant distance may be reduced

BOX 25-4 Multiple Implant Size Selection Criteria for FP-1 Prostheses in the Maxilla

- Natural tooth 2 mm below cementoenamel junction
- 1.5 mm from adjacent tooth
- 1.5 mm facial bone
- 3 mm from adjacent implant
- 3- to 4-mm diameter for anterior maxilla
- 4-mm diameter minimum for posterior maxilla

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FIGURE 25-33. **A,** The adjacent implants are closer than 3 mm to each other. As a consequence, the bone loss on each implant creates a horizontal defect. **B,** The soft tissue drape receded as a result of the horizontal bone loss between the implants.



FIGURE 25-34. **A,** When multiple adjacent implants are used for a FP-1 prosthesis, the diameter should often be reduced so 3 mm of bone exists between the implants. **B,** The final restoration often has a square tooth form and a reduced height of interimplant papilla.

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and bone maintenance is possible, the soft tissue drape is more difficult to form, especially in the interimplant papilla region. When placing two adjacent implants in the esthetic zone, their diameters should often be reduced compared with the ideal dimensions of a single-tooth implant.

The ideal diameter of an implant for a FP-1 prosthesis also should consider the faciopalatal dimension of bone. The 1.4-mm-wide defect, which may form next to the implant after loading, forms 360 degrees around the implant crest module. As such, if less than 1.5 mm of bone is present on the facial aspect of an implant, the vertical defect may become a horizontal defect, and the tissue may recede when it is thin or forms a soft tissue pocket when it is thick. The first condition decreases esthetics because the implant crest module may even become visible, but the second condition increases the risk of periimplantitis and further bone loss. Therefore, the ideal implant position and implant diameter should have 1.5 mm or more of bone on the facial of the implant.

The implant dimension in question is the size of the crest module, not the implant body dimension. For example, a 4.1-mm crest module (on a 3.75-mm implant body) needs 7.1 mm of mesiodistal crestal bone, a 3.5-mm crest module (on a 3.25-mm implant body) is indicated for 6.5 mm of bone, and a 5.2-mm crest module requires 8.2 mm of bone.

The mean papilla height between two adjacent teeth is 3.4 mm, ranging from 1 to 7 mm (depending on the tooth shape: square, ovoid, or tapering). The most common of interimplant papillary height is reduced in comparison and is 2 to 4 mm. Therefore, when a FP-1 restoration is desired, the prosthesis design (square tooth forms) and implant positions may need to be altered accordingly to optimize an esthetic result (Figure 25-34).

The amount of force transmitted to the implant body and abutment screw is also a consideration for implant diameter. The larger the diameter, the less stress to the crestal bone and components. Therefore, in a patient with moderate to severe

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bruxism, a larger-diameter implant should be considered, especially in the canine position, to assist in posterior disclusion of the teeth and canine guidance. However, splinting multiple implants is more effective than implant diameter to decrease stress complications. Hence, the reduced implant diameter related to functional forces is less important when multiple implants are splinted together.

The difference in the emergence profile between a 4-mm-diameter implant and a 5-mm-diameter implant is negligible and often not clinically relevant. However, the larger implant diameter has less surrounding soft tissue and is more difficult to control the creation of a papilla. Therefore, when in doubt (and stress factors are not a consideration), a smaller-diameter implant should be selected when adjacent implants are inserted in the esthetic zone. Thus, a 3.5- to 4-mm-diameter implant often is used in the central implant position for a FP-1 prosthesis. Likewise, a 3-mm-diameter implant often is used for a lateral incisor FP-1 restoration. The exceptions to this rule may be in a bruxing patient when the benefits of a larger-diameter implant with decreased occurrence of abutment screw loosening, crestal bone loss, and long-term body failure are more desirable.

Implant Number and Diameter

Several factors affect the strategic selection of implant size and position to restore a completely edentulous premaxillary arch with a FP-1 restoration. In general, two implant bodies should usually be 3 mm or more apart. Using the 3-mm interimplant guideline, the edentulous square-to-ovoid arch form dimension often does not accommodate interimplant spacing for more than four anterior implants from canine to canine. The largest interimplant distance is typically found in a tapered arch form. As the radius of the circle becomes smaller (from labial resorption, patient size, or dentate form), the premaxilla distance is reduced. As a result, usually no more than four implants are used to replace the anterior six teeth even when bone grafting restores a more compatible residual ridge form (Figure 25-35). Therefore, it is usually not indicated to place six implants to replace the six anterior teeth when the soft tissue drape is important to consider (even when the desire is for six independent crowns) (Figure 25-36).

When the natural canines are present and the missing teeth are the four maxillary incisors, the implant number is not as dependent on the dental arch form. As a general rule, the size of a lateral incisor is less than 6.5 mm, and the remaining arc of bone is smaller than the dentate arch. As a result, one implant per tooth often results in the implants being too close to each other (less than 3 mm). Most often two or three implants may be used to replace the four maxillary incisors. However, implant number is more important than implant size to decrease biomechanical complications. In other words, three smaller-diameter implants are better than two larger-diameter implants (Figure 25-37). Therefore, the most common scenario is to place three division B root forms (3.0–3.5 mm wide) in the lateral incisors and one central incisor region rather than two division A root forms in the lateral incisor sites (4.0 mm wide) (Figure 25-38). The two-implant treatment option is often designed for a square dental arch form, in an older woman, with little to no parafunction to fabricate a FP-1 prosthesis, and with a high lip line when the natural canines are present.

When the patient is missing a lateral and both central incisors, the three missing teeth may be safely restored with two implants. Three adjacent implants often result in a compromised interimplant papilla between the lateral and cental incisor. One implant (division B) is positioned in the lateral incisor region, and the other implant (division A) is placed in the opposite central incisor area (Figure 25-39, *A*). This

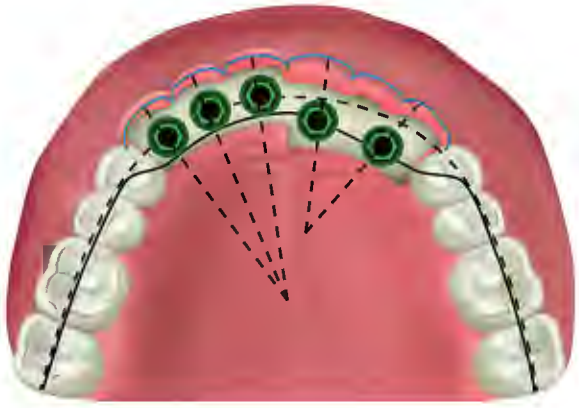


FIGURE 25-35. When multiple adjacent implants are placed in a premaxilla, the arch dimension often does not allow implant placement in the original teeth location without placing the implants closer than 3 mm apart *(left)*. When multiple anterior teeth are missing, most often only two implants can be positioned to replace the three anterior teeth (on the *right*).



FIGURE 25-36. When the six anterior teeth are missing and the desire is a FP-1 fixed prosthesis with more ideal soft tissue drape, four implants are suggested.

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FIGURE 25-37. When four anterior incisors are missing, most often three smaller-diameter implants are used as prosthetic support.



FIGURE 25-38. The four anterior teeth are replaced with three implants of smaller diameter to allow the interdental papilla to be formed between the two implants, and an ovate pontic develops the papillae next to the pontic.

eliminates a cantilever when implants are only inserted into the central incisor positions and decreases the risk of screw loosening. The interdental papilla of the adjacent natural canine and lateral incisor determines the papilla height next to the adjacent implant crowns.

In the presence of horizontal marginal bone loss on the anterior teeth adjacent to an implant site, orthodontic extrusion may be indicated to correct the interproximal bone level. When this option is used, a veneer or crown is usually required to restore the adjacent tooth after orthodontic extrusion. The restoring dentist may place a veneer, lower the adjacent contact, or modify the crown shapes on the implant and natural teeth to a more square form, which decreases the height requirements of the papilla and eliminates the absence of tissue in the interproximal area found in the original condition. These treatment plan decisions should be made before implant insertion.

When the patient is missing the two central incisors, two smaller-diameter implants should be used to restore the site (Figure 25-39, *B*). It has been suggested that an interdental papilla next to an ovate pontic is more esthetic than the papilla between two implants. However, one implant with a cantilevered pontic increases the risk of screw loosening, crestal bone loss, and component fracture. Whenever two implants are used to replace two adjacent central incisors, the implant diameter should not be as large as when replacing one missing tooth (Figure 25-40). A 5-mm implant often results with the implants too close and compromised soft tissue drape (Figure 25-41). Instead, the adjacent implants are reduced in diameter compared with a single-tooth implant. This provides greater soft tissue volume between the implants, allows the surgeon to place the implant more distal to avoid the incisive foramen, and leaves a thicker facial cortical plate for the implant (Figure 25-42). The papilla between the implants may be created in a similar fashion as next to an ovate pontic.

When the patient is missing a lateral and central incisor, two division B implants may also be used to restore this condition rather than using a division A implant in the central incisor position with a cantilever lateral crown (Figure 25-43). The cantilever from the central incisor implant increases biomechanical complications as screw loosening, uncemented restoration, bone loss, and implant fracture (Figure 25-44). The implant in the lateral incisor is often 3.0 mm wide, and the central incisor is 3.5 mm wide. The additional interproximal space permits an improved soft tissue drape condition. When the implants are out of the esthetic zone (FP-2, FP-3, RP-4, or RP-5 prostheses), the diameter of the implant is more related to the amount of force applied to the implant–bone–prosthetic system. Facial bone dimensions and interimplant spacing are less important.

Posterior Edentulous Maxillae Treatment Plans

Implant Diameter

The mesiodistal dimension of a premolar tooth is usually 7.0 mm, and the cementoenamel junction (CEJ) dimension is 4.8 mm and 2 mm below the CEJ (where the bone usually is located) the root dimension is 4.2 mm. As such, the premolar regions should most often use 3.7- to 4.2-mm-diameter implants for a FP-1 prosthesis. It should be noted that the premolar region is often in the esthetic zone. As such, augmentation in the width may be required to place the implant under the buccal cusp to improve the esthetics of a FP-1 prosthesis. Otherwise, a facial ridge lap on the crown may be necessary.

The maxillary molars have more than a 200% increase in surface area compared with the premolar teeth. Hence, molar implants should increase either diameter or number. The first molar is 10.4 mm in mesiodistal dimension, and the second molar is 9.8 mm. The CEJ dimensions of these teeth are 7.9 mm and 7.6 mm, respectively, and 2 mm below the CEJ, these teeth are both 7 mm in size (Table 25-2). However, the ideal implant diameter is 5 to 6 mm for the maxillary molars. Because

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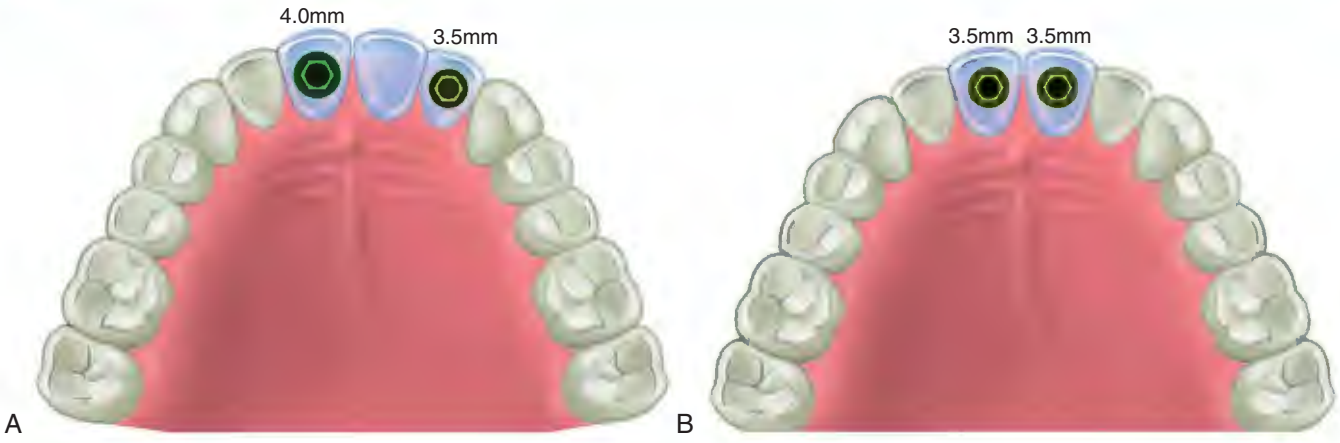


FIGURE 25-39. **A,** When two centrals and a lateral incisor is missing, most often two implants are used to replace the three teeth *(left)*. **B,** When two central incisors are being replaced, two smaller-diameter implants are used for prosthetic support.

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FIGURE 25-40. Two central incisor implants should not use a 5- or 6-mm-diameter implant because they are often too close together.



FIGURE 25-41. **A,** Two 5-mm-diameter adjacent implants are usually too close together when restoring two centrals. **B,** Any bone loss on either implant results in a loss of papilla height and the cervical soft tissue margins at risk.

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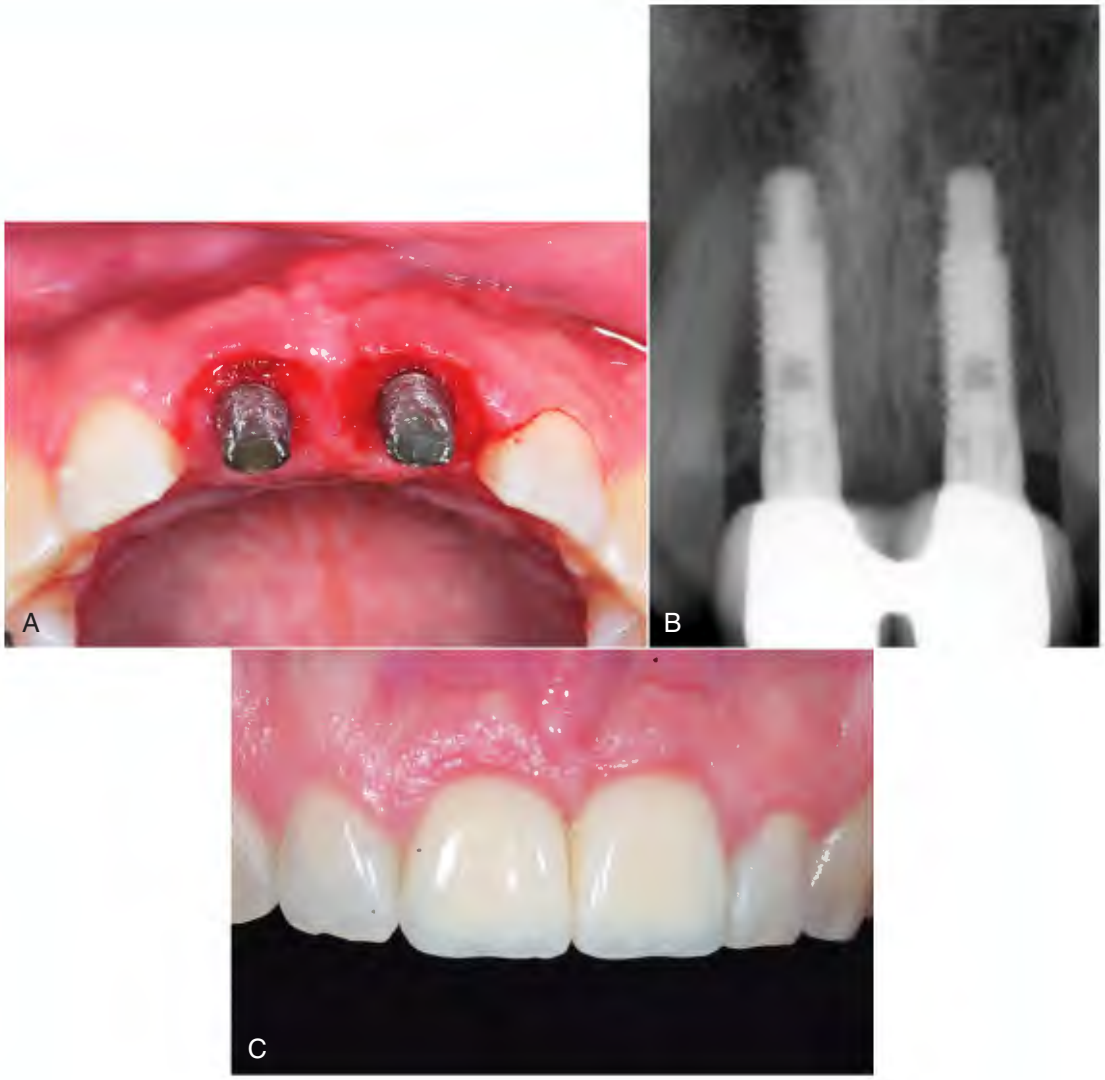


FIGURE 25-42. **A,** Missing central incisors should be restored with two implants. Most often, narrow-diameter implants (3.5 mm) are indicated. This permits more interimplant tissue to develop the soft tissue drape, similar to the papilla next to an ovate pontic. **B,** The two implants are 3 mm or more apart. **C,** The two central implant crowns are often more square shaped to lower the interproximal contact.

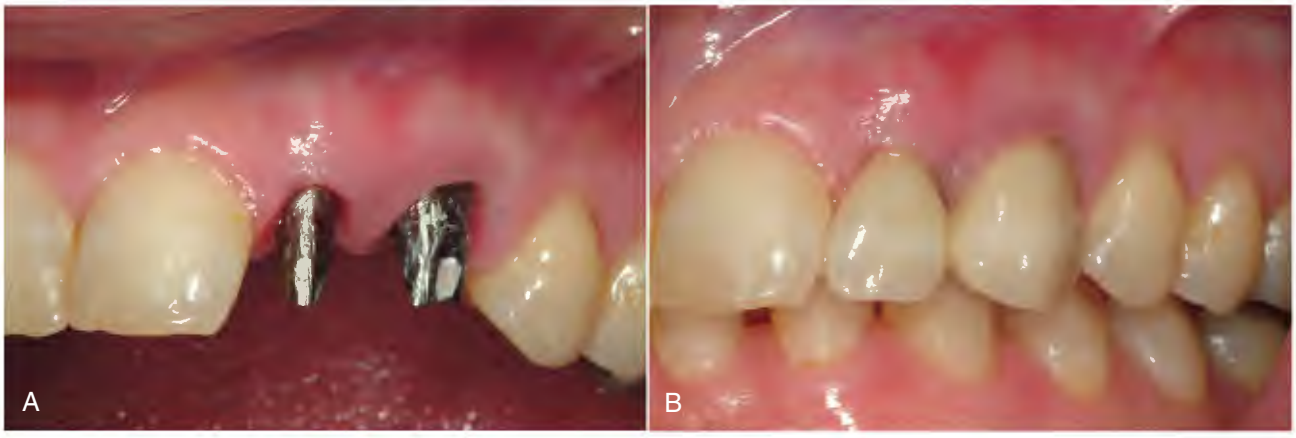


FIGURE 25-43. **A,** When a lateral incisor and adjacent central incisor are missing, two smaller-diameter implants are indicated. **B,** The 3-mm or greater intraimplant space permits a papilla to fill the interproximal space.

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TABLE 25-2
Maxillary Teeth Dimensions (Average)

Type of Teeth	Cervico-Incisal Height (mm)	Mesiodistal Crown (mm)	Mesiodistal Cervix (mm)	Mesiodistal CEJ (–2 mm)	Faciolingual Crown (mm)	Faciolingual Cervix (mm)
Central incisor	10	8.6	6.4	5.5	7.1	6.4
Lateral incisor	9	6.6	4.7	4.3	6.2	5.8
Canine	10	7.6	5.6	4.6	8.1	7.6
First premolar	8	7.1	4.8	4.2	9.2	8.2
Second premolar	8	6.6	4.7	4.1	9.0	8.1
First molar	8	10.4	7.9	7.0	11.5	10.7
Second molar	8	9.8	7.6	7.0	11.4	10.7

CEJ, Cementoenamel junction.



FIGURE 25-44. A cantilever from the central incisor implant increases the risk of biomechanical complications.

titanium is 10 times or more rigid than natural teeth, the modulus of elasticity for an implant of sizes greater than 6 mm may be too great and may cause stress shielding and bone loss. The 6-mm implant diameter should especially not be used in the anterior regions because the magnitude of the force is not large enough to strain the bone within the ideal physiologic window next to such a large implant. As a consequence, more crestal bone loss is often observed.

When the diameter or designs of molar implants do not provide sufficient surface area, the number of implants should be increased. Rather than one implant replacing a molar, two implants of 4 mm in diameter should be considered to compensate for very soft bone types or unfavorable force factors (e.g., parafunction).

Implant Number

A review of the literature indicates that full maxillary fixed implant–supported prostheses may be fabricated on four to six standard-diameter implants with posterior molar cantilevers. An average of four to six implants also is used to support bar overdentures. Yet the edentulous maxilla has the lowest implant survival for either fixed or removable implant restorations compared with mandibular prostheses with this treatment approach.[3,22–31] Reports concur with the finding that maxillary bone tends to be of poorer quality and volume and presents several biomechanical disadvantages, which were previously listed in this chapter. To compensate for the poor local conditions, a greater number of implants in the maxillary arch should be used to support the prosthesis along with a greater A-P distance. The first molar implant sites in a completely edentulous maxilla almost always have been invaded by the maxillary sinus, and most edentulous maxillary anterior regions are inadequate in width. Therefore, to insert more implants in the ideal positions, most maxillary arches require sinus grafts, and many also require premaxilla reconstruction to ideally restore the edentulous maxillary arch.

With these concerns in mind, ideally the minimum implant number for most completely edentulous maxillary fixed or RP-4 prostheses is usually seven in the ovoid arch form (see Figure 25-30). The suggested locations for this dentate arch form are at least one central (or lateral) incisor position, bilateral canine positions, bilateral second premolar sites, and bilateral distal half of the maxillary first molar sites (Figure 25-45). These seven implants should be splinted together to function as a biomechanical arch. These implant positions create sufficient space between each implant to allow for greater implant diameters in the molar regions (when required for force or bone density factors) without concern for the adjacent site. Keep in mind that the exact implant position is not necessary for FP-3 prosthesis. Hence, the implant spacing is less specific (Figure 25-46).

A square dental arch form may use a minimum of six implants: bilateral canines, bilateral second premolars, and bilateral first molar sites (see Figure 25-29). More moderate force factors or softer bone types may require eight implants in the edentulous arch (Figure 25-47). When force factors are moderate to severe or the dental arch form is tapered, the minimum implant number should increase to eight implants (see Figure 25-31). When eight or more implants are selected, the additional implant(s) are usually placed in the premaxilla, in the contralateral central (or lateral) incisor position or the second molar site(s) (Figure 25-48).

When force factors are greater than usual and bone density is poorer, additional implants should be used in any of the arch forms. In the square and ovoid arch form, one additional implant is often positioned in the premaxilla (Figure 25-49). In addition, for patients with higher force factors and poor bone density, one additional implant is planned in the distal half of each of the second molar positions to increase the biomechanical arch form, increase the A-P distance compared with the first molar site, and add an additional implant (Figure 25-50). This

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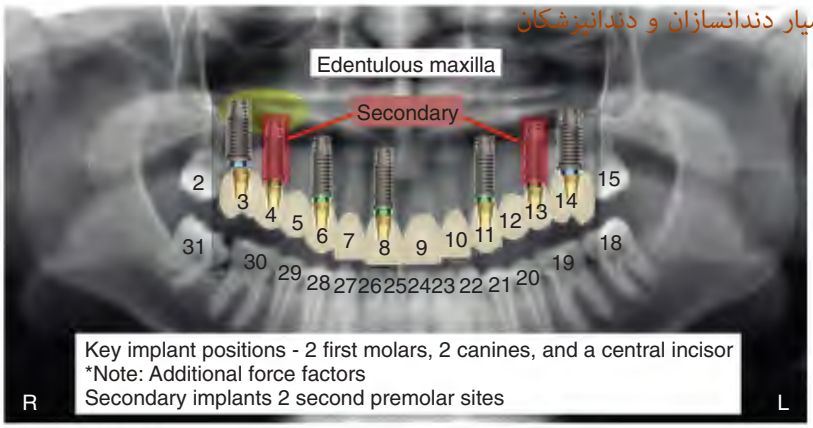


FIGURE 25-45. Ideally, a completely edentulous maxilla should have seven implants for a full-arch fixed restoration (or a completely implant-supported overdenture).

Implant positions: Key locations
5 to 14 units

Rule 1: No cantilever
Rule 2: No adjacent pontics
Rule 3: Canine and first molar



FIGURE 25-46. **A,** An ovoid arch form in a patient with three implants in the premaxilla and a total of seven implants for a FP-3 prosthesis. **B,** A full-arch fixed FP-3 prosthesis that has an ovoid anterior arch form supported by implants. **C,** The patient was restored with a maxillary full-arch implant-supported prosthesis opposing natural dentition. **D,** The panoramic radiograph of the patient with an ovoid dentate arch form. The implant position is less specific when the prosthesis is FP-3.

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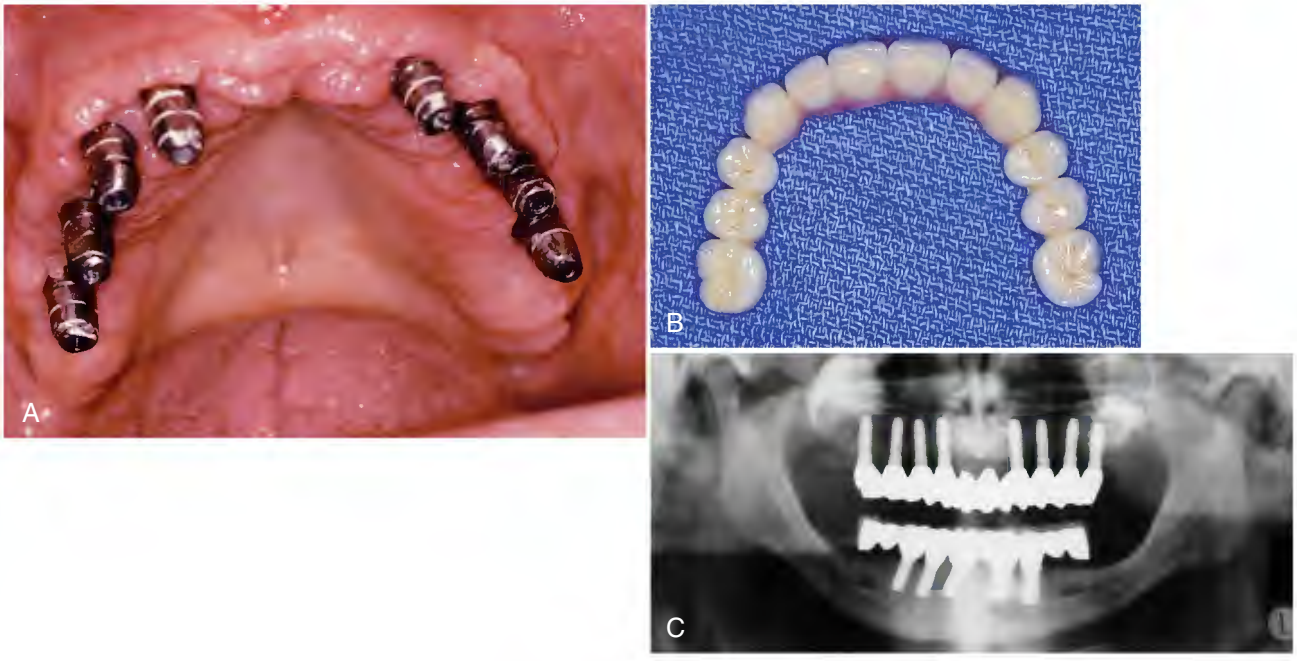


FIGURE 25-47. **A,** Eight implants were used in this square dentate arch form to fabricate a fixed prosthesis. Additional implants were indicated because the patient is a man and the opposing fixed prosthesis is implant supported. **B,** The fixed prosthesis follows a square dentate arch form. As a result, the anterior teeth are cantilevered less than 8 mm from the canine implants. **C,** A panoramic radiograph of the patient with a maxillary square dentate arch form.



FIGURE 25-48. **A,** A patient with a tapered arch form (after an iliac crest graft) was restored with four implants in the premaxilla (10 implants total). **B,** The fixed FP-3 prosthesis of the patient is supported by implants in the canine and central incisors position. Additional posterior implants are used and splinted together. **C,** The maxillary FP-3 fixed prosthesis opposing a fixed implant prosthesis.

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FIGURE 25-49. **A,** A full-arch maxillary edentulous arch with an ovoid dentate arch form. Eight implants were used (four in the premaxilla) to compensate for the softer bone type and the opposing implant-supported fixed prosthesis. The patient had an iliac crest bone graft to the maxilla and mandible. **B,** The maxillary fixed restoration in situ. **C,** The maxillary and mandibular fixed prostheses in situ. **D,** A panoramic radiograph of the maxillary and mandibular bone graft, implants, and restorations.

also is an excellent biomechanical design to minimize stress when a dentate tapered arch form is restored in an ovoid or square residual ridge form (Figure 25-51). These implant number and position guidelines also may be beneficial when an immediate load is placed on the implants.

The disadvantage of second molar implant(s) for an ideal treatment plan is the additional cost of the second molar implant(s) and associated restoration(s). Many patients do not display the second molar and do not require this tooth for function. As such, to decrease the cost, the restoring dentist may use a coping splinted to the arch rather than a porcelain-fused-to-metal crown. The reason for this implant position is for force transfer, not necessarily esthetics or function.

In conclusion, the number of implants used in an edentulous maxilla may range from six to 10, and the number of implants needed in an edentulous maxilla is related to arch shape. When force factors are moderate to severe or bone density is poor, more implants should be inserted and in greater diameter to enhance the surface area of support to the prosthesis. The A-P distance should also be increased by adding second molar implant(s) whenever forces to the premaxilla are greater than usual.

The dentist may use the following guidelines for implant locations in a completely edentulous maxilla:

1. The bilateral canine position is a key implant position and is planned for 4-mm-diameter implants.

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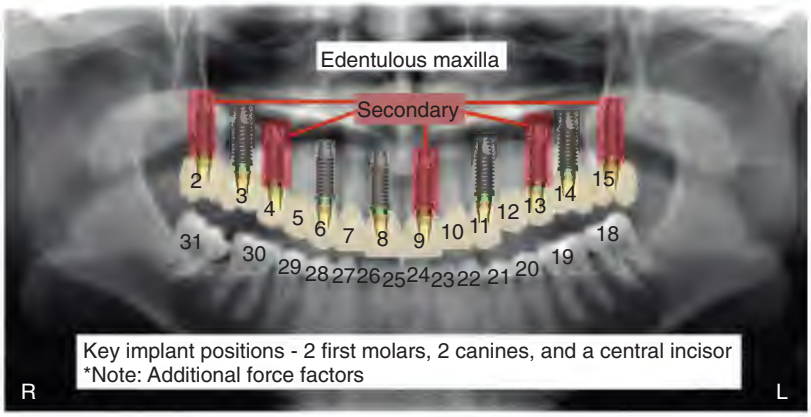


FIGURE 25-50. The ideal seven-implant positioning for a maxillary edentulous arch includes at least one central incisor position, bilateral canine positions, bilateral second premolar sites, and bilateral sites in the distal half of the first molars. In case of heavy stress factors, an additional anterior implant and bilateral second molar positions (to increase the anterior-posterior distance) may be of benefit.

Implant positions: Key locations
5 to 14 units

Rule 1: No cantilever
Rule 2: No adjacent pontics
Rule 3: Canine and first molar

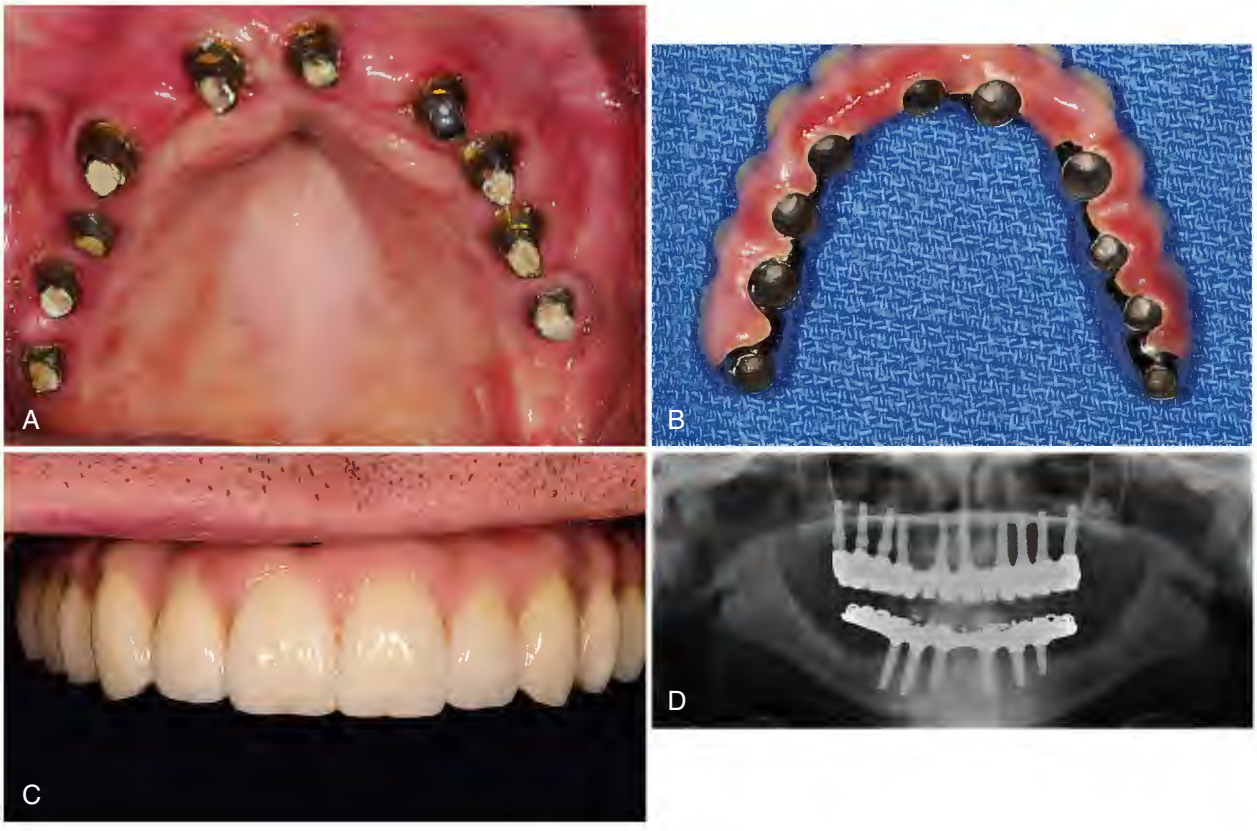


FIGURE 25-51. **A,** An edentulous maxilla after a bone graft with a tapered dentate arch form and 10 implants, which include the second molar. **B,** The maxillary full-arch prosthesis with four premaxillary implants in the tapered dentate arch form. **C,** The maxillary restoration in situ. **D,** A panoramic radiograph of the maxillary and mandibular restorations and implants.

2. The center of the first premolar is planned 7 to 8 mm distal from the center of the canine implant (for a 4.0-mm-diameter implant). This is an optional implant site when parafunction is moderate to severe.
3. The center of the second premolar is 7 to 8 mm distal from the first premolar site (14 mm from the midcanine position) on each side for a 4.0-mm-diameter implant. This is a key implant position.
4. The distal half of the first molar is 8 to 10 mm distal from the mid second premolar implant (this places the implant in the distal of the first molar and increases the A-P distance). Ideally, the implant should be 5 to 6 mm in diameter. This is a key implant position. When a 4-mm diameter is used, the first implant is 7 to 8 mm from the mid second premolar site, and the second implant is 7 to 8 mm more distal than the first implant.
5. The center of the second molar is 8 to 10 mm distal from the center of the first molar implant. This position is most important for the edentulous arch with a tapered dentate arch form, D4 bone types, or severe force factors.

The number of implants in the patient with multiple missing posterior teeth is often increased, especially when force factors

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are high, bone density is poor, and larger implant diameters are not used. When multiple adjacent posterior teeth are missing, the number of implants is more important than the implant size. When adjacent molars are missing, two regular-size implants are often considered when implant diameter cannot be increased to 5 or 6 mm.

Crown Height Space and Implant Number

The interarch distance is defined as the vertical distance between the maxillary and mandibular dentate or dentate arches under specific conditions (e.g., the mandible is at rest or in occlusion).[32] A dimension of only one arch does not have a defined term in prosthetics; therefore, the author proposed the term *crown height space*.[33] The CHS for implant dentistry is measured from the crest of the bone to the plane of occlusion in the posterior region and the incisal edge of the arch in question in the anterior region. In the anterior regions of the mouth, the presence of a vertical overbite means the CHS is larger in the maxilla than the space from the crest of the ridge to the opposing teeth incisal edge. In general, when the anterior teeth are in contact in centric occlusion, there is a vertical overbite. The anterior mandibular CHS is therefore usually measured from the crest of the ridge to the mandibular incisal edge. However, the anterior maxillary CHS is measured from the maxillary crestal bone to the maxillary incisal edge, not the occlusal contact position (Figure 25-52).

The ideal CHS needed for a fixed implant prosthesis should range between 8 and 12 mm. This measurement accounts for the "biological width," abutment height for cement retention or prosthesis screw fixation, occlusal material strength, esthetics, and hygiene considerations around the abutment crowns.

Excessive Crown Height Space

Crown height space greater than 15 mm is considered excessive and is primarily the result of the vertical loss of alveolar bone from long-term edentulism.[33] Other causes may include genetics, trauma, and implant failure. Treatment of excessive CHS before implant placement includes orthodontic and surgical methods. Orthodontics in partially edentulous patients (especially in the growth and development state) is the method of choice because other surgical or prosthetic methods are usually more costly and have greater risks of complications. Several surgical techniques may also be considered, including block onlay bone grafts, particulate bone grafts with titanium mesh or barrier membranes, interpositional bone grafts, and distraction osteogenesis. A staged approach to reconstruction of the jaws is often preferred to simultaneous implant placement, especially when large-volume gains are required. Significant vertical bone augmentation may even require multiple surgical procedures.

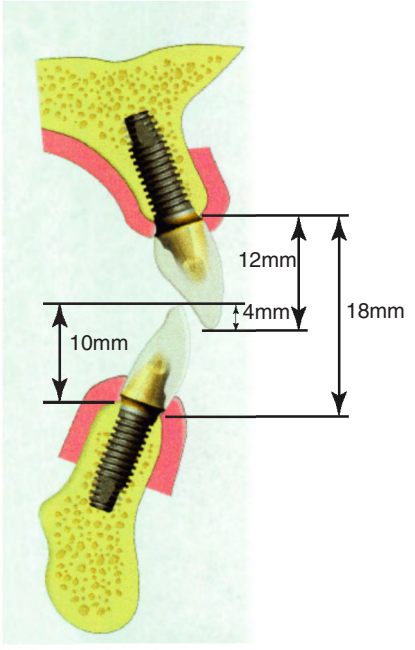


FIGURE 25-52. The crown height space in the maxillary anterior is measured from the crest of bone to the incisal edge, not the occlusal contact in occlusion.

Distraction osteogenesis has several advantages over onlay bone grafting techniques for vertical bone growth. Vertical bone gains are not limited by factors such as graft size or expansion of the existing soft tissue volume. There is no donor site morbidity, and the surgery may be performed in an office setting. However, distraction osteogenesis requires patient compliance, and bone volume gains are often unidirectional. In addition, clinical studies found that secondary bone augmentation procedures are often required for dental implant placement.[34] Misch et al. presented a unique approach combining vertical distraction and horizontal onlay bone grafting to reconstruct the deficiency three dimensionally.[35,36] Osseous distraction is performed first to vertically increase the ridge and expand the soft tissue volume. Secondarily, an onlay bone graft is used to complete the repair of the defect.

In case of excessive CHS, bone augmentation may be preferred to prosthetic replacement, especially in C–h or D bone volumes. Surgical augmentation of the residual ridge height reduces the CHS and improve implant biomechanics by both position and number. Augmentation often permits the placement of wider-body implants with the associated benefit of increased surface area.

Prosthetics is the most commonly used option to address excess CHS because it does not require additional surgeries. However, from a biomechanical risk scenario, it is not favorable to reduce stress to the system. Therefore, implant support should be increased and cantilevers limited to reduce the risk. Using gingiva-colored prosthetic materials (pink porcelain or acrylic resin) on fixed restorations or changing the prosthetic design to a removable restoration should often be considered when the prosthesis is used to restore excessive CHS.

Biomechanic Consequences of Excessive Crown Height Space

Force magnifiers are situations or devices that increase the amount of force applied to a system and include a screw, pulley, incline plane, and lever.[37] The biomechanics of CHS are related to lever mechanics. The properties of a lever have been appreciated since the time of Archimedes, 2000 years ago ("Give me a lever and a fulcrum and a place to stand, and I can move the world"). The issues of cantilevers and implants were demonstrated in the edentulous mandible, where the length of the posterior cantilever directly related to complications or failure of the prosthesis.[38] Rather than a posterior cantilever, the CHS is a vertical cantilever when any lateral or cantilevered load is applied and therefore is also a force magnifier.[39] As a result, because CHS excess increases the amount of force, any of the mechanical-related complications related to implant prostheses

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may also increase, including uncemented prosthesis, screw loosening (prosthetic or abutment), overdenture attachment complications, and so on.

When the direction of a force is in the long axis of the implant, the stresses to the bone are not magnified in relation to the CHS. However, when the forces to the implant are on a cantilever or a lateral force is applied to the crown, the forces are magnified in direct relationship to the crown height. Bidez and Misch evaluated the effect of a cantilever on an implant and its relation to crown height.[39] When a cantilever is placed on an implant, there are six different potential rotation points (i.e., moments) on the implant body. When the crown height is increased from 10 to 20 mm, two of six of these moments are increased 200%.

A cantilevered force may be in any direction: facial, lingual, mesial, or distal. Forces cantilevered to the facial and lingual direction are often called *offset loads*. The bone width decrease is primarily from the facial aspect of the edentulous ridge. As a result, implants are often placed more lingual than the center of the natural tooth root. This condition often results in a restoration cantilevered to the facial, and the more lingual implant position results in offset loads.

The vertical distance from the occlusal plane to the opposing landmark for implant insertion is typically a constant in an individual (with the exception of the posterior maxilla because the sinus cavity expands more rapidly than crestal bone resorption in height). Therefore, as the bone resorbs, the crown height becomes larger, but the available bone height decreases. An indirect relationship is found between the crown and implant height. Moderate bone loss before implant placement may result in a crown height–bone height ratio greater than 1, with greater lateral forces applied to the crestal bone than in abundant bone (in which the crown height is less).

A linear relationship exists between the applied load and internal stresses within the bone.[40,41] Therefore, the greater the load applied, the greater the tensile and compressive stresses transmitted at the bone interface and to the prosthetic components. Yet many implant treatment plans are designed with more implants in abundant bone situations and fewer implants in atrophied bone volume. The opposite scenario should exist. The lesser the bone volume, the greater the crown height and the greater the number of implants indicated.

An angled load to a crown will also magnify the force applied to the implant. A 12-degree force to the implant will be increased by 20% compared with a long-axis load. This increase in force is further magnified by the crown height. For example, a 12-degree angle with a force of 100 N will result in a force of 315 N-mm on a crown height of 15 mm.[39] In other words the CHS force increase is even greater than the angled load increase.

Maxillary anterior teeth are usually at an angle of 12 degrees or more to the occlusal planes. Even implants placed in an ideal position are usually loaded at an angle. Maxillary anterior crowns are often longer than any other teeth in the arch, so the effects of crown height cause greater risk. The angled force to the implant also may occur during protrusive or lateral excursions because the incisal guide angle may be 20 degrees or more.[42] Anterior implant crowns will therefore be loaded at a considerable angle during excursions compared with the long-axis position of the implant. As a result, an increase in the force to maxillary anterior implants should be compensated for in the treatment plan.

In most implant designs and bone density types, most forces applied to the osseointegrated implant body are concentrated in the crestal 7 to 9 mm of bone.[39] Therefore, implant body height is usually not an effective method to counter the effects of crown height. In other words, crown–root ratio is a prosthetic concept that may guide the restoring dentist when evaluating a natural tooth abutment. The longer the natural tooth root, the shorter the crown height, which acts as a lever to rotate the tooth around an axis located two thirds down the root. However, the crown height–implant ratio is not a direct comparison. Crown height is a vertical cantilever that magnifies any lateral or cantilever force in either a tooth- or an implant-supported restoration. However, this condition is not improved by increasing implant length to dissipate stresses. The implant does not rotate away from the force in relation to implant length. Instead, it captures the force at the crest of the ridge.

The greater the CHS, the greater number of implants usually required for the prosthesis, especially in the presence of other force factors. This is a complete paradigm shift from the concepts advocated originally, with many implants placed in greater-available bone and small crown heights and fewer implants used with greater crown heights in atrophied bone. The cantilever should also be reduced in greater CHS conditions and may need to be eliminated completely if other force conditions are present.

An increased CHS may increase the forces to the crestal bone around the implants and increase the risk of crestal bone loss. The CHS increases when crestal bone loss occurs around the implants. This in turn may further increase both the CHS and the moment forces to the entire support system, resulting in screw loosening, crestal bone loss, implant fracture, and implant failure.

An increase in the biomechanical forces are in direct relationship to the increase in CHS. Therefore, the treatment plan of the implant restoration should consider stress-reducing options whenever the CHS is increased. Methods to decrease stress include[35,36]:

1. Shorten cantilever length.
2. Minimize offset loads to the buccal or lingual.
3. Increase the number of implants.
4. Increase the diameters of implants.
5. Design implants to maximize the surface area of implants.
6. Fabricate removable restorations that are less retentive and incorporate soft tissue support.
7. Remove the removable restoration during sleeping hours to reduce the noxious effects of nocturnal parafunction.
8. Splint implants together, whether they support a fixed or removable prosthesis.

As a consequence of the increase in risk of biomechanical issues related to an increased CHS in the maxilla, the implant number should often be increased. Hence, the number of implants in a maxillary arch with a large CHS should be more than a mandibular arch even when the bone density is similar (Figure 25-53).

Fixed Prosthesis Design

The ideal CHS for a fixed prosthesis is between 8 and 12 mm, accounting for an ideal 3 mm of soft tissue, 2 mm of occlusal material thickness, and a 5 mm or greater abutment height. A CHS greater than 12 mm may be of concern in fixed restorations. The replacement teeth are elongated and often require the addition of gingival-tone materials in esthetic regions. The greater impact force on implants compared with teeth, combined with the increased crown height, creates increased moment forces on implants and risks of uncemented or

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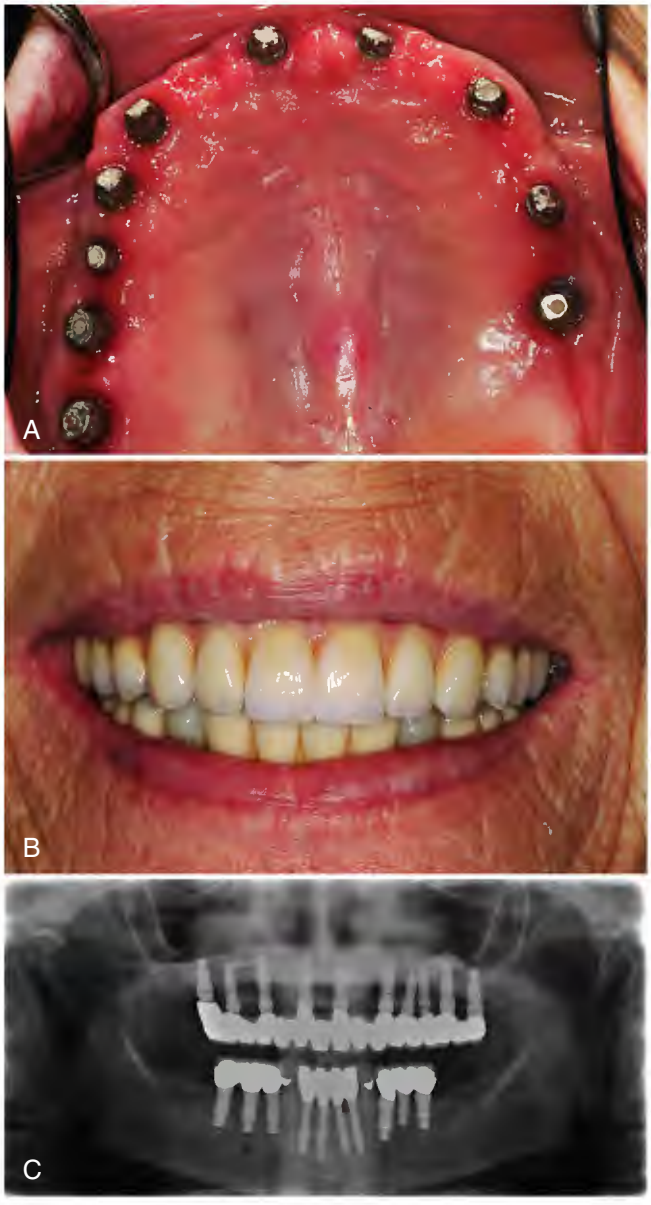


FIGURE 25-53. **A,** An edentulous maxilla with a crown height space (CHS) greater than 15 mm with 10 implants (four in the premaxilla). The ovoid arch form with softer bone on the left, opposing teeth, and implants in the mandible requires more implants. **B,** A fixed FP-3 porcelain-fused-to-metal restoration supported by 10 implants on a patient with a greater CHS, moderate force factors, and softer bone type. **C,** Panoramic radiograph of the patient illustrating the 10 maxillary implants opposing teeth and an implant prosthesis in the mandible.

unretained prostheses, component, and material fracture. These problems are especially noted when associated with less favorable biomechanics on cantilevered sections of fixed restorations.

Crown height space greater than 15 mm means a large amount of metal must be used in the substructure of a traditional fixed restoration to keep porcelain to its ideal 2-mm thickness (Figure 25-54). Fine-tuning techniques for traditional fixed restorations are required under these conditions.[36,43] Controlling surface porosities of metal substructures after casting as their different parts cool at different rates becomes increasingly difficult. Furthermore, when the casting is reinserted into the oven to bake the porcelain, the heat is maintained within the casting at different rates, so the porcelain cools in different regions at different rates.[43] If not controlled properly, both of these factors increase the risk of porcelain fracture after loading[44] (Figure 25-54, *B* to *D*). For excessive CHS, considerable weight of the prosthesis (approaching 3 oz of alloy) may affect maxillary trial placement appointments because the restoration does not remain in place without the use of adhesive. Noble metals must be used to control alloy's heat expansion or corrosion; therefore, the costs of such implant restorations have dramatically increased.[45] Proposed methods to produce hollow frames to alleviate these problems, including the use of special custom trays to achieve a passive fit, may double or triple the labor costs.

An alternative method of fabricating fixed prostheses in situations of CHS of 15 mm or greater is the fixed complete denture or hybrid prosthesis, with a smaller metal framework, denture teeth, and acrylic resin to join these elements together (Figure 25-55). The reduced metal framework compared with a porcelain-to-metal fixed prosthesis exhibits fewer dimensional changes and may more accurately fit the abutments, which is especially important for a screw-retained restoration. It is less expensive to fabricate than a porcelain-to-metal fixed prosthesis, is highly esthetic (premade denture teeth), easily replaces teeth and soft tissue in appearance, and is easier to repair if fracture occurs. The denture teeth in these prostheses should not be acrylic or composite, owing to a high fracture rate. Instead, porcelain denture teeth are suggested. Because acrylic resin acts as an intermediary between the porcelain denture teeth and metal substructure, the impact force during dynamic occlusal loading may be reduced compared with a porcelain–metal restoration. As a general rule, fixed hybrid prostheses (FP-3) are used for situations with CHS of 15 mm or greater. However, when the CHS is less than 15 mm, the decrease in bulk of acrylic increases the risk of fracture and complications. Therefore, a porcelain–metal restoration is suggested.

On occasion, undercontoured interproximal areas are designed by the laboratory in such restorations to assist oral hygiene and have been referred to as "high water" restorations. This is an excellent method in the mandible; however, it results in food entrapment, affects air flow patterns, and may contribute to speech problems in the anterior maxilla. Hence, the excessive CHS condition has several conditions that may alter the treatment plan.

Crown height space is a considerable force magnifier; therefore, the greater the crown height, the shorter the prosthetic cantilever that should extend from the implant support system. When the CHS is greater than 15 mm, no cantilever should be considered unless all other force factors are minimal. The occlusal contact intensity should be reduced on any offset load from the implant support system. Occlusal contacts in centric relation occlusion may even be eliminated on the most posterior aspect (or offset region) of a cantilever. In this way, a parafunction load may be reduced because the most cantilevered portion of the prosthesis is only loaded during functional activity (e.g., chewing).

Maxillary Implant Overdentures

The primary advantages of a RP-4 maxillary IOD compared with a fixed prosthesis is the ability to provide a flange for maxillary lip support, the improved sulcular hygiene, and the reduced laboratory fee compared with a fixed restoration. As a

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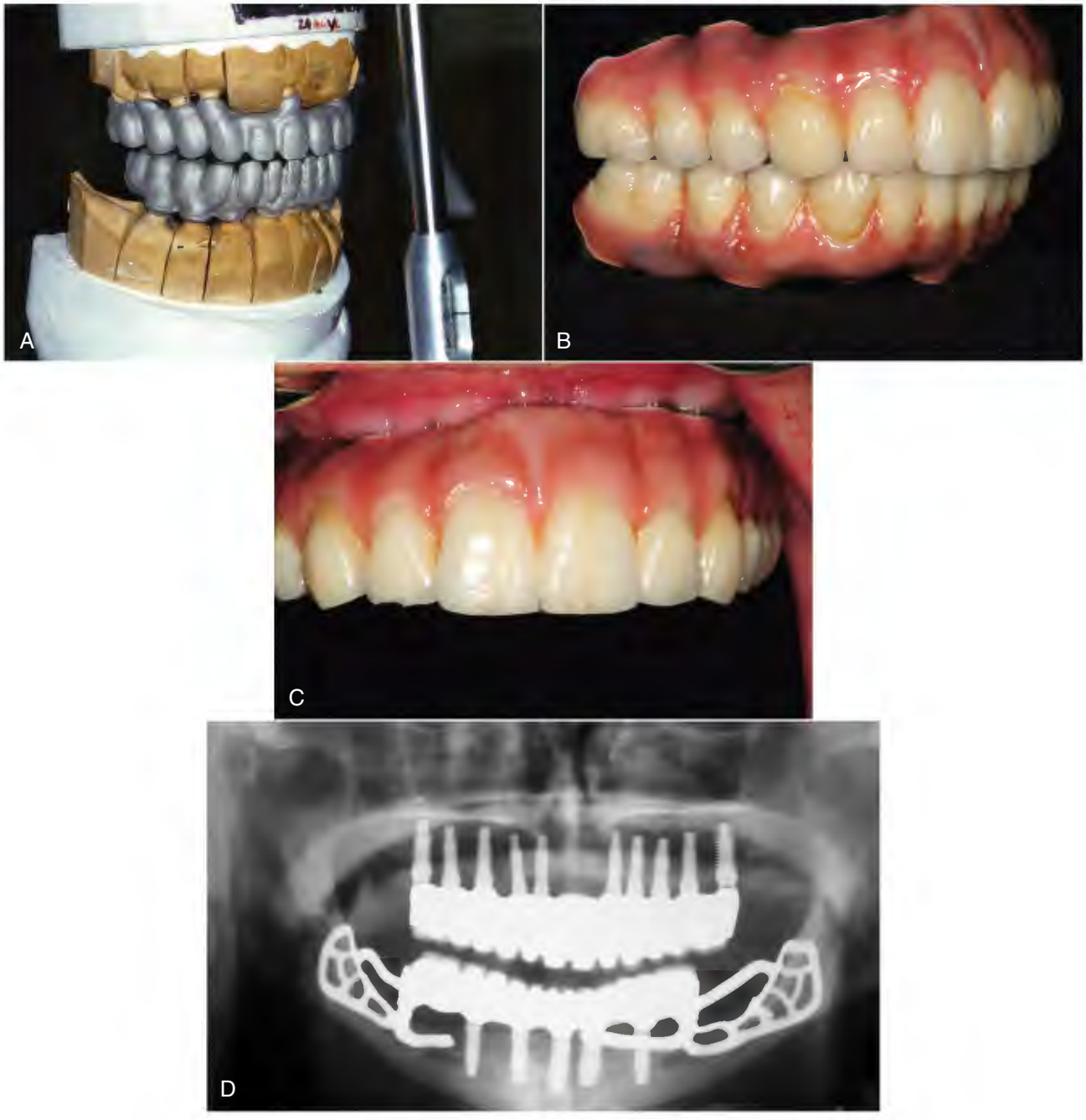


FIGURE 25-54. **A,** A fixed porcelain–metal restoration of an arch with a CHS greater than 15 mm must use a large amount of metal to insure the porcelain is only 2 mm thick in any directions. **B,** The porcelain on a FP-3 prosthesis should be 2 mm thick to reduce the risk of fracture. Heating and cooling of large metal castings are more difficult to control in order to reduce complications. **C,** The maxillary restoration in situ. **D,** A panoramic radiograph of the maxillary and mandibular implant prostheses with an increased CHS.

consequence, before the selection of a specific prosthesis type and to facilitate the diagnosis, the labial flange above the maxillary teeth of the existing denture (or wax try-in of a new prosthesis) may be removed and the facial appearance of the maxillary lip without labial support assessed. If the maxillary lip requires additional support, two options are available:

1. A bone or soft tissue graft to the premaxilla is performed before or in conjunction with implant insertion or at uncovery for a fixed implant prosthesis.
2. A maxillary IOD is fabricated with a labial flange on the prosthesis.

Removable prostheses often require a CHS greater than 12 mm for denture teeth and acrylic resin base strength, attachments, bars, and oral hygiene considerations.[35,36] The amount of CHS in an edentulous region greatly varies. The larger CHS may facilitate the fabrication process of removable overdentures because it is easier for denture tooth setup and greater bulk of acrylic to strengthen the prosthesis. The inadequate CHS may make an overdenture contraindicated. In these situations, the denture tooth position may be affected, the prosthesis may repeatedly fracture, and the attachments may be compromised (Figure 25-56). When less than 12 mm of CHS is present,

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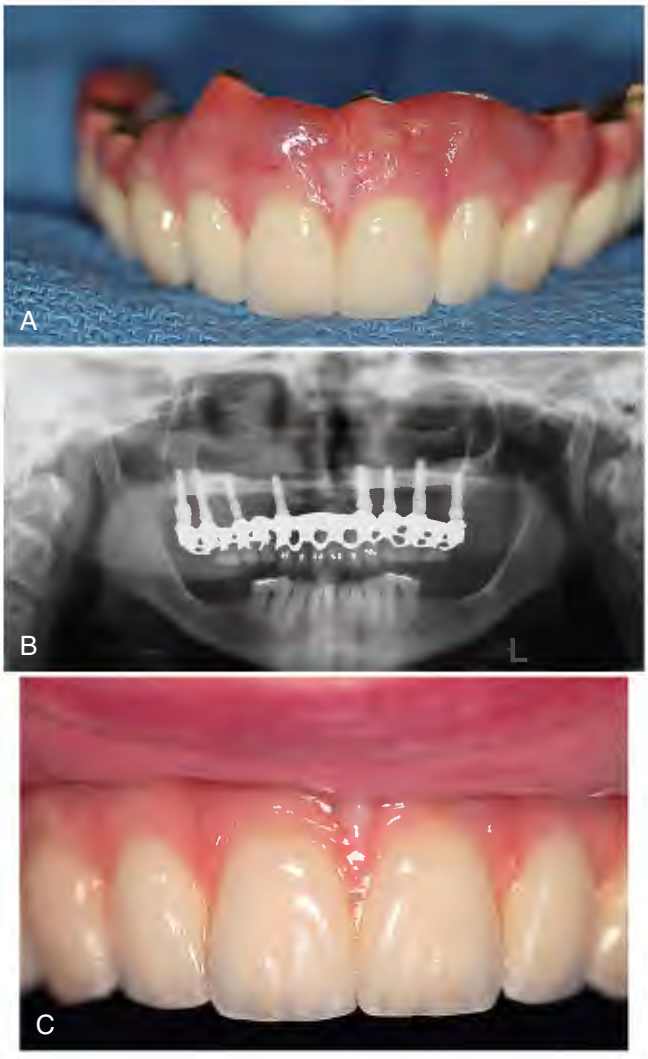


FIGURE 25-55. **A,** A large crown height space may be restored with a hybrid prosthesis of a metal framework, porcelain denture teeth, and acrylic. **B,** Panoramic radiograph of a FP-3 hybrid maxillary prosthesis, with a metal framework, porcelain denture teeth, and acrylic. **C,** The hybrid fixed maxillary prosthesis in situ. It may be made esthetic, has reduced laboratory costs, is lightweight, and may be repaired more easily than a traditional ceramic-to-metal restoration.

an osteoplasty is considered before implant insertion (Figure 25-57). It should be noted that if the patient ever desires to have a RP-4 or fixed restoration and sinus grafts are necessary, the bone removed in the premaxilla is ideal to augment the sinus floor.

In the maxilla, horizontal and vertical loss of bone results in a more palatal ridge position. As a consequence, implants are often inserted more palatally than the natural tooth position. Removable restorations have several advantages under these clinical circumstances. The removable prosthesis does not require embrasures for hygiene. The facial cantilevered fixed prosthesis may be impossible to perform sulcular hygiene. The removable restoration may be removed during sleep to decrease the effects of an increase in CHS on nocturnal parafunction. The removable restoration may improve the lip and facial support, which is deficient because of the advanced bone loss. The overdenture may have sufficient bulk of acrylic resin to decrease the risk of prosthesis fracture. The increase in CHS permits denture tooth placement without infringement of the implant–prosthetic substructure.



FIGURE 25-56. Less than 12 mm crown height space (CHS) for an implant overdenture may compromise the position of the overdenture teeth and increase the risk of prosthesis fracture. An insufficient CHS is a major problem for the fabrication of a maxillary overdenture.

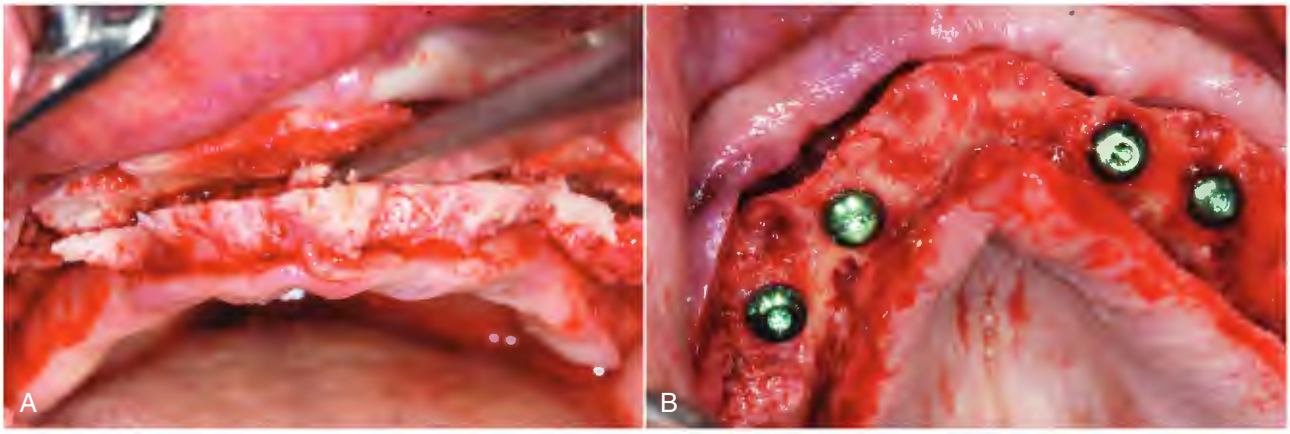


FIGURE 25-57. **A,** During surgery, the CHS for an overdenture may require an osteoplasty before implant placement. **B,** The implants are inserted for a RP-5 overdenture.

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A rigid overdenture (RP-4) has identical requirements for implant support in position and number as a fixed prosthesis because it is rigid during function. Soft tissue support in addition to implant-supported removable implant restorations with an excessive CHS are recommended when it is not possible to adequately engineer the implant support system. Misch describes the "hidden cantilever" beyond the cantilevered bar with a rigid IOD.[46] When the overdenture has no movement during function, the cantilever does not stop at the end of the cantilevered substructure but ends at the last occlusal contact position on the prosthesis, often the distal of a second molar (Figure 25-58).

The position and type of overdenture attachments may render an overdenture rigid during function even in the absence of distal cantilevers on the bar. For example, when three anterior implants are splinted together and a Hader clip is used to retain the prosthesis, if the Hader clips are placed at angles to the midline, the attachments have limited movement and result in a rigid overdenture during function (Figure 25-59). Misch suggests the prosthesis movement, not the individual attachment movement, should be evaluated.[46] Overdentures with both implant and soft tissue support benefit from a prosthesis designed to have more than one direction of movement.

The excessive CHS on a RP-5 prosthesis often makes the restoration more unstable and often requires more soft tissue support. In RP-5 overdentures, there are two different components of the CHS: (1) the distance from the crest of the ridge to the height of the overdenture attachment and (2) the distance from the overdenture attachment to the occlusal plane. The greater the distance from the attachment to the occlusal plane, the greater the force on the prosthesis to move or rotate on the attachment and the greater the prosthesis mobility (and less the stability). Hence, more tissue support is required during function. This may cause more sore spots under the prosthesis and may accelerate the posterior bone loss.

Fewer reports have been published for maxillary IOD compared with mandibular overdentures. Most clinical reports discuss RP-5 restorations with posterior soft tissue support and anterior implant retention. According to Goodacre et al., mandibular overdentures have one of the highest implant success rates, and the restoration with the highest implant failure rate is a maxillary overdenture (19% failure rate).[3] For example, in 1994, Palmqvist et al. reported similar poor results in a 5-year prospective, multicenter study on 30 maxillae and 103 mandibles.[24] Jemt and Lekholm reported that the survival rate of

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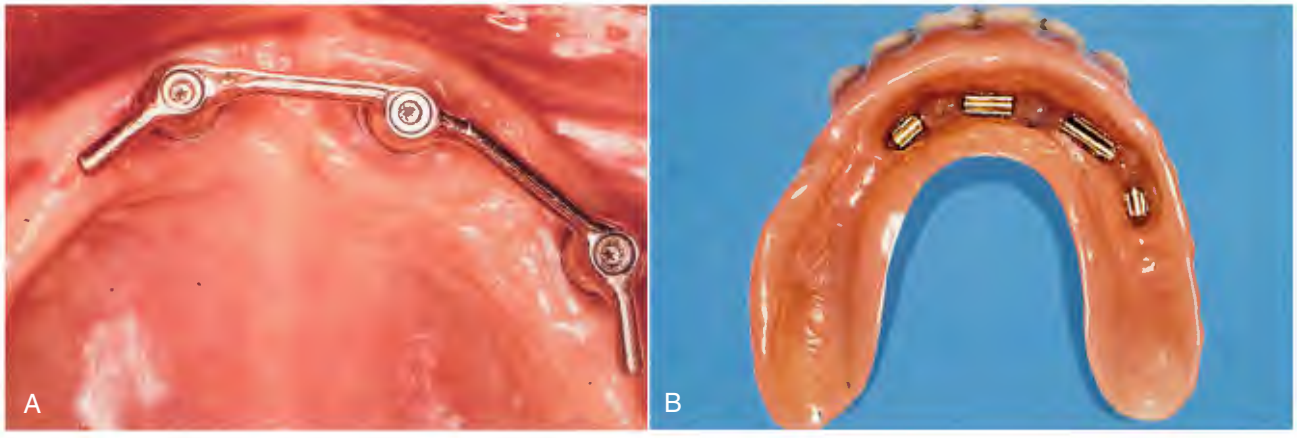


FIGURE 25-58. **A,** A hidden cantilever is when the overdenture prosthesis is rigid and therefore the cantilever extends beyond the connecting bar. When Hader clips are positioned at an angle to each other, the prosthesis is rigid. In this case, the cantilever extends bilaterally to the second molar in the restoration. **B,** Hader clips rotate around a bar. However, when placed in different planes of movement, the prosthesis is rigid and has no movement during function.

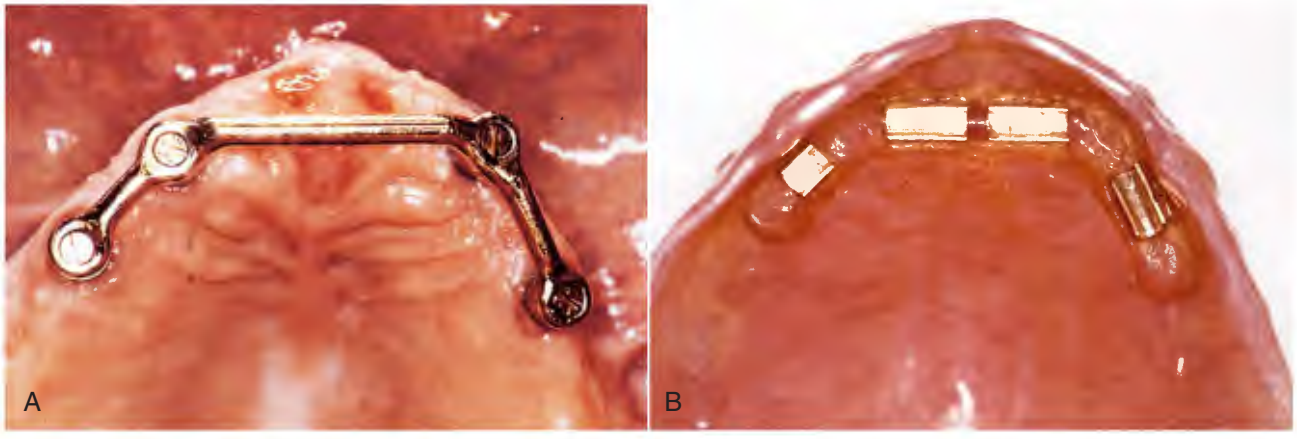


FIGURE 25-59. **A,** The Hader bar in this patient is in three different planes of rotation. **B,** The three Hader clips cannot rotate around the arch, so the four implants support a rigid RP-4 prosthesis. The cantilever extends to the second molar.

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mandibular implants was 94.5% and 100% for mandibular prostheses.[26] In the maxillae, the implant survival rate was 72.4%, and the prosthesis survival rate was 77.9%. The authors suggested that the treatment outcome may be predicted by bone volume and quantity. A prospective study by Johns et al. reported on maxillary IODs at 1 year, 3 years, and 5 years.[27] Sixteen patients were followed throughout the whole study with a cumulative success rate of 78% for prostheses and 72% for implants. A pooled implant survival rate of maxillary IODs was reported at 76.6% at 5 years.[28–31]

Alternatively, Misch followed 75 maxillary IODs (RP-4) and 615 implants for 10 years with 97% implant survival and 100% prosthesis survival rates. The primary differences in these treatment modalities have been a completely implant-supported, retained, and stabilized maxillary IOD (RP-4); a greater implant number; and key implant positions following the guidelines of treatment planning based on basic biomechanical concepts to reduce failure and decrease risks.

Maxillary Implant Overdenture Treatment Options

Whereas only two treatment options are available for maxillary IODs, five treatment options are available for the mandibular IOD (Box 25-5). The difference is primarily due to biomechanical disadvantages of the maxilla compared with the mandible. Independent implants are not an option for maxillary IODs because bone quality and force direction are severely compromised. In addition, the attachment is closer to the tissue, and the CHS from the attachment is greater, so the prosthesis has more movement (Figure 25-60). Cantilever bars are not recommended for the same reasons.[47] As such, the two treatment options are limited to a removable prosthesis RP-5 restoration with four to six implants with some posterior soft tissue support, or a RP-4 restoration with six to 10 implants (which is completely supported, retained, and stabilized by implants).

Posterior implants (premolar and molar) without implant support in the canine regions are sometimes connected with a full-arch bar for a maxillary overdenture (Figure 25-61). This is not indicated when a bar extends from premolar to premolar around an arch because the overdenture prosthesis is completely implant supported (RP-4) because it does not move during function or parafunction. As such, the overdenture acts as a fixed restoration. The rigid removable IOD should have the same implant support as a complete-arch fixed restoration (not less).

Another poor treatment option for fully edentulous maxillae is the placement of implants in each posterior quadrant (no canine position) with independent bar segments and an overdenture (Figure 25-62). This treatment option is prone to failure for the following reasons:

1. If the IOD in the maxilla has only posterior implants and is not rigid, the prosthesis rocks forward and up every time the patient bites into food or the mandible moves into excursions. The rigid, posterior implants act as fulcrums, and the restoration is not stable. The implants in the premolar regions act as the fulcrum, and the incisal edge of the prosthesis is cantilevered from this position. As a result, the attachment system repeatedly fails. This type of prosthesis resembles a Kennedy class IV partial denture and is the least stable restoration in prosthetics (Figure 25-63). In fact, it is usually less stable than a conventional denture.
2. The posterior implants in this type of restoration are in a straight line and do not resist the lateral forces as well. Often the attachments repeatedly need replacement, and all the implants on one side of the arch may fail (Figure 25-64). Maxillary complete fixed prostheses and overdentures have a greater incidence of implant failure and prosthetic complications than mandibular counterparts even when the implant positions are similar.[3,22,24] These observations further emphasize the need for more implants and fewer pontics in the restoration of a maxilla compared with the mandible.

BOX 25-5 Maxillary Implant Overdenture Options

1. RP-5 prosthesis: four to six implants in three to five arch positions
2. RP-4 prosthesis: six to 10 implants in all five arch positions

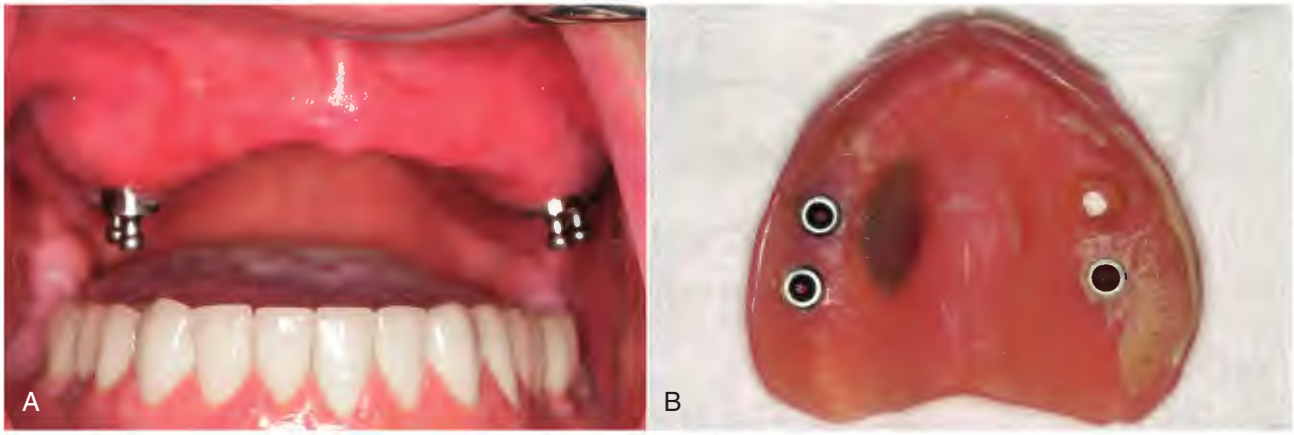


FIGURE 25-60. **A,** Individual implants in posterior regions of an overdenture. The prosthesis is unstable and rocks up in the front and down in the back. Overdentures with bilateral, independent implants are more prone to complications of the implant system (implant–bone interface, abutment screws, prosthetic screws, and so on). **B,** The prosthesis has instability. The attachments repeatedly wear and need replacement.

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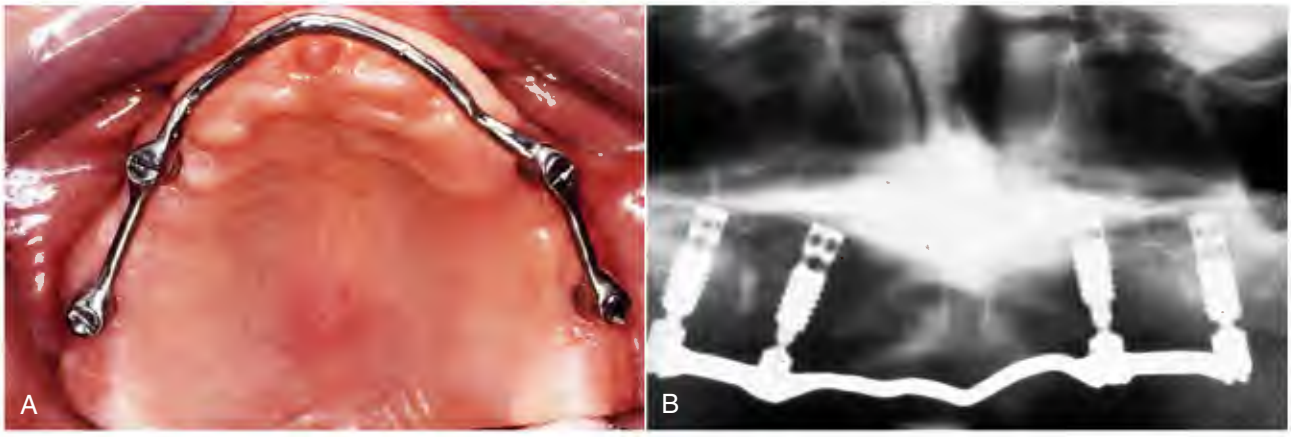


FIGURE 25-61. **A,** This overdenture bar extends from second premolar to second premolar. The anterior bar represents a span of eight pontics and is too long for proper prosthetic support. The overdenture, when in place, is rigid over this bar design, and as such, requires as much support as a fixed prosthesis. **B,** A panoramic radiograph of the four implants and bar for a RP-4 overdenture. The anterior implant has 50% bone loss within the first year of function.

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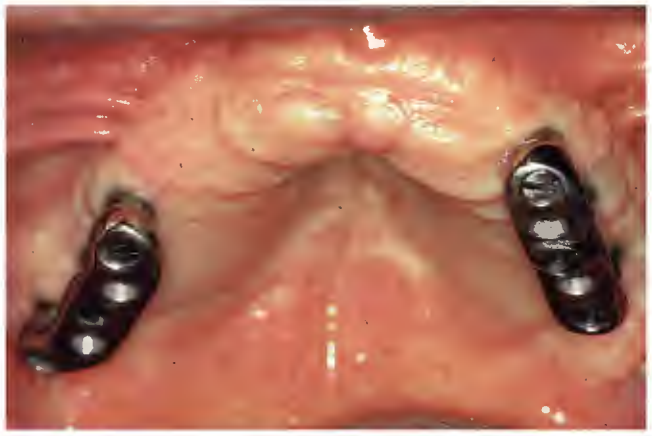


FIGURE 25-62. Posterior implants with individual bars allow rocking of the prosthesis, which accelerated attachment wear and prosthetic screw loosening.



FIGURE 25-63. A Kennedy-Applegate class IV partial denture has natural posterior teeth for the clasp attachment and the restoration replaces anterior teeth. This is a very unstable type of prosthesis because it rocks on the posterior, rigid teeth.

Option 1: Maxillary RP-5 Implant Overdenture

The first treatment option is a RP-5 prosthesis. This option is not as beneficial to the patient compared with mandibular RP-5 restorations. A maxillary denture often has good retention, support, and stability. A RP-5 maxillary IOD may rock and have more movement than a denture because the anterior implants act as a fulcrum under the prosthesis. The major advantages of a RP-5 maxillary IOD is the maintenance of the anterior bone and a less expensive treatment option than a RP-4 or fixed prosthesis. The RP-5 overdenture treatment is less expensive than a RP-4 overdenture because bilateral sinus grafts are not required to support molar implants. Therefore, the RP-5 treatment plan is often used as a transition to a RP-4 prosthesis when financial considerations of the patient require a staged treatment over several years.

When the premaxilla under a conventional denture loses height of bone, the denture begins to rotate up in the front and down in the back. As a result, the maxillary denture becomes much less stable to any lateral forces. Hence, protection of the premaxillary bone is eminent. Implants can prevent the continued bone resorption of the premaxilla. The patient is



FIGURE 25-64. Posterior implants with individual bars. The coping screw repeatedly became loose and the implant eventually failed.

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encouraged to have implants placed before complications related to bone loss.

The first treatment option for a completely edentulous maxilla uses four to six implants supporting a RP-5 prosthesis, of which three are usually positioned in the premaxilla. Based on the poor success rates reported in the literature, specific biomechanical requirements, and poor bone quality, the fewest number of implants for a RP-5 maxillary overdenture should be four, with a wide A-P spread (Figure 25-65). Implant number and location are more important than implant size, but the implants should be at least 9 mm in length and 3.5 mm in body diameter.

An improved number of implants for a RP-5 prosthesis is five. The key implants are positioned in the bilateral canine regions (guideline 3 of treatment planning) and at least one central incisor position (guideline 2 of treatment planning). Other secondary implants may be placed in the first or second premolar region (five-sided arch of treatment planning) (Figure 25-66).

When an implant cannot be placed in at least one central incisal position, the incisive foramen may be considered for implant insertion. Another alternative is the use of a lateral incisor implant. In such cases, owing to the reduced A-P spread of the lateral incisor in the anteriormost implant site, the second premolar position also should be used on the contralateral side (along with the canine) to improve the A-P spread. Six implants are often indicated for a RP-5 prosthesis when force factors are greater (Figure 25-67).

The implants are always splinted together with a rigid bar. There is no distal cantilever, and the bar design should follow the dental arch form but slightly lingual to the maxillary anterior teeth. The prosthesis should have at least two directions of movement; however, three or more are preferred. Therefore, a Dolder clip or O-ring may be used if it is placed in the center of the arch and perpendicular to the midline. A Dolder clip has a spacer over the clip to allow some vertical movement before rotation. When O-rings are used to retain the restoration, they may be positioned more distal than a center Dolder clip, often immediately distal to the canine position. O-rings may also be used just distal to the last abutment on each side or between the implants. When intermediate O-rings are used, relief is provided distal to the bar to allow prosthesis movement toward the tissue under posterior occlusal forces.

The maxillary RP-5 IOD is designed exactly as a complete denture with fully extended palate and flanges. The restoration should be allowed to move slightly in the incisal region during function so that the restoration may rotate toward the posterior soft tissue around a fulcrum located in the canine or premolar position.

The benefits of a RP-5 maxillary overdenture are retention and stability from the implants. Posterior support is obtained from the soft tissue. Of course, the other primary benefit is the maintenance of the premaxillary bone because of the implant stimulation. There is also a reduced fee compared with a RP-4 prosthesis because bilateral sinus grafts are not required for

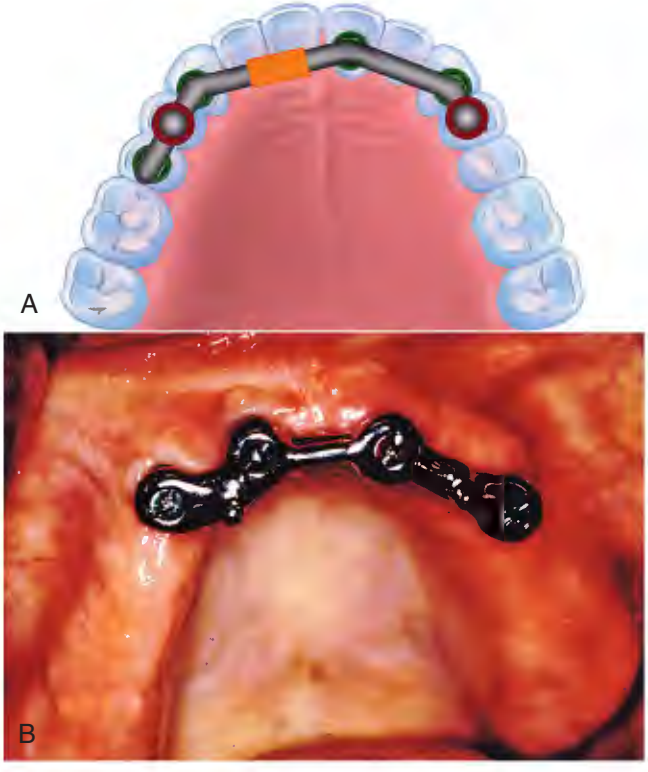


FIGURE 25-65. At least four implants, splinted together, are indicated for a maxillary implant overdenture, at least three of which are placed in the premaxilla.



FIGURE 25-66. An improved implant number for a RP-5 implant overdenture is five implants. One implant is in each of the five rotation positions of an arch.

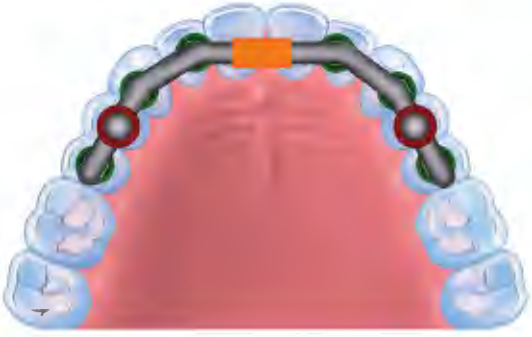


FIGURE 25-67. An alternate design with six implants includes key implants in the canine regions, implants in the lateral incisor regions, and secondary implants in the second premolar regions to improve the anterior-posterior spread. Dolder clips or O-rings can be used in such a way as to allow two directions of prosthesis movement.

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molar implants, and the number of implants may be as few as four.

Option 2: Maxillary RP-4 Implant Overdenture

The second option for a maxillary IOD is a RP-4 prosthesis with six to 10 implants, which is rigid during function (Figure 25-68). This option is the preferred IOD design because it maintains greater bone volume and provides improved security and confidence to the patient compared with a denture or RP-5 restoration. The loss of bone width in the premaxilla does not require a bone graft or hydroxyapatite graft for lip support as for a fixed prosthesis. However, the cost of treatment is more similar to that for a fixed hybrid prosthesis. The RP-4 restoration most often still requires sinus grafts and posterior implants. Bone grafts for the entire premaxilla for a fixed prosthesis may require the iliac crest as a donor site because larger volumes of bone are required. Hence, the RP-4 restoration may be required for facial esthetics if augmentation procedures are not performed (Figure 25-69).

Unfortunately, many practitioners believe that the RP-4 overdenture requires fewer implants and less attention to the biomechanics of occlusal load compared with a fixed restoration just because the restoration is removable. In the author's opinion, this is a primary cause of implant failure in maxillary IODs. When the IOD is completely supported, retained, and stabilized by the implant support, it acts as a fixed prosthesis. Combined factors such as reduced cost, patient fear of bone grafting, and lack of advanced training of the doctor are often the determining factors motivating the choice for a maxillary IOD.

Treatment planning for RP-4 maxillary overdentures is very similar to fixed prosthesis because the IOD is fixed during function. Two of the key implant positions for the RP-4 maxillary IOD are in the bilateral canines and distal half of the first molar positions (guidelines 3 and 4 in treatment planning). These positions usually require sinus grafts in the molar position. Additional posterior implants are located bilaterally in the premolar position, preferably the second premolar site. In addition, at least one anterior implant between the canines often is required (guideline 2 in treatment planning). The anterior implant often may be placed in the incisive canal when inadequate bone width is present (Figure 25-70). Therefore, six implants is the minimum suggested number for a RP-4 treatment option, and seven implants are used more often. When force factors are greater, the next most important sites are the second molar positions (bilaterally) to increase the A-P spread and improve the biomechanics of the system. A tenth implant may be placed in the premaxilla for a tapered arch form.

The six to 10 implants are splinted together around the arch with a rigid bar (five-sided arch in treatment planning). Four or more attachments are usually positioned around the arch. This provides a retentive, stable overdenture prosthesis. Usually palatal coverage is maintained. This helps prevent speech problems and food impaction.

The occlusal scheme for this RP-4 restoration is similar to that for a fixed prosthesis: centric occlusion around the arch and only anterior contact during mandibular excursions (unless

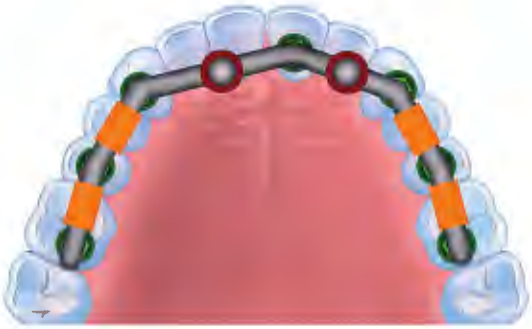


FIGURE 25-68. A maxillary overdenture bar and RP-4 prosthesis is supported by seven to 10 implants and is rigid during function.



FIGURE 25-69. A RP-4 implant overdenture may use six to 10 implants, similar to a fixed prosthesis because the restoration is rigid. In this patient, the nine implants are used in a patient with an excessive crown height space and greater force factors.

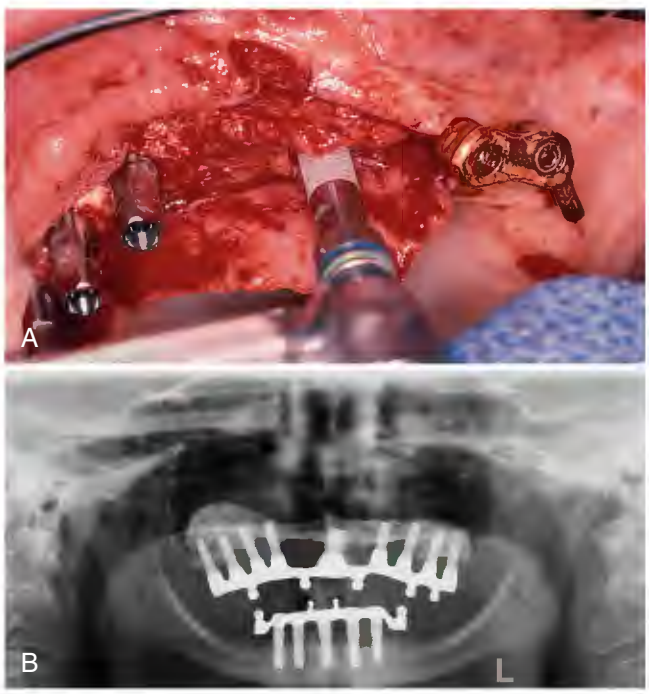


FIGURE 25-70. **A,** An anterior implant may be positioned in the incisive canal when the residual ridge is insufficient for an implant in the central incisor position. **B,** A panoramic radiograph of maxillary and mandibular implants supporting RP-4 prostheses. The central incisive implant allows the use of three implants in the premaxilla, splinted to posterior implants.

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opposing a mandibular complete denture). The maxillary overdenture should be removed during sleep to prevent nocturnal parafunction. If the patient wears maxillary and mandibular overdentures, only the mandibular restoration needs to be removed.

Fixed Prosthesis versus Overdenture Complications

Maxillary IOD complications, such as attachment wear and prosthesis or component fracture, are more frequent than with a fixed restoration and primarily occur as a result of inadequate bulk of acrylic and minimal strength of the small framework compared with a fixed restoration (Table 25-3).

The CHS is critical for maxillary overdentures, and more often a lack of space may compromise tooth position compared with the mandibular situation. A minimum of 12 mm of CHS is required for IOD to insure adequate room for a connection bar for the implants and bulk of acrylic in the IOD.

The palatal coverage of most maxillary IODs should be similar to that of a complete denture (Figure 25-71). The extent of range from full to horseshoe palate designs has been reported in the literature with varied degrees of success.[47] Many maxillary denture wearers have accommodated to the acrylic resin palate of a denture. Yet many restoring dentists routinely eliminate the palate on maxillary IODs with consequences such as food entrapment (because the tongue often crushes food against the palate and pushes the food debris under the restoration) and impaired speech (because air is forced under the palatal flange and over the labial flange of the denture) (see Figure 25-58, *B*). The patient rarely complains of these two problems with a denture and, as a result, is unhappy with the final implant restoration. In addition, the risk of prosthesis fracture is increased when the palate is removed because the bulk of acrylic is reduced. Therefore, the palate of the prosthesis usually should be maintained with the IOD.

Some patients express a primary desire to eliminate the palate of the maxillary complete denture. These patients include gaggers and patients uncomfortable with anything approaching the soft palate, patients with tori or exostoses, singers and actors because of a perceived change of voice caused by the change in volume from the prosthesis, food and wine consumers who use their palate to taste subtle differences in preparations, and a new denture wearer unfamiliar with the palatal aspect of a maxillary denture. As a result, patient needs and desires may require the natural palate of the patient to be left uncovered when wearing a maxillary overdenture.[48]

To reduce the complications of speech or food impaction when the palate of the restoration is reduced, the following technique has been used with some success. The palate of the preexisting prosthesis is coated with a pressure-indicating paste or spray. The patient is asked to pronounce the linguoalveolar consonants *T* and *D*. In dentate patients, when these sounds are produced, the tip of the tongue contacts the anterior alveolar ridge, and the sides of the tongue are in tight contact with the maxillary teeth and palatal gingiva. The maxillary overdenture palate is not eliminated any farther than 5 mm posterior to the tongue contact area. This ensures that the tongue will still contact the acrylic resin on the palate and will prevent food and air from being forced under the denture.

The processing model for the prosthesis then is scored 1 mm wide and 1 mm deep with a round bur corresponding to this position. The score line proceeds from the hamular notch in the posterior along the hard palate 5 mm medial to the alveolar ridge–palatal line angle (position of the greater palatine artery) to the anterior aspect 5 mm distal to the tongue position noted previously. The cast is not scored over the midpalatal suture because this soft tissue is very thin and cannot be readily depressed. When the denture is processed, a small lip of acrylic resin fills this score line, and when the overdenture is inserted, it will depress the tissue along this region gently and ensure intimate tissue contact. This further prevents food and air from being pushed under the overdenture. Because the *D* and *T* position of the tongue is several millimeters posterior to the position of the maxillary teeth, several millimeters of acrylic resin remain on the premaxilla. This reduces the risk of fracture of the maxillary overdenture.

The anterior implants, connection bar, and attachments should be lingual to the position of the anterior teeth so as not to interfere with proper denture tooth position. However, this position may increase the height of the palatal slope in the region of the premaxilla compared with the original denture. To reduce this occurrence, a low-profile bar and attachment is often the design of choice to minimize the prosthesis bulk. Before designing the connecting bar and attachment design, a

TABLE 25-3
Comparison of Maxillary Restorations

Factor	FP-3	RP-4
Psychological	+++	+
Material	Porcelain fused to metal	Bar, metal, and overdenture
Lip support	+	+++
Esthetics	Pink porcelain (=)	Resin (=)
Phonetics (airway, leakage)	+	+++
Function (food entrapment)	+++	+
Maintenance	+++	More change of attachments (—)
Repair ease	—	+
Force factors	—	Remove at night (+)
Number of implants	=	=

+++, Best; +, better; =, similar; –, poor.

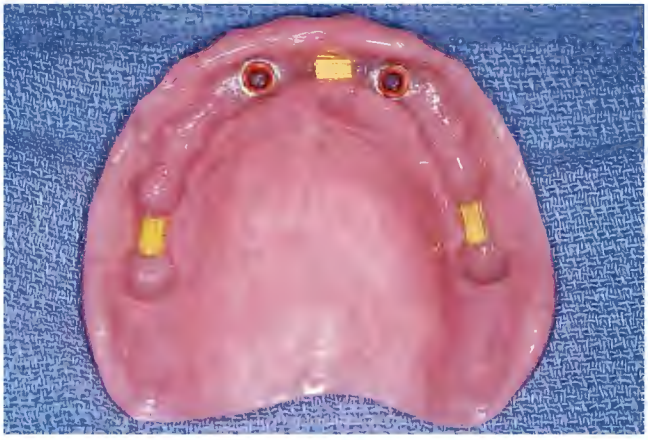


FIGURE 25-71. A maxillary implant overdenture should have a palatal coverage to decrease fracture, food impaction, and speech problems.

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vacuum or press form is made of the contour of the preexisting denture and overdenture try-in prosthesis (similar to the method used for the surgical template), and the template helps design the bar-attachment system within the confines of the final prosthesis.

Conclusion

Maxillary IODs may be as predictable as mandibular overdentures when biomechanical considerations specific to the maxilla are incorporated in the treatment plan. In general, this requires implants in greater numbers and a greater awareness of prosthetic principles.

Only two maxillary IOD treatment options are available. The fewest number of implants for this restoration is four to six implants to support a RP-5 prosthesis. A rigid IOD (RP-4) most often requires the placement of seven or more implants. A completely implant-supported overdenture requires the same number and position of implants as a fixed restoration. Thus, sinus grafts and anterior implants usually are indicated, whether the restoration is fixed or removable. In other words, maxillary IODs are completely different than their mandibular counterpart. In the completely edentulous maxilla, an IOD is often the treatment of choice. Unlike in the mandible, the maxillary lip often requires additional support as a consequence of bone loss. An ideal high lip line exposes the interdental papillae between the anterior teeth. Using overdentures to replace the hard and soft tissue is easier than attempting to do this with bone and soft tissue or porcelain-to-metal restorations.

The maxillary partial and complete edentulous arch is a common occurrence in dentistry. Implant restorations are usually the treatment of choice compared with traditional fixed or partial dentures or complete dentures.

The treatment plan for an edentulous maxilla or partially edentulous premaxilla with multiple adjacent teeth missing is often different than the mandibular restoration. As a consequence, the unique aspects of the arch include the use of grafting more often, more implants to replace the missing teeth, and a more specific implant size.

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CHAPTER 26

Principles of Fixed Implant Prosthodontics: Cement-Retained Restorations

Carl E. Misch

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Protection of the Prosthesis

A predictable surgical protocol for endosteal rigid fixation was developed and reported by Brånemark and Adell et al. more than 30 years ago.[1,2] However, on occasion, an implant may fail during the initial healing process from traumatic surgery, compromised healing, poor case selection, or unknown reasons. Patients understand that medicine is not an exact science and that their bodies may respond with individual variation to a standardized procedure. As a result, patients are more inclined to accept the implant surgical failure. To the contrary, once the implant is uncovered and the patient is told that it is successful, any short-term complications that lead to its loss or compromise of the implant often become unacceptable to the patient.

The patient rarely can evaluate the causes of implant surgical failure but, on the contrary, can assess several aspects of the prosthetic result, such as esthetics, occlusion, function, speech, and maintenance. The additional time, appointments, laboratory steps, and associated cost of inventive prosthetics required on poorly placed implants are not fully appreciated. Patients may believe that bone loss or implant loss resulted because the screws were too tight or too loose, the casting did not fit adequately, or the occlusion was incorrect rather than understand the original cause of poor bone quality or poorly angled implant bodies from the surgical phase. All of these factors complicate patient management for restoring dentists.[3]

The time required to remove a failed implant after initial healing and place an additional implant is often minimal and often may be accomplished at the second-stage surgical appointment. The time required to fabricate the prosthesis is usually five or more prosthetic appointments. An implant failure after final prosthesis delivery also may result in five additional prosthetic appointments and additional laboratory fees. In addition, an implant failure after loading may cause significant bone and soft tissue loss. As a result, replacing the implant may require bone and soft tissue grafting and additional time required before reimplantation. The patient may blame the restoring dentist for the associated bone loss after implant failure.

The restoring dentist usually educates the patient about the limitations of the restoration of a malpositioned tooth. Orthodontic treatment or extraction often is suggested with natural teeth rather than a compromised final prosthetic result. Yet, still too often, dentists consider implants successful with the sole criterion of rigidity. They often overlook an underengineered implant foundation with too few implants, improper implant placement in mesiodistal and buccolingual directions, an excessive sulcus depth, insufficient load-bearing surface area of the implant body, poor angulation, poor bone quality, unacceptable soft tissue contour and quantity, and the relationship of these to esthetic requirements and their influence on complications. Long-term acceptable criteria should be established and the limiting factors identified before the prosthetic reconstruction to minimize the occurrence of complications related to the restoration, maintenance, or patient management.

The retention system of the prosthesis should be designed before surgery. In a screw-retained fixed prosthesis, anterior implants are to be placed more lingual than for a cement-retained restoration because the access hole to the prosthetic screw is placed in the cingulum. The correction of facially placed implants for screw-retained restorations may be more difficult and may lead to unmanageable esthetic compromises.

A cement-retained restoration should ideally have 8 mm or more of crown height space (CHS). This dimension permits at least 1 mm for occlusal material on the crown, 5 mm of abutment height for retention and resistance form (with a subgingival margin), a 1-mm subgingival margin, and 2 mm for a junctional epithelial attachment above the bone (Figure 26-1). If inadequate space is present, an osteoplasty of the bone is indicated before implant insertion. In other words, the restoring dentist should identify the type and contour of the restoration, including the type of retention system (i.e., cement or screw retained), early in the treatment plan and convey this information to the implant surgeon before implant placement. The surgical phase should aim at providing the best possible foundation to protect the long-term performance of the prosthesis.[3]

Cement-Retained versus Screw-Retained Implant Fixed Prostheses

The discussion of screw versus cement retention of the prosthesis applies to the crown or superstructure, not the abutment (Figure 26-2). The abutment is screw retained into the implant body because of reduced surface area of the small diameter and length of abutment posts and to eliminate the risk of cement at the bone-level margin of the abutment and implant. Abutment screw loosening is a prosthetic complication and is addressed in Chapter 28.

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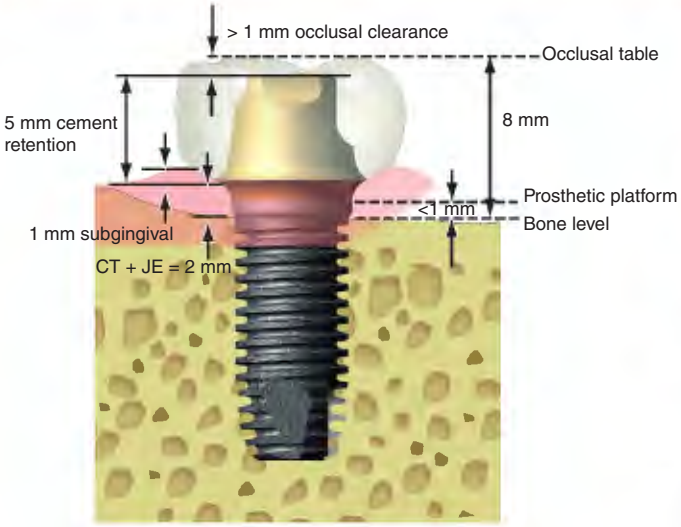


FIGURE 26-1. A cement-retained implant crown should ideally have 8 mm or more of crown height space. This dimension permits a 5-mm-high abutment (with a 1-mm subgingival margin). *CT,* Connective tissue; *JE,* junctional epithelium.



FIGURE 26-2. Implant restorations may be screw retained *(right)* or cement retained *(left)* to the implant abutments.

Retrievable Restoration

Implant prostheses have more complications (i.e., abutment screw loosening, porcelain fracture, crestal bone loss, and implant failure) during the first year of loading. As such, if the prostheses were able to be removed, it would be advantageous. Some implant manufacturers and dentists recommend screw-retained fixed prostheses on implants as a general rule, suggesting that only a screw-retained restoration is retrievable (Figure 26-3). In addition, if screw loosening occurs and the crown no longer is connected to the implant body, the implant is protected from overload. However, these two reasons to screw retain a restoration overlook several factors.

Although widely variable figures have been published, one can estimate that fixed partial dentures (FPDs) on natural teeth have a mean life span of 10 to 15 years.[4-8] In contrast, implant-supported fixed prostheses routinely have demonstrated an implant survival rate greater than 90%.[9-16] The complication most often observed with fixed prostheses supported by natural teeth for which a new prosthesis is required is decay.[4,7] The second most often occurring complication is related to endodontics. Implant abutments do not decay or need endodontic therapy. As a result, this is a primary reason fixed restorations on natural teeth often have a shorter long-term life span than implant restorations. Hence, implant prostheses have more short-term complications, and natural teeth have more long-term complications.



FIGURE 26-3. The primary advantage of a screw-retained prosthesis *(right)* is retrievability. However, this implies that the cemented implant restoration *(left)* cannot be readily removed.



FIGURE 26-4. A coping may be cemented to a natural tooth, and a lingual or buccal screw may be used to retain the prosthesis.

If a restoring dentist desires to fabricate a screw-retained prosthesis to permit removal and facilitate the management of potential complications, a consistent thinking process would be to use this type of restoration for prostheses on natural teeth because of their higher incidence of late complications. A screw-retained prosthesis may be fabricated for natural teeth in fewer appointments and with less cost than for implants. A coping may be cemented to the tooth with a receptor site for a screw, and the screw may retain the prosthesis (using the same impression and stone model technique) (Figure 26-4). Yet almost all restoring dentists choose to cement tooth-supported restorations. Many of these same dentists still feel obligated to retain implant-supported restorations with screws for retrievability yet continue to use permanent cement on natural abutments. This is an inconsistent philosophy to retain fixed restorations.

The need for implant prosthesis removal often is justified by the need to address problems that have evolved from the screw-retained procedure (e.g., prosthetic screw loosening and increased risk of porcelain fracture). Clinical experience, case series studies, and implant registries indicate higher complication rates with screw-retained fixed prostheses.[12,14,17] As the

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profession has evolved and understands the benefit of cement-retained restorations, the trend toward the use of cement-retained prostheses has grown.[15-20]

Advantages of Cement-Retained Prostheses

Considerable advantages can be gained with cement-retained restorations, including retrievability, ease of splinting implants, reduced incidence of unretained prostheses, more passive castings, improved correction of nonpassive castings, progressive loading, improved direction of loads, improved hygiene of the implant sulcus, enhanced esthetics, improved access, reduced fracture of components, reduced crestal bone loss, reduced porcelain fracture, reduced cost, and less chair time[18-20] (Box 26-1). As a result, the vast majority of the fixed prostheses are cement retained in the United States. This chapter presents the principles for cement-retained fixed implant prostheses.

Retrieval of the Cement-Retained Fixed Prosthesis

The statement that screw-retained restorations are retrievable implies that cemented prostheses are not. For almost every fixed prosthesis on natural teeth, a transitional prosthesis is cemented and then retrieved to cement the final restoration (Figure 26-5).

BOX 26-1 Advantages of Cement-Retained Restorations

1. Retrievable (soft access cement)
2. Ease of splinting implants
3. Reduced unretained restorations
4. More passive casting
5. Easier correction of nonpassive casting
6. Progressive loading
7. Improved force direction of loads
8. Improved hygiene of implant sulcus
9. Enhanced esthetics
10. Improved access
11. Reduced fracture of components
12. Reduced crestal bone loss
13. Reduced porcelain fracture
14. Reduced cost
15. Less chair time

Hence, cemented fixed prostheses can be retrievable when a "soft-access" cement is used as a luting agent.

In a screw-retained prosthesis, the access hole is covered with composite. To retrieve the screw-retained restoration, the dentist must remove the occlusal obturation, the underlying cotton pellet, and the coping screw. After the prosthesis is reinserted, the screws may need to be changed and are torqued, and the occlusal access holes are restored by the dentist. This represents a considerable time investment. To remove and recement a cemented prosthesis is easier and faster.

Protection of the Implant

A loose prosthetic screw can protect the implant under the loose crown because the mobile crown reduces the stress to the implant body. But for implant prostheses with more than one implant splinted together, one must remember that every time a screw loosens, the remaining abutments bear an additional force. The forces include increased moment force offset loads and additional forces on the remaining abutments. The increased loads to the remaining implants may lead to implant loss, component fracture, and bone loss.[21,22] It is easier to splint cemented crowns together than to connect screw-retained restorations.

Unretained Restorations

Reports indicate that as many as 6% to 20% of maxillary prosthetic screws loosen at least once during the first year of function.[23] The prosthetic screws are less than 1.5 mm wide and engage only three or four threads of the abutment (Figure 26-6). The condition is found more often in single-tooth restorations than when abutments are splinted.[13,14,22] However, in clinical studies, reports of unretained cemented implant prostheses constitute fewer than 5% of cases.[24,25] Recurring uncemented prostheses are a more unusual occurrence compared with loose prosthetic screws. Hence, when implant abutments are splinted together, it is safer to cement rather than screw retain the restoration.

Passive Casting

Ideally, when a prosthesis is retained by prosthetic (coping) screws, the restoration passively sits on top of the abutments, and the prosthetic screws fixate the two components together. The screws place a compressive or tensile force on the abutments, but no force is transmitted to the implant bodies (Figure



FIGURE 26-5. A transitional prosthesis on teeth is cement retained. Hence, cement-retained restorations are retrievable.



FIGURE 26-6. A prosthetic screw is only 1.5 mm in diameter and only engages three or four threads of the abutment.

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26-7). If, however, the casting of the prosthesis does not sit passively on the abutments for screws, the force of the prosthetic screws are then transmitted to the implant bodies (Figure 26-8).

A screw is a combination of inclined planes and wedges and is one of the most efficient machine designs. A torque force of 20 N-cm applied on a screw can move two railroad cars. This same force applied to a nonpassive casting tends to distort the superstructure, underlying bone, and implant components (Figure. 26-9). Because the force is constant, it can introduce biomechanical creep into the system, which can fatigue materials and bone. An implant does not predictably move within bone, yet retained stresses from nonpassive castings must be accommodated through a bone remodeling process.

When the screw-retained prosthesis is attached to the abutment for screw retention of the implant, no space exists between the crown and abutment. Instead, a metal-to-metal system with zero tolerance for error is created. Nonpassive screw-retained restorations may create permanent strain conditions on the implant system that can be many times greater than that of cemented prostheses. The microstrain applied to the bone may fall beyond the overload zone and into the pathologic zone in which bone remodeling occurs with crestal bone loss or even implant failure.

Nonpassive castings are a primary cause of unretained restorations, crestal bone loss, implant component fracture, and implant mobility.[26,27] A truly passive screw-retained dental restoration is virtually impossible to fabricate on multiple splinted implants.[27] Too many variables are out of the dentist's control when attempting to fabricate a prosthesis with zero tolerance for error, and laboratory procedures may lack the precision needed for such an exact result.

All impression materials shrink while setting.[28] For example, polysulfide materials shrink 0.22%, and addition silicone (polyvinyl-siloxane) shrinks 0.06% at 24 hours.[29,30] Shrinkage may be clinically relevant because implant analogs used in the impression for a screw-retained restoration do not compensate for the dimensional change of the impression material (Figure 26-10).

Dental stone expands 0.01% to 0.1% and does not correlate to the dimensional changes of impression materials.[31-33] In addition, the wax patterns distort while setting or spruing, and the investment material expands[32] (Figure 26-11). The metal castings shrink when cooled, and the shrinkage does not permit an accurate metal-to-metal connection.[34-37] The metal superstructures are often thicker and larger in implant prostheses than in traditional prostheses because the implant abutment is of reduced diameter, and bone loss volume often is replaced by the final prosthesis. Dimensional changes during metalwork fabrication are correlated directly with the size of the casting.[38]

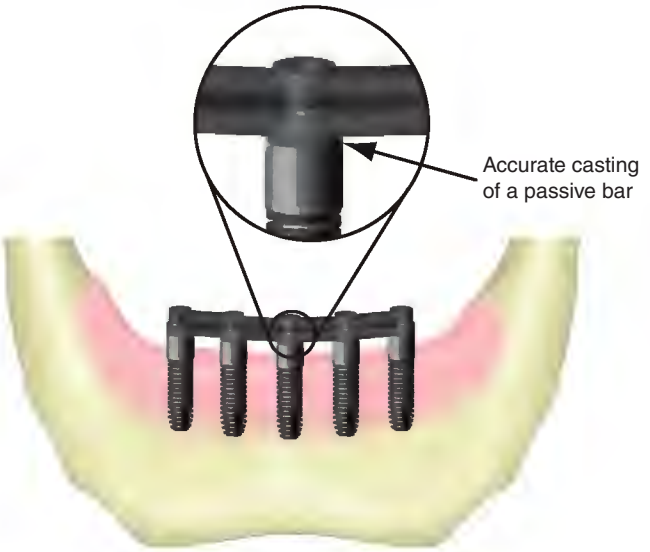


FIGURE 26-7. A screw-retained prosthesis ideally sits passively on the abutments, and the prosthetic screws are held in place by compressive, tensile, and shear forces.

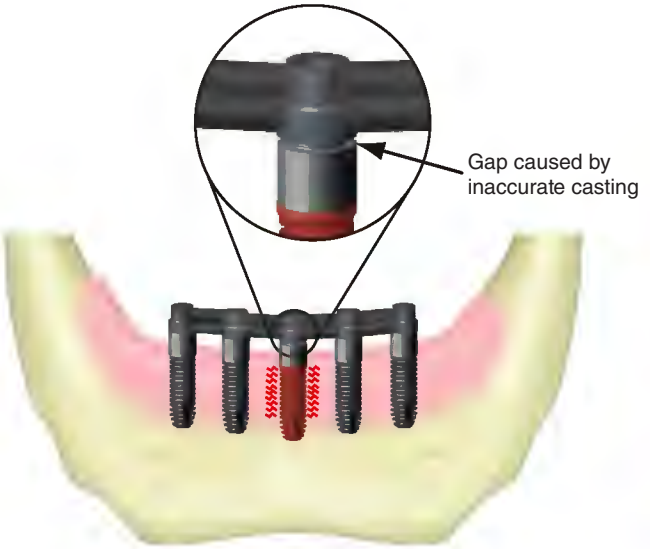


FIGURE 26-8. If the prosthesis is not passive, the torque force placed on the prosthetic screw is transferred to the implant body.

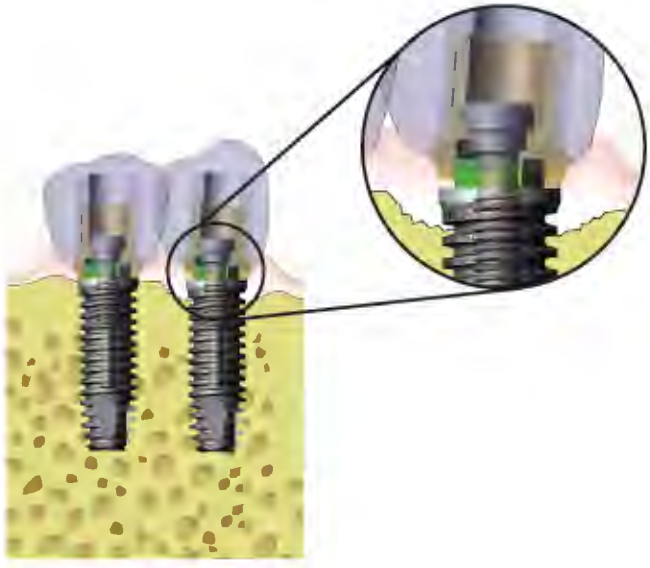


FIGURE 26-9. A nonpassive casting will distort, and the implant may move or strain the bone when the screw is torqued into position.

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FIGURE 26-10. All impression materials shrink after setting. This causes the implant analogs to be in a different position than in the mouth.



FIGURE 26-11. Dental stone expands while setting, and wax patterns distort. Both of these conditions alter the implant analog position.

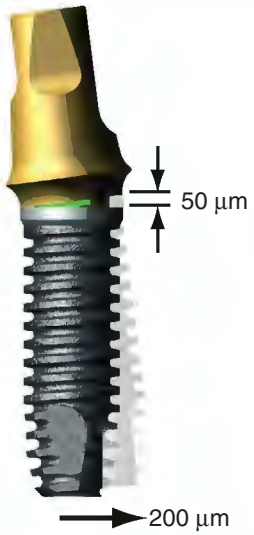


FIGURE 26-12. A misfit of 50 microns of casting may require the prosthesis and implant to move 200 microns before everything is passive.

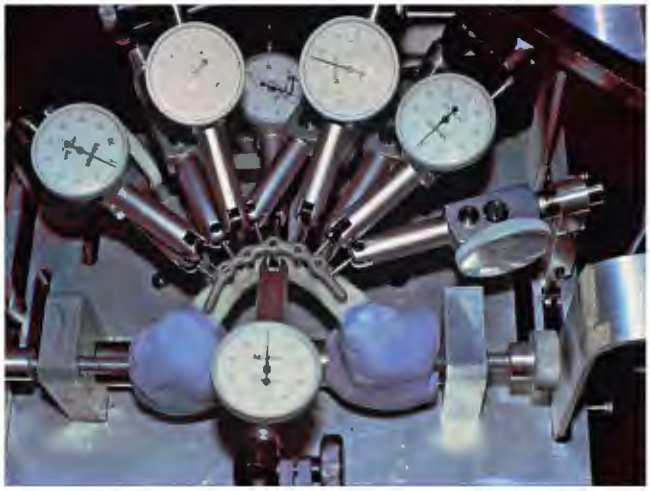


FIGURE 26-13. In a study by Strong and Misch with 100 castings, the most passive casting fabricated to splint five implants moved every implant in a D1 bone simulant from 3 to 8 microns.

The marginal fit and tolerance between the implant analog and implant abutment are often different from actual implant and abutment components.[39] Implant components are not all fabricated to exact dimensions, and each transfer of an implant component has a slightly different size, which leads to misfit and is magnified by the number of different pieces used during the fabrication steps.

Full-arch restorations more often are not passive despite an acceptable metal try-in because the volume of porcelain or acrylic shrinkage may have caused material distortion. Porcelain and acrylic shrinkage also is related directly to material volume and may distort the superstructure even though the superstructure was initially passive.[32]

As a result of all these variables, implant prosthesis distortions ranging from 291 to 357 microns may be observed during the fabrication of the restoration.[37] Passive final restorations are highly unlikely when more than two implants are splinted together and support a prosthesis with screw retention as the method of fixation. If a casting has a 50-micron misfit, the casting and implant may have to move 200 microns before the system is completely passive (Figure 26-12). This is a considerable risk to create crestal bone loss, loose prosthetic screws, and implant failure.

In a study by Strong and Misch, a screw-retained bar was fabricated on five Nobelpharma implants placed in a simulated anterior mandible made of polymethylmethacrylate with a hardness factor of D1 bone density. Three different impression materials and two different dental stones were used (with both direct and indirect impression procedures). The castings were cast with precious metal. After 100 castings were fabricated, the most passive bar (retained with 10 N-cm) moved every implant from 3 to 8 microns (Figure 26-13). This provides a visual report that screw-retained restorations immediately load implants enough to distort the bone–implant interface, which makes the casting appear as clinically passive.

The "clamping down" while tightening the prosthetic screws of an inaccurate structure may lead to screw loosening and fracture.[40] After prosthesis delivery, an abutment for screw retention or prosthesis screw may loosen between appointments.[41]

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This usually indicates that the casting is not seated passively, yet the cause often is overlooked. Instead, the screws are tightened again (often with more torque), and the bone must remodel to release the strain in the implant system. This strain may lead to crestal bone loss and even implant failure.

Passive castings represent a considerable advantage for cemented prostheses. Stone dies are often used for cemented prostheses, and the expansion of the stone makes the casing more passive. In addition, die spacers on the stone dies help create approximately a 40-micron cement space that compensates for some of the dimensional variation of laboratory materials and permits the fabrication of a more passive casting with cement-retained restorations (Figure 26-14). This cement space even may extend to the margin of the restoration because cement fills the space and decay is not a consequence with implants.

Correction of Nonpassive Prostheses

If a cemented prosthesis is not passive, the casting or abutment may be modified slightly at the same try-in appointment. High-speed carbides with copious amounts of water may be used to modify the abutment, adjust the internal aspect of the casting, or both and may provide an immediate solution.

A screw-in prosthesis that is not clinically passive requires casting separation and soldering of the casting or a new impression (Figure 26-15). The separation of the metal superstructure must respect specific dimensions to ensure the precision of the soldering (0.008 inch). Too much space causes solder shrinkage and a weak joint; too little space may cause distortion from expansion during heating of the casting.[42] Indexing the separate pieces also requires greater time, and the patient must return for another appointment after the laboratory process of soldering, which includes an additional laboratory fee.

Progressive Loading

The bone around an implant takes 1 year or more to obtain its full strength. As a consequence of the surgery, the bone remodels with woven bone (the bone of repair), which is 60% mineralized and is less organized than lamellar (load-bearing) bone. In addition, the strength of bone is often increased after loading in response to the microstrain conditions that change within the bone cell. A gradual loading process to the bone may increase the bone strength and delay the full occlusal load until the bone is stronger.[43] A bilateral comparative study demonstrated that even single-tooth implants sustained greater crestal bone loss and exhibited less dense bone when they were not loaded gradually compared with progressively loaded restorations.[44]

The transitional restoration for a screw-retained fixed prosthesis is more difficult to fabricate. As a result, dentists often do not fabricate a transitional restoration in nonesthetic regions or maintain the same removable prosthesis during the fabrication of the final restoration as was used during implant healing. And even when a screw-retained transitional is fabricated, it is not completely passive. As a result, the implant-to-bone interface is not loaded gradually to improve its density. Instead, the implant-to-bone interface is initially loaded when the nonpassive screw-retained prosthesis is inserted. A screw-retained prosthesis presents difficulty in progressively loading the bone because of the misfit factors for a zero tolerance system as previously discussed.

A cement-retained transitional prosthesis may be used before the delivery of the cement-retained final restoration and gradually load the implant-to-bone interface with acrylic occlusals and gradually increase occlusal contacts over an extended time frame. This protocol does not affect the properties of the final prosthesis retention and leads to an increase in bone density and strength.

Axial Load

A cement-retained implant prosthesis and the implant body may be loaded axially, thus decreasing crestal bone loads. The decrease in crestal bone strain may reduce the incidence of bone loss.[45,46] In addition, the literature has provided evidence that offset loading may cause increased incidence of component failure or screw loosening.[47,48]

In contrast, the axial occlusal load on a screw-retained restoration must load the occlusal screw region. Screw holes are usually 3 mm in diameter, representing 30% or more of the total occlusal surface of posterior teeth and 50% of their functional area because only two thirds of the occlusal table is in the functional regions of loads.[20] Occlusal screws are usually in the ideal location (along the long axis) for primary occlusal contact[45] (Figure 26-16). Most manufacturers suggest the placement of a composite occlusal restoration over the screw access hole or offset loading the crown lateral to the occlusal screw



FIGURE 26-14. Stone expansion and die spacers are advantageous for a passive cement-retained prosthesis.



FIGURE 26-15. A nonpassive screw-retained restoration requires separation and soldering to improve this condition.

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FIGURE 26-16. The ideal location for an occlusal contact is directly over the implant body. The access hole is rarely loaded even when filled with composite resin. Hence, most screw-retained crowns are off-axis loaded.



FIGURE 26-17. A screw-retained restoration does not have a hermetic seal. Therefore, bacteria may exist in the crevice and contribute to crestal bone loss.



FIGURE 26-18. A screw-retained anterior crown often has a facial contour, which makes sulcular hygiene difficult. The floss can reach the top of the free gingival margin but cannot enter the sulcus (which is at a right angle to the ridge lap crown).

region. To direct loads along the long axis of the implant body with a screw-retained crown, occlusal adjustments are made on the occlusal composite obturation placed over the top of the screw. These restorations require additional chair time and wear more rapidly than porcelain or metal, which is the occlusal contact material of choice for a cement-retained restoration. Anterior restorations that are screw retained cannot be loaded as ideally as cemented prostheses. The prosthesis fixation screw is often placed in the cingulum area.

A related advantage is that cemented restorations permit the design of narrow occlusal tables because no minimum dimensions are required for screw holes and surrounding metal. This in turn proves a valuable advantage to prevent overcontouring and promote the design of an emergence profile favorable to periimplant tissue health.

Hygiene of the Implant Sulcus

A screw-retained restoration does not fit the abutment or implant body with a hermetic seal. Therefore, a screw-retained prosthesis does not seal the abutment-to-crown interface or margin, which may harbor bacteria in the crevice (Figure 26-17). The crevice may even act as an endotoxin pump if the components are flexing under load, encouraging the proliferation of microorganisms in the sulcular region.[49,50] This is especially a concern in a subgingival margin. When these screw-retained components are disassembled, the dentist often smells an odor indicative of anaerobic bacteria activity. A cemented crown seals the crown–abutment connection and impairs bacteria penetration.

A screw-retained restoration in the anterior region or in the esthetic zone usually requires the abutment for screw retention to be positioned in the cingulum or the central fossa region of the crown. As a consequence, the facial aspect of the implant crown is cantilevered from the implant with a ridge lap of porcelain, which complicates hygiene procedures at the facial cervical region[51] (Figure 26-18). The emergence profile of an anterior cemented crown does not require a facial porcelain ridge lap because the implant may be placed under the incisal edge rather than the cingulum. This also facilitates the achievement of an esthetic result.

Esthetics

An abutment for cement retention angulated slightly too facially often may be prepared as a natural tooth. The implant body even may be prepared to this effect. A screw-retained restoration on an implant placed slightly too facial may not be able to be modified. Hence, the esthetic aspect of the restoration may be compromised.[52] The occlusal holes in the posterior screw-retained restorations require occlusal restorations to avoid an unesthetic result. Even when composite is placed into the access holes, the restoration is less esthetic. The occlusal aspect of a cement-retained crown is all porcelain and is more esthetic.

Occlusal Material Fracture

The third most common complication for fixed prostheses on natural teeth is porcelain fracture.[4,5] Occlusal material fracture is more common with implants than natural teeth because of the lack of periodontal stress relief with implants and a resultant higher impact force to the occlusal material.[23] A decreased incidence of porcelain or acrylic fracture of the prosthesis has been observed with cement-retained restorations compared with screw-retained prostheses. The screw hole may increase stress

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concentration to the restoring material and more often leads to unsupported porcelain (Figure 26-19). For example, a study presented by Nissan et al. examined the porcelain fracture incidence of screw-retained restorations compared with cemented prostheses.[53] The study used a split-mouth evaluation for bilateral edentulous sites in partially edentulous patients. Ceramic fracture was 38% for screw-retained versus 4% for cemented prostheses. The mean loading period for these restorations was 5 years.

After the material fractures, the repaired site is weaker than its original strength, and recurrent fractures are more common. The patient's concerns and psychological comfort with the prosthesis often are affected. A cement-retained prosthesis does not have a weak link through the surface of the occlusal material.

Access

Access is more challenging in the posterior regions of the mouth for insertion of screw-retained restorations, especially in patients with limited jaw opening. The screwdrivers to place and torque the prosthetic screws are usually greater than 15 mm in height. The manipulation of small screws and screwdrivers is far more time consuming and challenging than the abutment preparation and cementation of a cemented restoration.

When a screw or screwdriver is dropped in the posterior regions of the mouth, the patient may swallow or aspirate the device.[54-56] This is a greater risk when working in the posterior region; small components are not magnetic because precious metals or titanium is used for the screws, so a functional fit is necessary to carry them to the receptor site, and they often become dislodged.

Component Fracture

A long-term complication of screw-retained prostheses is fatigue failure of the screw components.[23,57] The narrow diameter of the prosthesis screw reduces its long-term strength. The bending fracture resistance for a solid object is $\pi/4(R^4)$.[58] In other words, a screw twice the diameter is 16 times stronger. Because the diameter of the occlusal screw is the smallest of any implant component, the screw is most at risk for breakage (Figure 26-20).

Fatigue fracture is related to the number of cycles of load. The fatigue or endurance limit is about half the ultimate strength of a material. The prosthesis screws receive increased cyclic loads under parafunction. As a result, the coping screws are at long-term risk of fracture or loosening. These complications account for many of those encountered in screw-retained prostheses with screw loosening reported in up to 38% of the posterior single-tooth restorations.[59,60] Screw loosening increases the force to any other implant still part of the support system of the prosthesis and may lead to additional prosthesis screw complications, abutment screw loosening or fracture, and even implant body fracture for components that remain connected.

Wearing of the threads from screw loosening may occur when the restoration is removed and reinserted repeatedly over several years or when retorqued after loosening. As a result, screw fracture and component loosening may increase in long-term restorations. Cemented prostheses have no small-diameter components and no metal-to-metal wearing; as such, similar complications are not observed.

Cost and Time

The laboratory costs for a screw-retained restoration are greater than those for a cemented prosthesis.[17,60] Screw-retained restorations require additional laboratory components such as impression transfers, analogs, copings, and screws (Figure 26-21). As a



FIGURE 26-20. Fatigue fracture of prosthetic screws occurs more often than abutment screws because they are smaller in diameter.



FIGURE 26-19. Screw-retained crowns have a greater incidence of porcelain fracture than cement-retained crowns.



FIGURE 26-21. There are many more prosthetic components necessary to fabricate a screw-retained restoration compared with a cemented prosthesis.

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consequence, implant manufacturers may generate four times more profit in screw-retained restorations compared with cement-retained restorations. In addition, laboratory components and time are increased to fabricate the prosthesis. Consequently, laboratory costs are 1.5 to 2 times higher than for a cemented restoration.

Fewer and shorter prosthetic appointments are required to restore a patient with a cemented prosthesis than with a screw-retained restoration.[61] Passive castings, progressive loading, and esthetics management are less complex for cemented prostheses.

Advantages of Screw-Retained Prostheses

There are several advantages to a screw-retained prosthesis as compared with a cement-retained restoration. These include low-profile retention, reduced moment forces with overdentures, reduced risk of residual cement, and splinting nonparallel abutments (Box 26-2).

Low-Profile Retention

The primary advantage of a screw-retained superstructure is the lower profile retention of the abutment system.[62] Cemented prostheses require a vertical component of at least 5 mm to provide retention and resistance form.[63] A crown height reduction of 2 mm may decrease the retention as much as 40% when the implant abutment is only 4 mm in diameter.[18] The screw-retained system is more resistant to removal forces than the cement abutment when the abutment height is less than 5 mm. The low-profile abutment may also offer significant advantages for removable prostheses (RP-4 or RP-5) (Figure 26-22). The lower height of the superstructure permits easier placement of denture teeth. The greater volume of acrylic also increases the strength of the acrylic portion of the restoration.

On occasion, low-profile retention is required for posterior fixed prostheses with short crown height. However, in such conditions, the space required to insert a screwdriver may be a limitation not appreciated until the prosthetic appointment. The prosthesis should be screw retained if the crown height does not allow sufficient abutment height and surface for cementation.

Osteoplasty before implant placement can increase the abutment height to improve the retention of the cemented fixed prosthesis. However, the dentist must consider the decrease in implant body height. In addition, a gingivoplasty after osteoplasty almost always is indicated to decrease sulcular depth and improve oral hygiene conditions. The dentist also may consider placement of additional implants and abutments or a customized abutment to increase cement retention.

An abutment with reduced height may be required when the implant is positioned too lingual or palatal (Figure 26-23). A 5-mm or greater height of the abutment may interfere with a tongue position or occlusion.

Reduced Moments of Force

A screw-retained superstructure bar for a RP-5 overdenture (implant and soft tissue support) may be subjected to less moment forces during prosthesis movement. The moment force to the implant is reduced with a low-profile abutment when stress breakers on the superstructure separate the removable prosthesis from the implant support (Figure 26-24). These elements decrease the effect of lateral loads on the implant body.

Risk of Residual Cement in the Sulcus

Another advantage of screw-retained crowns is the absence of residual cement in the gingival crevice, which may cause irritation to the surrounding tissues and lead to increased plaque retention and inflammation, similar to an excess cement condition with crowns on natural teeth.[64]

When possible, the crown margin of a cement-retained prosthesis should be above the tissue so that cement excess can be readily removed. Subgingival margins increase the incidence of incomplete cement removal on teeth or implant abutments. The

BOX 26-2 Advantages of Screw-Retained Prostheses

1. Low-profile retention
2. Reduced moment forces for overdentures
3. Reduced risk of residual cement
4. Splinting nonparallel implants



FIGURE 26-22. An overdenture bar is often screw retained with a low-profile abutment because the additional bulk of acrylic reduces fracture, and the position of denture teeth is less impacted by the position of the bar.



FIGURE 26-23. A low-profile abutment may be necessary to restore an implant positioned too lingual in the anterior mandible.

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cement may remain embedded deeper into the sulcus of the implant abutment because of the less tenacious junctional epithelial tissue and the lack of connective tissue attachment compared with a natural tooth.

Nonparallel Implants

When implant bodies are unparallel by more than 30 degrees, an abutment for cement retention cannot be adequately prepared for a path of insertion. A low-profile screw abutment may engage the implant bodies at significant angles. For example, a pterygoid or zygomatic implant may be placed at 45 degrees from anterior implants, yet these implants may be splinted together with a screw-retained restoration (Figure 26-25).

Therefore, greater low-profile retention, reduced moment force in RP-5 overdentures, greater space for denture teeth or occlusal materials, and absence of cement residues are advantages for screw-retained superstructures. Most of these conditions are more characteristic of implant-supported overdentures than fixed restorations.



FIGURE 26-24. A low-profile abutment reduces lateral moment forces on the implants when a RP-5 restoration (soft tissue support and implant retention) is fabricated.

An interesting note is that in the mid 1980s and 1990s, practitioners who challenged the concept of implant-supported, cement-retained restorations were regarded as a minority. Over the past decades, the profession has reassessed its position, and today most fixed prostheses on implants (≈90%) are restored with cement-retained restorations rather than screw-retained prostheses.[20,60,65]

Complications of Cemented Prostheses

Residual Cement

The most common complication of a cement-retained implant restoration is residual cement left in the gingival sulcus of the implant[65] (Figure 26-26). Residual cement in the sulcus after cementation of the prosthesis is a source of periimplantitis.[64,66,67] The occurrence of this complication is more often found with implants than natural teeth. In a report by Wilson, excess dental cement was found in 81% of patients with clinical or radiologic signs of periimplant disease.[68] Hence, this complication has led some practitioners to encourage screw-retained restorations.

There are several reasons why implant prostheses have more residual cement complications than natural teeth. They primarily include the position of the prosthetic margin in relation to the free gingival margin and a difference in the sulcular attachment to the implant or tooth.

Difference in Gingival Attachment

The natural tooth–to–soft tissue interface includes (1) the sulcus, (2) the junctional epithelial attachment, and (3) the connective tissue attachment. Each of these three zones is approximately 1 mm in height at the midfacial and lingual tooth position. A periodontal probe inserted into the soft tissue crevice will go through the sulcus and the epithelial attachment zones. The periodontal probe stops at the connective tissue attachment region because six of the 11 fiber groups in the soft tissue physically insert into the cementation of the tooth (Figure 26-27). Hence, if excess cement is expressed into the gingival crevice, it does not extend to the level of the bone.

An implant–soft tissue interface does not have a connective tissue attachment zone. A dental probe introduced into the crevice may proceed to the level of the bone. Hence, there is no



FIGURE 26-25. **A,** Six maxillary implants positioned beyond 30 degrees' angulation and zygomatic implants are positioned toward the palate. **B,** A screw-retained restoration permits these implants to be splinted together. The low-profile abutment on the medial-positioned implants is also an advantage.

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FIGURE 26-26. Residual cement below the implant crown margin is a source of periimplantitis.

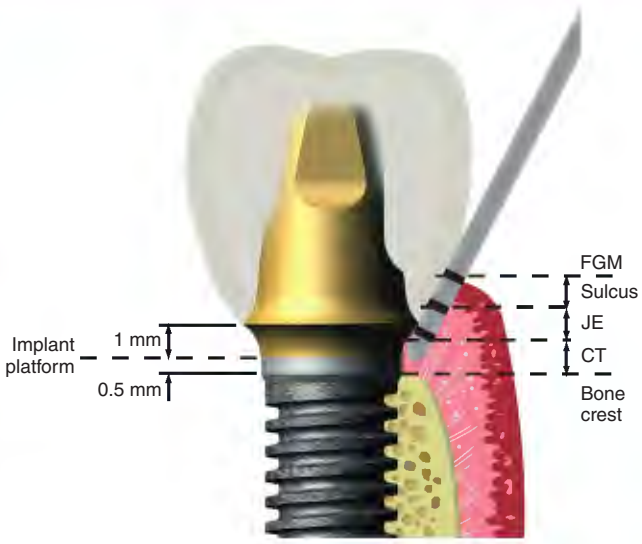


FIGURE 26-28. A periodontal probe inserted next to an implant may proceed to the level of the bone because there is no physical barrier on the implant above the bone. *CT,* Connective tissue; *FGM,* free gingival margin; *JE,* junctional epithelium.

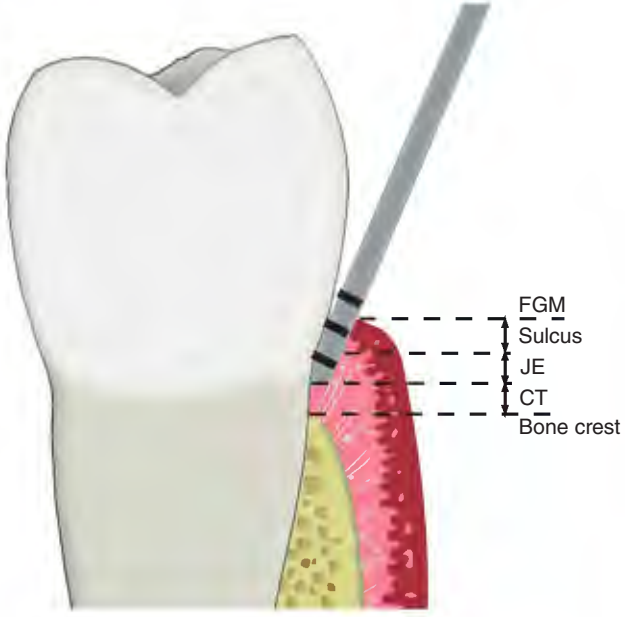


FIGURE 26-27. A periodontal probe penetrates the sulcus and the epithelial attachment zone. It is stopped by the connective tissue attachment region because periodontal fibers physically insert into the cementum of a tooth. *CT,* Connective tissue; *FGM,* free gingival margin; *JE,* junctional epithelium.



FIGURE 26-29. When the implant is countersunk below the bone, the bone usually remodels below the abutment connection and increases the periimplant pocket depth.

barrier to prevent excess cement from extending deeper into the soft tissue region (Figure 26-28).

In addition, the gingival crevice of an implant may be more than 3 mm in depth, especially in the interproximal region because a scallop of bone does not exist around an implant (compared with a 3-mm incisal scallop of an anterior natural tooth). The tissues on the crest of the ridge may also be thicker than 3 mm even on the midfacial and palatal regions. As a result, the sulcular depth of an implant may be more than 3 mm thick, especially in the maxilla. When the implant platform is positioned below the bone, the bone loss below the abutment connection also increases the sulcus depth (Figure 26-29). As such, the extrusion of excess cement may extend many millimeters below the free gingival margin of an implant crown.

BOX 26-3 Subgingival Crown Margin Indications

1. Existing caries
2. Previous restoration
3. Increase retention*
4. Subgingival tooth fracture*
5. Cervical defects
6. Root sensitivity

*Implants and teeth.

Position of a Crown Margin

There are seven indications for a subgingival margin in prosthetics: existing caries, to replace a previous restoration with a subgingival margin, to increase retention, to improve esthetics, subgingival tooth fracture, to correct cervical defects, and to reduce root sensitivity[69] (Box 26-3).

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Implant restorations do not decay or have cervical defects or tooth fractures. Hence, in cemented implant restorations, the margin of the crown should be at or above the free gingival margin out of the esthetic zone when increased abutment height is not necessary to increase retention.[18] This would permit easy access to the crown margin to remove any excess cement.

When a subgingival margin is indicated in a restoration, it should not proceed more than 1.0 mm ± 0.5 mm into the sulcus.[69,70,71] Unfortunately, many practitioners (and laboratories) attempt to place the implant crown margin at the abutment flare of an implant abutment for cement. Because the abutment is usually wider than the implant body dimension and then tapers to the incisal portion, the implant abutment flare appears to many dentists as a crown margin (Figure 26-30).

The flare of an implant abutment is often placed near the crest of the residual bone, especially when the implant body is countersunk below the crest of the residual bone (Figure 26-31). As a consequence, the restoring dentist has difficulty in capturing the "margin" of the abutment flare in an impression because it may reside more than 2 mm below the free gingival margin, especially in the interproximal region.

To capture the abutment flare ("margin") of the abutment several millimeters below the tissue, the dentist often makes an implant body transfer impression to capture the position of the implant body. The laboratory, whether it is using a dental impression of the "margin" or a stock abutment for cement retention with an implant body impression, places the crown margin to the abutment flare, several millimeters below the gingival margin.

When the dentist attempts to seat the implant crown several millimeters below the tissue, the subgingival crown contour pushes the tissue away from the abutment, which often prevents the crown from being passively seated, and the tissue pushes the crown and elevates its position from the "margin." As a result, the dentist often cements the restoration before evaluation of the occlusion or esthetics. Hence, an occlusal adjustment or esthetic try-in is not accomplished before cementation.

When excess cement extrudes from the subgingival crown "margin," it then extends beyond the abutment flare into a subgingival undercut of the abutment (Figure 26-32). Because the margin is several millimeters below the free gingival margin and in an undercut below the flare, the dentist has difficulty removing the excess cement.

An alternative to this problem selected by many dentists and laboratories is for an implant body transfer and analog with an indirect laboratory technique followed by the fabrication of a customized abutment. The customized post is designed with the crown margin 1 mm below the free gingival margin (Figure 26-33). Hence, the crown may be passively seated, the esthetics and occlusion modified as needed, and the excess cement able to be more easily removed. This option is often encouraged by dental laboratories and implant manufacturers because this technique is associated with a greater laboratory fee, and the purchase of a transfer coping and an analog is necessary.

All of the problems of difficult impression making, increased laboratory and implant company fees, difficulty in seating the restoration, and residual excess cement stem from the dentist (and laboratory technician) believing the abutment for cement flare is a crown margin. The abutment flare is not a "margin" for a crown; rather, it is a biomechanical feature to increase abutment taper, increase crown retention, and increase strength



FIGURE 26-31. The abutment flare is usually placed near the crest of residual bone, especially when the implant is countersunk below the crest *(right side)*.



FIGURE 26-30. The abutment flare is wider than the implant body and appears to many dentists and technicians as a crown margin.



FIGURE 26-32. When the crown margin is at the abutment flare, the tissue resistance often squeezes the crown more coronally, and the cement extrudes below the abutment flare into an undercut region.

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FIGURE 26-33. The prefabricated abutment flare of most implant designs places the abutment flare near the platform of the implant, which may be several mm below the tissue *(left)*. A customized abutment may be fabricated that positions the margin 1 mm below the tissue *(right)*.

BOX 26-4 Advantages of an Abutment Flare

1. Increased abutment taper
2. Increased crown retention
3. Increased abutment wall strength
4. Improved subgingival cervical contour



FIGURE 26-34. The abutment screw is usually 2.5 mm in diameter and passes through the abutment for cement. As a consequence, the incisal aspect of the abutment cannot taper beyond 3 mm at the top. Hence, the abutment flare increases the amount of taper, surface area, and strength to resist fracture.

of the abutment wall. It can also improve the subgingival cervical contour of the tissue, which improves the emergence profile of a crown to improve the cervical esthetics (Box 26-4).

The Abutment Flare

The wider the base of an abutment, the more taper may be placed on the abutment. Because the implant body has a smaller diameter than the tooth it replaces, the amount of taper is reduced. A limiting factor of the abutment taper is the outer wall of the abutment at the incisal aspect. The abutment for cement retention has a fixation screw hole 2.5 mm in diameter, so the abutment screw may enter and fixate the abutment to the implant body (Figure 26-34). As a consequence, a 3.5-mm-diameter abutment at the base may have a taper of only 5 degrees. A 6-mm-wide abutment at the base may have a taper of 25 degrees. The greater the taper, the easier it is for the dentist to splint implants together or have a path of insertion for the prosthesis. When the cervical aspect of the abutment is 3 to 4 mm in diameter (and is similar to the implant body dimension), the taper of the abutment is limited to 5 to 10 degrees. This makes it almost impossible to splint implant crowns together and makes it necessary for the implant body position to be similar to the path of insertion of the crown. Hence, the abutment flare is designed because it is wider than the implant body, so the taper may be greater.

The wider an abutment, the more surface area for cement and the greater the retention of a cemented crown. Hence, when the abutment is wider than the implant body, the cement retention is increased. The greater the retention, the less hard the cement requirements in shear and tension used to retain the restoration. Hence, the restoration may be more easily removed to correct a prosthetic complication.

The more metal dimension flanking the abutment fixation screw hole, the greater the strength of the abutment to prevent fracture. When the cervical aspect of the abutment for cement retention is wider than the implant body, the strength of the abutment to prevent fracture is dramatically increased. An abutment for cement may be compared to an open cylinder in mechanics. The strength of an open cylinder is $^{\pi}_{4}(R^4 - RI^4)$, where R is the outer radius and RI is the inner radius.[52] In other words, small changes of the outer diameter of the abutment increase the strength of the abutment to the power of four times.

The wider abutment at the base allows the subgingival contour to be increased and improves the emergence profile of the crown to be more similar to a natural tooth. Because the implant body is smaller than the tooth it replaces, a wider abutment permits the crown to have a greater emergence profile.

As a consequence of the biomechanical advantages of a wider cervical portion of an abutment and improved emergence profile, there is an undercut from the abutment flare to the implant body. This feature increases the difficulty to remove residual cement beyond the crown margin when the margin is positioned at the abutment flare.

Instead of positioning the crown margin at the implant abutment flare, the crown margin should be positioned at the gingival sulcus (or above) when it is out of the esthetic zone, or no more than 1.5 mm below the free gingival margin of the sulcus (for esthetics or for more retention). The crown margin preparation may be a knife edge because the abutment is narrower than the tooth it replaces (Figure 26-35). Hence, the crown margin may more easily be captured in the impression, a stock abutment may be used, a stone die may be used to fabricate the crown, the crown may more easily be passively seated to check or modify occlusion or esthetics, and the residual cement may more easily be removed from the crown margin (Figure 26-36).

In conclusion, when the flare of the implant abutment is within 1.0 mm ± 0.5 mm of the gingival margin, it may be used as the crown margin. When the abutment flare is more than 1.5 mm below the tissue margin, it may remain below the tissue and crown margin with no consequence. There is no report indicating the subgingival abutment flare below the crown margin increases any risk of plaque retention or gingival shrinkage or contributes to crestal bone loss. If the abutment flare is

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above the gingival margin of the tissue as a result of gingival shrinkage or the implant body protruding several millimeters above the bone and a subgingival margin is desired, the abutment flare may be prepared to place the crown margin below the margin of the tissue (Figure 26-37).

Abutment Retention

Uncemented restorations on natural teeth are one of the most common complications of fixed prostheses.[4,5] After the crown on the natural abutment becomes uncemented, a significant concern is caries. Decay may proceed rapidly and result in loss of the abutment, creating a need for endodontic treatment, post and core, a new prosthesis, or an abutment with even poorer retention. These same conditions exist if the natural retainer becomes uncemented from an implant–tooth restoration.

The implant abutment is at greater risk of uncementation than a natural tooth (Figure 26-38). The implant abutment is made of metal, so dental cements do not adhere to the interface as with dentin of a natural tooth. The porosity of an implant abutment is usually less than a tooth. The implant abutment is usually smaller in diameter and usually has less surface area than a natural tooth. The dentist often desires to make the restoration retrievable to more easily handle future complications. As such, a softer cement is often used for implant crowns. In addition, there is greater impact force to a cement–abutment interface for implant prostheses compared with natural tooth abutments. The partially retained implant fixed prosthesis then acts as a cantilever with a dramatic increase in moment force on the implant(s) that still retain the prosthesis. Crestal bone loss, prosthesis or abutment screw fracture, implant fracture, or mobility and failure of the implant are likely complications.

The principles of retention and resistance may be addressed specifically for both natural teeth and implant abutments. The retention features of a fixed-cemented restoration resist the removal of the retainer along the path of insertion. The forces applied to remove the crown in this direction are primarily shear or tensile forces on cement. The resistance of a crown opposes the movement of the abutment under occlusal loads



FIGURE 26-35. The crown margin is positioned at or within 1.5 mm of the free gingival margin and above the abutment flare.



FIGURE 26-36. The crown margin is positioned 1 mm ± 0.5 mm below the free gingival margin in esthetic zones. The excess cement may easily be removed, similar to a crown for a natural tooth.

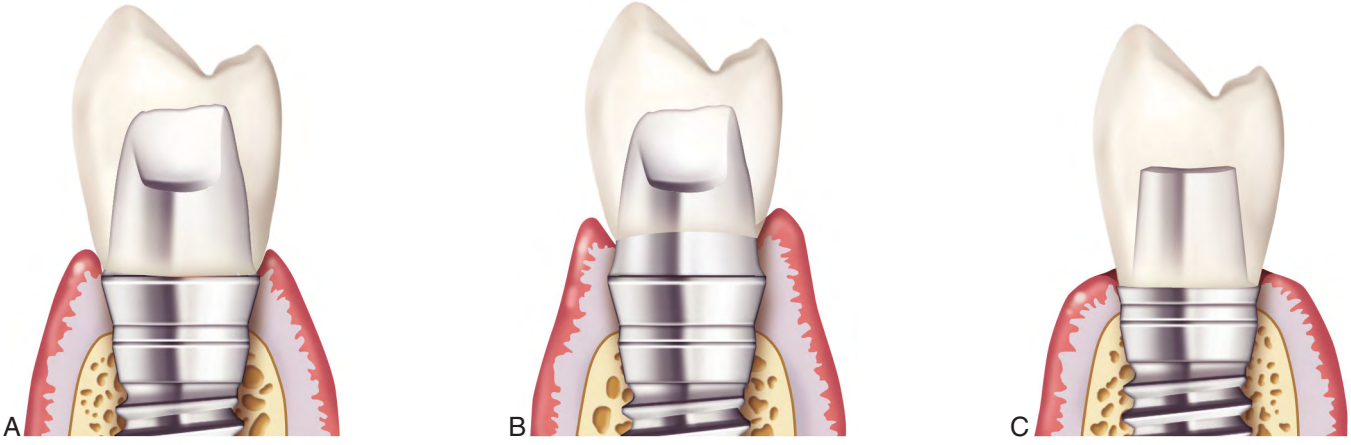


FIGURE 26-37. When the abutment flare is within 1.5 mm of the gingival margin, it may be used as the margin for the crown *(left)*. When the abutment flare is below 1.5 mm of the free gingival margin, the crown margin is coronal to the flare and within 1.0 mm ± 0.5 mm of the free gingival margin *(center)*. When the abutment flare is above the tissue, it is prepared, and the crown margin is placed within 1.0 mm ± 0.5 mm of the free gingival margin.

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FIGURE 26-38. Cemented crowns on implant abutments may become unretained more often than natural teeth. The distal implant became uncemented and the mesial abutment had an increase in moment force, causing the abutment screw to become loose.

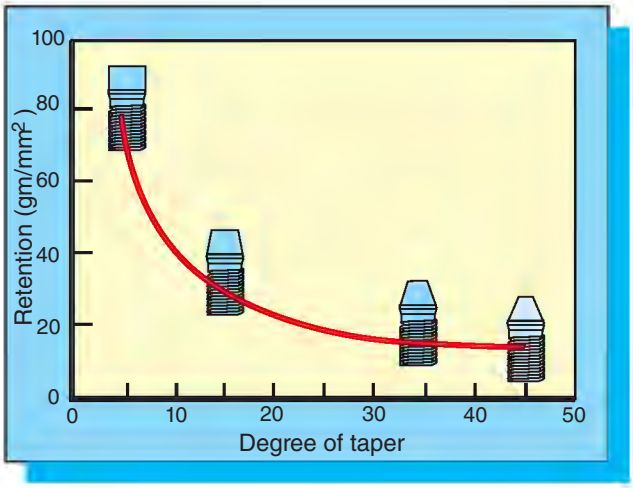


FIGURE 26-39. As the taper of an implant abutment is increased from 6 to 25 degrees, the retention of the crown is rapidly decreased.

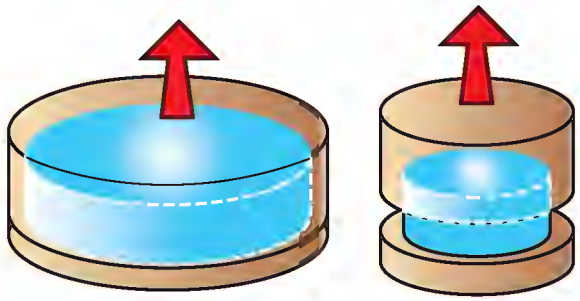


FIGURE 26-40. The greater the surface area of an abutment, the greater the retention. Hence, wider implant abutments *(left)* have greater retention than narrow-diameter implant abutments *(right)*.

BOX 26-5 Features of Abutments Related to Retention and Resistance

1. Taper
2. Surface area
3. Height
4. Abutment geometry
5. Surface roughness
6. Luting agent

and prevents removal of the restoration by forces applied in an apical or oblique direction. These are primarily compressive and tensile forces on cement. As with most materials, cements exhibit lower retention strengths compared with their resistance strengths (e.g., zinc phosphate exhibits greater than 100-MPa compression strength and only 5- to 9-MPa tensile strength).[69]

Specific features in the geometric configuration of the implant abutment for cement retention or a prepared tooth are requisites to avoid uncementation. The tenets of retention and resistance of fixed prosthodontics are directly applicable to implant abutments and include taper, surface area, height, the geometry of the abutment preparation, surface roughness, and luting agents[70-72] (Box 26-5).

Abutment Taper

The retention of a crown rapidly decreases as the taper is increased from 6 to 25 degrees.[71] (Figure 26-39). Taper degree is the sum of both sides of the preparation. A typical tapered diamond bur shows a taper of about 3 degrees on each side or a 6-degree total taper. The parallelism of the axial walls has been recognized to be the single most effective factor for retention.[73] The ideal taper originally was recommended to be within 2 to 5 degrees of parallelism of the path of insertion, which also was placing minimal stress concentrations on prepared abutments.[69] However, clinically acceptable preparations present a taper in the range of 20 degrees.[73-75]

Premanufactured stock implant abutments for cement may exhibit a total taper from 10 to an excess of 30 degrees. As a result, the retentive surfaces of some more tapered, unprepared implant abutments may provide less retention than natural abutments. Therefore, the preparation in the cervical third of the abutment near the crown margins may be indicated in the more tapered implant abutments to reduce the taper even when the path of insertion is satisfactory.

Abutment Surface Area

The parameters of retention are similar for a tooth or implant and mainly are influenced by the diameter and height of the abutment.[76] The surface area of an implant abutment influences the amount of retention. A linear increase in retention occurs as the diameter increases for preparations with identical height, and a wider abutment offers greater retention than a narrower abutment[77] (Figure 26-40). Molars are more retentive than premolars because of their increased surface area, all other factors being equal. It should be noted that controversy exists as to whether the increased surface area is responsible for the increased retention or whether the height-to-width ratio is more relevant.[78-80]

The diameter of an implant abutment for cement retention is often less than 5 mm, which is comparable to that of a prepared lateral incisor. Therefore, the decreased surface area results in poorer retention than most natural abutments. In addition, cements do not adhere as well to titanium as they do to prepared dentin. As a result, additional retention features for an implant abutment should often be incorporated.

Wider implant abutments have more retention than standard-size abutments. The wider abutment usually is obtained

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by two methods. First, a wider implant body has a wider abutment for cement than a smaller-diameter implant. Second, the abutment may have a wider emergence design than the implant body (or abutment flare). The greater-diameter abutment has advantages of providing a greater taper, a thicker outer body wall, and more surface area for retention.

Abutment Height

A tall preparation provides greater retention than a short abutment.[76,81] An additional 2 mm of height may increase retention up to 40%, especially when the abutment is only 4 mm in diameter. The increase in height and the height-to-width ratio are determinants for retention. An increase in height from 4 to 7 mm results in a 67% increase in retention.[18] When the height of the implant abutment is less than 5 mm, the diameter of the implant abutment is more critical to improve cement retention or resistance. A customized abutment, larger in diameter than the stock abutment, may be necessary to retain the restoration.

The additional abutment height not only increases the surface area, which increases retention, but also increases resistance because it places more axial walls under compressive and tensile stress rather than shear stress. Therefore, the retention and the resistance are increased, which decreases the risk of uncementation.

Limited natural tooth crown height (because of limited interarch space or short clinical crown) also decreases retention. Splinting of natural teeth with limited crown height to improve retention often compromises access for hygiene in the interproximal areas. Instead, crown lengthening is often indicated in case of limited interarch space to improve the retention of the prosthesis and the esthetic result without compromising home care. Crowns of reduced size require minimal tapering and additional retentive elements such as grooves or boxes to limit the path of insertion and direction of dislodgement.[69,81]

Geometry of Abutment

The strength of the cement interface is weakest under the shear component of a force. The surface area of an abutment submitted to shear forces is more critical than the total surface area under tensile force.[69,81] Manufactured implant abutments for cement are usually circular in cross-section, providing little resistance to shear forces, especially on individual, unsplinted crowns. A flat side on the implant abutment preparation decreases shear forces on the cement interface. Whenever possible, a preparation with one or two flat sides should be made on circular abutments for cemented prostheses.

A tapered implant abutment post may provide multiple paths of insertion or removal. The addition of one or more parallel-sided grooves to an abutment limits the path of withdrawal of the crown to one direction[69,82] (Figure 26-41). Therefore, whenever possible, retentive elements such as grooves parallel to the path of insertion, should be added to a short or excessively tapered implant abutment for cement. Additional grooves parallel to the path of insertion mechanically resist rotational forces, place compressive forces on the cement in these regions, and dramatically improve cementation[83] (Figure 26-42). The outer wall of some two-piece abutments may be thin. As such, a groove may perforate or weaken the component.

Abutment Surface Texture

The surface texture of the abutment increases the retention of a restoration by creating microretentive irregularities into which the luting agent projects. The surface retention depends on the surface texture, the type of burs used for the preparation, and the type and thickness of the luting agent.[84-87] The dentist may use a large-size crosscut fissure bur (e.g., Brassler #702) and copious water spray to reduce the height and perform the gross reduction of the metal abutment post.[88] The dentist may then use a coarse diamond over the surface of the implant abutment to increase the amount and depth of microscopic scratches on the surface to more than 40 microns (Figure 26-43). The internal aspect of the casting should also be air abraded with 50 microns of alumina to enhance its retention for cementation by as much as 64%.[86]

Several implant manufacturers provide abutments for cement with retention lines 1 mm apart, which increase mechanical retention and aid in determining the proper abutment height. However, wax patterns are more difficult to remove in the laboratory when these retention lines are present. As a consequence, the laboratory often blocks out these retentive components.

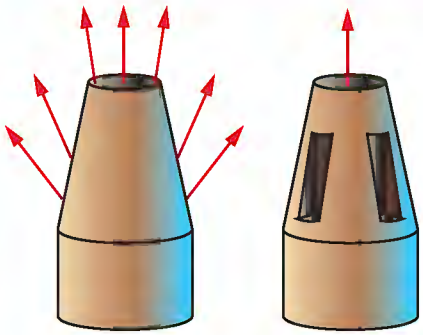


FIGURE 26-41. A tapered abutment *(left)* has multiple paths of insertion or removal. Grooves in the axial walls of the abutment limit the path of removal and decrease uncemented restorations.



FIGURE 26-42. Short abutments may increase retention and resistance by preparing parallel grooves in the axial walls and by having a subgingival margin that increases abutment height.

Resistance and Abutments

The resistance opposes the uncementation of the prosthesis against forces directed in apical, oblique, or horizontal directions.[69,81] The resistance provided by implant abutments is usually greater than retention because the cement is placed primarily under compressive or tensile forces. Forces most likely

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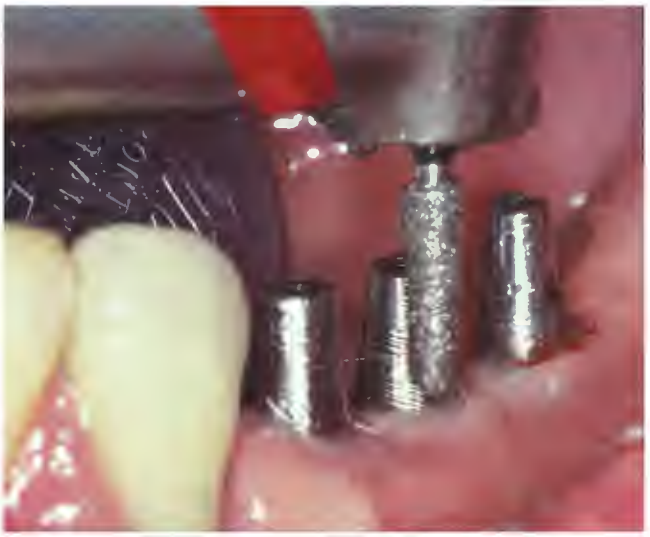


FIGURE 26-43. A coarse diamond may be used to roughen the surface of the abutment above the finish line of the crown margin.

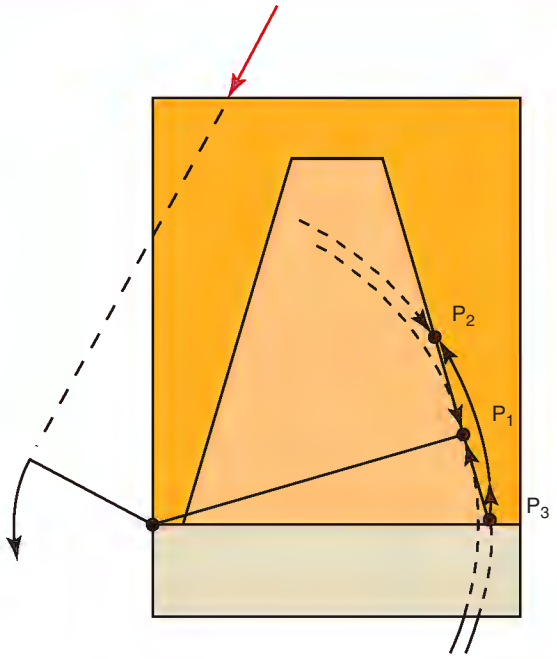


FIGURE 26-44. The dislodging force to a crown is related to the arc of rotation and is a radius of a circle determined by the edge of the crown margin to the base of the abutment (P_3). The taller the abutment, the more resistance to the lateral force.

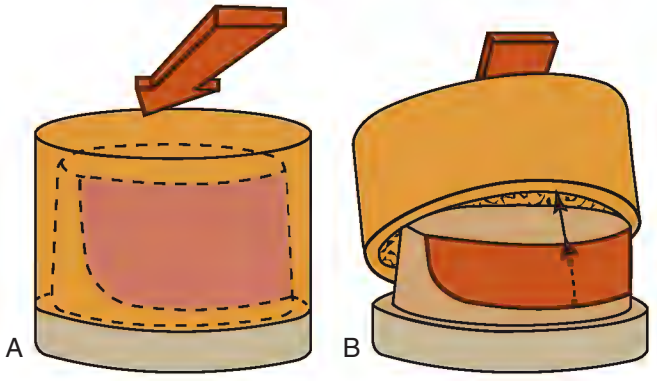


FIGURE 26-45. An increase in abutment height increases resistance to a lateral force because more of the axial walls are placed under compressive forces (**A**). A short abutment height has less resistance to a lateral force or cantilever force (**B**).

to cause uncemented restorations related to resistance are associated with parafunction, long spans, cantilevers, mobile natural abutment teeth joined to implants, offset loading, and horizontal loads from occlusal contacts.

When a force is directed within the margins of the abutment crowns, leverage or tipping forces are limited. However, for implant-supported prostheses, forces often are projected away from the abutment, usually facially. In addition, excursive movements generate a leverage force, especially on maxillary anterior abutments. The forces affect not only the bone-to-implant interface but also the cemented abutment crown. The arc of rotation of the crown influences the dislodging forces and is affected by the direction of forces. The surface design and conditions of the preparation farthest from the fulcrum or rotation point provide the resistance to uncementation.

The greatest resistance factors of the abutment for cement retention to a moment force are a minimum abutment taper and maximum abutment height. The higher the abutment, the greater its resistance to lateral forces. The height of the abutment must be greater than the arc formed by the crown rotating about a fulcrum at the margin of the opposite side of the restoration[69] (Figure 26-44).

Premanufactured implant abutment heights range from 4 to 10 mm and are often 5, 7, or 9 mm in height. Some manufacturers only supply 5-mm-high abutments to save preparation time for the dentist. Although this may be adequate in some situations, a cantilever or fixed prosthesis with a large crown height often may require longer implant abutments to resist the arc of removal or to resist lateral forces in the anterior regions of the mouth (Figure 26-45).

A wider-diameter implant abutment provides greater retention but may offer less resistance to moment forces than a narrow abutment for a similar height and degree of taper. The wider abutment for cement has a longer axis of rotation and provides a reduced area of resistance at the opposite side of the preparation. The worst resistance form is with a short, wide abutment, for example, in a molar region (Figure 26-46, *top*)

A linear relationship exists between convergence angles and the resistance of a crown to dislodgement. The greater the convergence angle and the larger the abutment circumference, the greater the abutment height needed to provide resistance to dislodgement.[69,89,90] Therefore, on one hand, the wider abutment has more surface area for cement retention; but on the other hand, when lateral or moment forces cause tipping forces on the crown, the wider arc of tipping forces makes the height of a wide abutment critical to resist the tipping forces. These conditions are improved when the path of rotation is changed by placing boxes or grooves perpendicular to the arc of rotation, provided the path of insertion is preserved (Figure 26-46, *bottom*). Hence, short, wide posterior implant abutment posts give improved results with mesial and distal grooves when bilateral balanced occlusion is used (e.g., against an opposing denture).

These factors are important not only for a single crown but also for an implant fixed prosthesis. Because a canine implant has a lateral force, abutment height is important. When questionable, a vertical directional groove decreases the risk of

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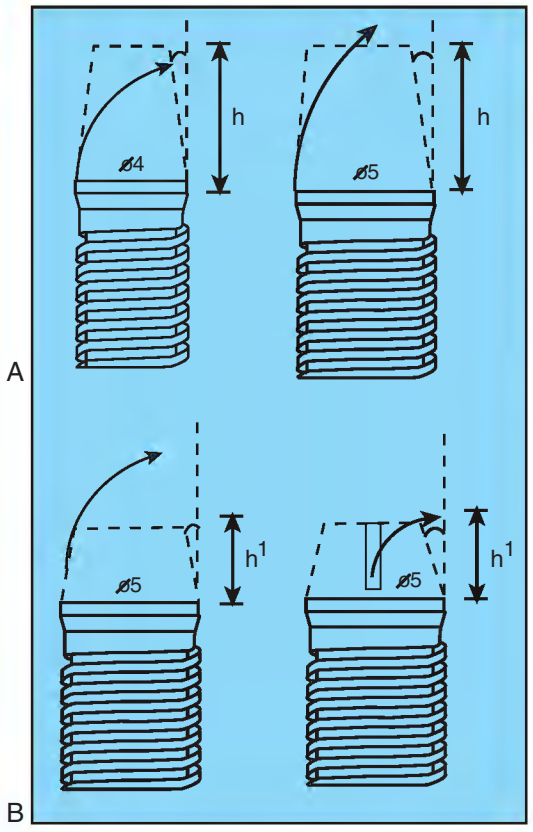


FIGURE 26-46. When a crown receives a lateral force, it tends to rotate upward on one side of the implant. The arc of rotation is related to the diameter of the implant. The greater the width, the greater height the arc of rotation. The abutment should be higher than the arc of rotation. Therefore, a wider implant requires a taller abutment than a smaller-diameter implant *(top)*. The arc of rotation is decreased when directional grooves are prepared into the abutment *(bottom)*. Therefore, when abutment height is questionable, directional grooves decrease the risk of uncementation *(bottom right)*.

uncementation (Figure 26-47). When considering a full-arch maxillary fixed prosthesis, occlusal forces placed on the anterior teeth tilt the restoration apically in the anterior region and coronally in the posterior region, forming an arc of displacement, with the radius equal to the distance between the most anterior and the most posterior implant. The most distal abutment height should be above the arc of displacement. The greater the anteroposterior (A-P) distance, the greater the radius for the arc of displacement and hence the greater the abutment height requirements.

Since the introduction of implant-supported cantilevered prostheses for completely edentulous arches (i.e., Brånemark approach), the cantilever has gained acceptance in implant dentistry. A cantilevered restoration also forms an arc of removal when force is applied on the cantilevered portion. The radius of the arc of displacement is equal to the anterior to posterior contacts, not the A-P distance of the implants. The height of the implant abutment farthest from the fulcrum or cantilever is the primary element for resistance[69] (Figure 26-48).

Moment forces produce rotation or bending. The moment is defined as a vector, *M*, the magnitude of which equals the product of the force magnitude *(f)* multiplied by the perpendicular distance (*d*, also called moment arm) from the point of application to the line of action of the force ($M = f \times d$). The



FIGURE 26-47. The two implants replacing the canine and first premolar have minimal abutment height and will receive lateral forces. Vertical directional grooves parallel to the path of insertion of the prosthesis decreases the risk of uncementation.

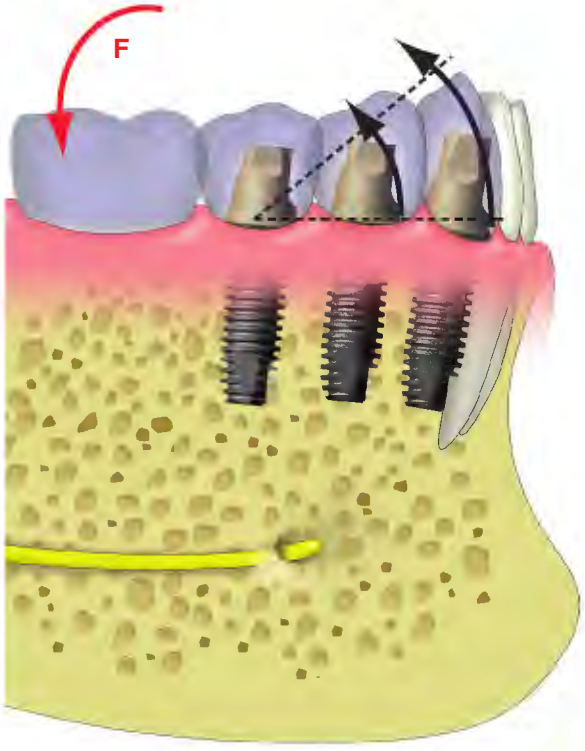


FIGURE 26-48. In a cantilevered prosthesis, tensile forces (F) are applied on the crown farthest from the cantilever. The height of the implant abutment should be greater than the arc of displacement of the prosthesis to increase the amount of resistance and compressive forces to the cement seal below the arc of displacement. The abutment farthest from the cantilever has the greatest height requirement.

moment load imposed also is referred to as torque or torsional load and may be destructive to implant systems.

Torque or bending moments placed on implants as a result of, for example, cantilever bridges or bar sections may result in interface breakdown; bone resorption; prosthetic screw loosening; and fracture of the implant, components, or prostheses. However, one of the most common complications is an uncemented restoration, which may occur as often as 60% of the time in three-unit cantilevered restorations. Proper restorative designs must include features to resist such forces. The tensile

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FIGURE 26-49. Buccal or lingual vertical directional grooves (or both) may be used with a mesial or distal cantilever to modify the arc of displacement and decrease the risk of uncementation.

and shear forces on the abutment for cement retention from the posterior cantilever bar or pontics may be reduced by vertical grooves on the buccal and lingual aspects of the posterior abutments. As a result, the arc of displacement and the moment force on the restoration are mechanically reduced[69,77] (Figure 26-49).

Implants often are placed more medial than the occlusal or incisal contacts of the overlying prostheses. Both of these conditions create offset loads on the implant abutments and greater tensile and shear forces on cement or screw fixation devices. Buccolingual offset loads place the cement under tension, which may increase uncementation. When the implant crown has an offset load to the facial or lingual, the radius of rotation for dislodging forces is increased. Hence, additional resistance features are indicated on the mesial or distal of the abutment (Figure 26-50). These loads may be reduced on a cement-retained prosthesis by placing vertical grooves on the mesial and distal aspects of the restoration (Figure 26-51). The same features are beneficial when horizontal forces are introduced from a mutually protected occlusion or bruxism.

In summary, when the cantilever is to the mesial or distal, the grooves or boxes in the abutment preparation should be on the facial or lingual of the preparation. When the cantilever is to the facial or lingual, the groove or box should be placed on the mesial or distal of the abutment.

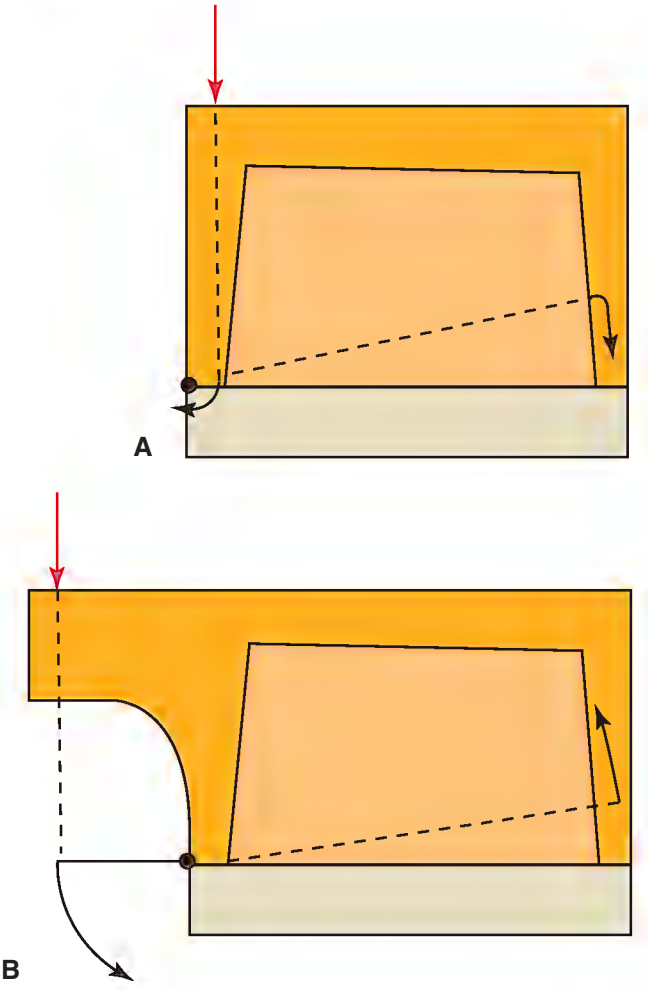


FIGURE 26-50. **A,** An offset load is often placed on an implant crown. **B,** This load acts as a cantilever force and increases the radius of the arc of rotation for dislodging forces.

Types of Abutments for Cement Retention

Two broad categories of abutments for cement retention are used in implant dentistry: a single unit (or one-piece abutment) and a two-piece abutment for cement retention. The one-piece abutment does not engage the antirotational feature of an implant body but fits flush with the implant platform (Figure 26-52). In the two-piece abutment for cement, one component (the abutment) engages the antirotational feature of the implant body (i.e., external hex), and another component (abutment screw) fixates the abutment and implant body (or analog) together (Figure 26-53).

One-Piece Abutment for Cement Retention

A one-piece abutment can be torqued into position with a 20-N-cm force or more. The one-piece abutment does not engage the hexagon of the implant body, eliminating the risk of incomplete seating. The abutment is less expensive to manufacture because it is easier to fabricate and only has one component. The abutment also has thicker walls because the center does not have to gain access for an abutment screw. This allows the preparation of additional grooves for resistance or for preparations with a greater taper or angle than a two-piece abutment, which may perforate the thinner axial walls of a two-piece system.

The one-piece abutment for cement retention should be prepared with one or two flat sides to limit the abutment rotation and loosening when retaining the prosthesis by placing the cement and intaglio surface of the crown under compression

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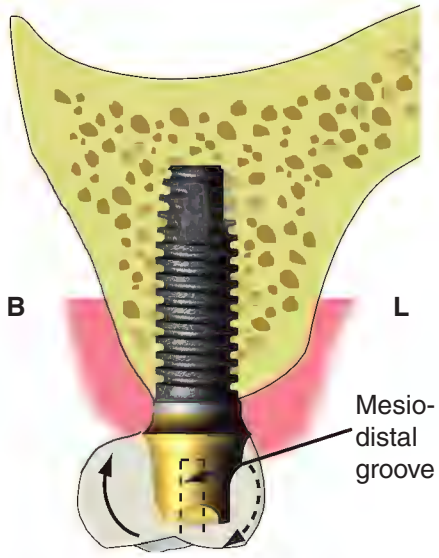


FIGURE 26-51. Mesial and distal vertical directional grooves decrease tensile and shear forces on a prosthesis subjected to buccal or lingual offset loads.



FIGURE 26-52. A one-piece abutment for a cement-retained prosthesis does not engage the antirotation feature of an implant body.



FIGURE 26-53. A two-piece abutment for a cement-retained restoration has one component (the abutment) engage the antirotation feature of the implant (i.e., external hex), and another component (abutment screw) fixates the implant abutment and implant (or analog) together. The abutment may be straight *(left)* or angled *(right)*.

forces. Cements are up to 20 times stronger in compression compared with shear forces.

One-piece abutments also have disadvantages, and many manufacturers do not provide this abutment option. Because the abutment does not engage the antirotational system of the implant body, the post may loosen and rotate, which is often found when used as an independent crown abutment. Therefore, all single-tooth or independent implant crowns should have a two-piece abutment to engage the antirotational feature of the implant body.

A second disadvantage is evident when an angled abutment is indicated. One-piece angled abutments that are threaded into the implant rotate on a wide arc and are not thread timed to a constant position. Hence, even when able to be threaded into place, the abutment most often is angled to the wrong direction.

A third disadvantage is the rotational force applied to torque the abutment is transferred to the implant–bone interface, especially near the crestal region of bone. These torque forces are shear forces to bone and may be in the pathologic overload zone for bone strain in softer bone types and may contribute to crestal bone loss or even may cause the implant to rotate and lose integration. As a general rule, the one-piece abutment is not used to restore implant prostheses.

Some manufacturers provide cement-retained, one-piece, angled abutments similar to a post for an endodontic tooth. However, because the post portion of the crown is only 2 to 2.5 mm in diameter, an inadequate surface area for cement retention is a common problem. In addition, the implant platform is often level or countersunk below the bone level. As a consequence, there is a risk of trapping residual cement deep below the tissue and impairing its removal at this level.

Two-Piece Abutment for Cement Retention

The two-piece abutment for cement retention is used for most all situations when the restoration is cement retained. The dentist should especially use a two-piece abutment for single-tooth implants or independently restored implants to engage the antirotational aspect of the implant body. An angled abutment also uses a two-piece abutment to engage the antirotational feature at the correct angular position before the placement of the abutment screw. A two-piece abutment and abutment screw are also recommended when an angled abutment is required to improve esthetics or correct the path of insertion of the cement-retained restoration, whether the implant is freestanding or joined to other implants.

The dentist must use a two-piece abutment when selecting an indirect technique for a cement-retained prosthesis fabrication. The dentist makes an implant body impression that also transfers the antirotational feature of the implant. The laboratory may then attach an implant body analog (and antirotation feature) to the impression transfer before pouring the impression in stone. The laboratory may then select the abutments, prepare the abutments, and fabricate the restoration on the indirect model. The dentist may then position the abutments in the mouth similar to the stone model position with the use of the antirotational feature.

Angled two-piece abutments have several disadvantages. Angled abutments are usually 15 to 30 degrees off axis of the implant body. Hence, the implant surgeon may place the implant without regard to the position of the final crown or to the occlusal load. The greater the angle of load to the implant system, the greater the shear component of the load and the

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greater the risk of abutment screw loosening or fracture of the abutment under offset loads.

The metal thickness on the side of an angled abutment also decreases in direct relation to the degree of angulation (see Figure 26-53). The resistance of bending fracture for the abutment is proportional to the thickness of metal at the power of 4 ([Outer radius]^4 – [Inner radius]^4). Therefore, the risk of fracture is increased from both an increased shear load and decrease in metal component strength.

The thin aspect of the angled abutment also prevents preparation and reduction of the abutment when the implant is too facial. The abutment thickness also may preclude the preparation of additional retention features such as directional grooves. Therefore, the reduction of metal along the angled abutment can result in a significant compromise.

Manufacturers usually increase the abutment flare on angled abutments in order to increase the thickness of metal (Figure 26-54). Hence, an implant body that is too facial is made even worse when the angled abutment with a flare is placed. The crown margin more often must engage the abutment flare because the access hole to the abutment is just above the flare. When an angled abutment is planned for the restoration, the implant should not be positioned at the cervical aspect of the crown. Instead, the implant and abutment should be inserted deeper into the sulcus, so the abutment flare is at the desired crown margin.

There are two categories of the two-piece abutment designs: a stock, premanufactured abutment and a laboratory, customized abutment designed for a specific implant. Abutment designs may be customized to enhance the emergence profile of the crown in relation to the soft tissue or increase crown retention (by making the abutment wider or taller). Laboratory technicians also may prefer these "anatomic" abutments because they often resemble a prepared tooth, providing a comfort zone to prepare the implant crown because it is similar to conditions under which they are trained for natural tooth abutments (Figure 26-55).



FIGURE 26-54. Angled two-piece abutments for cement retention have less metal flanking the abutment screw on one side. As a consequence, many designs place more metal at the implant flare, which compromises the cervical aspect of the restoration.

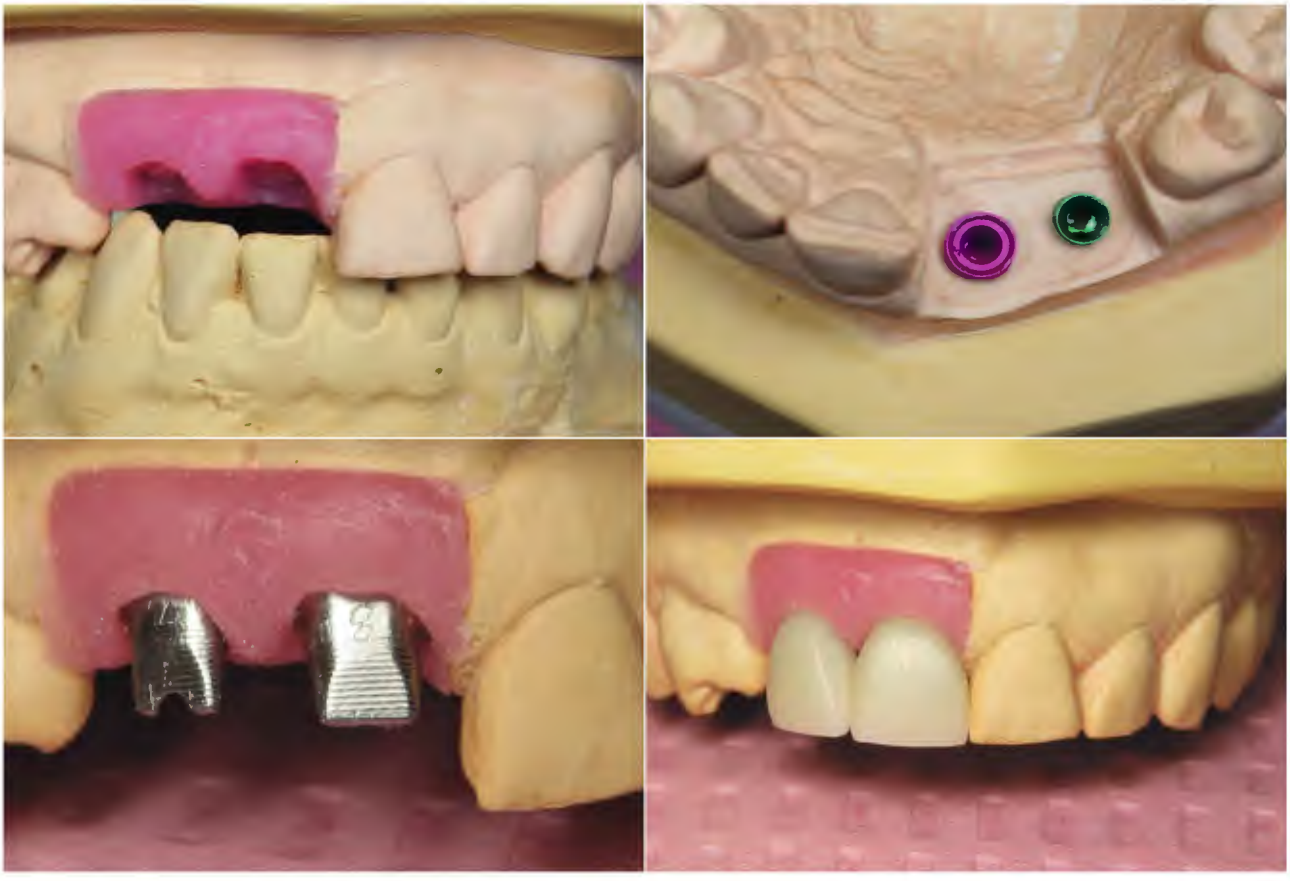


FIGURE 26-55. An implant may be restored with a custom abutment. The dentist makes an implant body impression and uses implant body analogs to transfer the implant position *(upper left* and *upper right)*. The custom abutment is made to appear similar to a natural tooth crown preparation *(lower left)*.

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The most widely used custom abutment is a plastic pattern that is waxed for contour and height and cast in precious metal. The advantage is a reduced cost. The disadvantage is that the casting cannot match the precision of a machined interface for the antirotational feature of the implant body. As a result, the misfit leads to higher risk of abutment screw loosening.

The lack of precision in the custom abutment primarily occurs in two regions of the casting. The first is the corner region of each hexagon. A lapping tool is used to finish the casting but cannot provide the same precision as the premade machined abutment. As a result, there is less rotational resistance of the matting surfaces and the rotational forces that are applied to the abutment screw, with increased risk of loosening and long-term fracture.

The second area of the lack of precision is the seating of the head of the abutment screw. The custom cast abutment has one side of the abutment screw head fitting more securely to the abutment than the other. The lapping tool does not reach the internal aspect of the abutment screw hole in the casting, and no improvement can be made to the receptor site within the abutment. This less stable connection is more likely to result in abutment screw loosening.

A second option for a custom abutment is a premachined titanium sleeve component. The laboratory waxes onto the metal sleeve and casts precious alloy to the machined coping. A mechanical retention binds the materials of the titanium sleeve and casting to give adequate strength. The primary advantage of the approach is the accuracy of fit for the hexagon engagement and the abutment screw head. As a result, the screw connection is more secure, and the risk of screw loosening is decreased. The disadvantage of this component is that the union between the titanium alloy and precious metal casting is not chemical and may lead to crevice breakdown and fracture. The literature cautions about the risk of contamination and poor chemical bonding between the titanium portion of the customized abutment and the precious alloy used to cast the plastic pattern. Hence, the custom abutment may separate and require refabrication in the future.

The custom abutment may also use a combination of plastic sleeve and machined precious metal coping (Figure 26-56). The "combo custom abutment" has advantages of an accurate machined fit and a more secure metal-to-metal connection after the casting is secured to the metal coping. A machined interface is superior to a custom-cast interface because it maintains the precision of the hexagonal interface at the implant body and the head screw position. The cast metal custom abutment binds the precious metal coping with a greater strength than when cast to titanium. Studies suggest that when noble metal machined cylinders are combined with casting alloys that are high in gold or palladium as in the combination design, the cast interfaces are microstructurally sound.[91] The primary disadvantage of this custom abutment design is its higher cost.

Porcelain may be added to the custom combination abutment because precious metals are used as part of the casting. The porcelain may be customized to any tooth shade or even pink in subgingival areas for improved color and appearance in high esthetic zones (Figure 26-57).

The dentist should make a careful selection of the abutment design most adapted to the specific case. Custom abutments require more laboratory expertise than the prefabricated two-piece titanium abutment. However, in cases such as an anterior single-tooth implant with high esthetic requirements, the use of enhanced emergence profile with white or pink porcelain on the abutment may mean the difference between a poor implant restoration and an acceptable crown.

Whether a stock or custom abutment is used, abutments require careful implant positioning because many errors in implant body placement cannot be corrected simply by adding an angled or customized abutment. For example, the anterior implant body may be positioned or angled too facial. The angled stock or anatomical abutment under these conditions creates facial overcontours that can negatively affect the cervical aspects of the crown.

Natural Teeth and Implant Abutments: A Comparison of Prosthetic Indices

The long-term survival of fixed prostheses on natural teeth is well documented. The four most common causes of failure of fixed prostheses on natural teeth are caries of abutment teeth (22%–38%), endodontic-related complications (failure and fracture), uncemented restorations (17%), and porcelain fracture (16%).[4,7,8] Fixed prostheses on implants in partially edentulous patients have provided equal or superior survival rates. The most common causes for failure of cement-retained implant-supported restorations include early loading failure, uncemented restorations, fracture of occlusal materials, or loose implant components.

Retrospective studies that identify the causes for fixed prosthesis failure permit fine-tuning of the fundamental principles of fixed prosthodontics and highlight the areas where more attention to detail is required. For example, stress factors account for the most common complications of implant prostheses and almost two thirds of complications for fixed restorations on natural teeth. After the diagnosis and treatment plan are established properly, the most common causes of excessive stresses on cemented implant prostheses may be overload, faulty occlusal schemes, and undiagnosed partially retained restorations (which cause cantilever forces).[58]

Crown Margin Location

Position for Natural Teeth

A common axiom in restorative dentistry is to establish supragingival margins whenever possible. They allow visualization and preparation of finish lines, facilitate accurate impressions, allow postinsertion evaluation, improve hygiene conditions, and promote the preservation of the biological width.[69,70,92] Subgingival restorations are indicated in the case of (1) caries, (2) replacement of preexisting restorations, (3) esthetics, (4) retention, (5) root fracture, (6) cervical defects, and (7) root sensitivity[70] (see Box 26-3). If the crown margin does not belong in at least one of these categories, a supragingival margin design is indicated. The main goal of a supragingival margin is to decrease the risk of gingival inflammation (which includes reduced risk of residual cement), which has been described as a major consequence of subgingival margins.[93,94]

Partially edentulous patients requiring implants often need complete oral rehabilitation. Crowns may be required on several teeth to restore the proper anatomy, occlusal plane, and occlusal scheme. Periodontal disease or extrusion of existing teeth is common, and the root surfaces of these teeth often are exposed after periodontal therapy and soft tissue management. The exposed cemental areas of teeth are particularly vulnerable to decay, more so than the enamel surface, especially if the recipient of a crown margin. The most common cause of natural abutment failure is caries. Therefore, strategies to reduce decay

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on restored teeth are encouraged, such as the judicious choice of margin location, use of medicaments, and addition of resistance and retention features to counteract dislodging forces.

The supragingival crown margin concept may be modified slightly to design crown margins not only above the tissue but also on enamel to decrease the risk of caries (Figure 26-58). Therefore, the supragingival axiom may be replaced by the enamel margin criterion in patients with cementum above the gingiva.[18]

The lingual aspect of teeth rarely is involved in esthetics, caries, or root sensitivity. If additional retention is not needed or if previous restorations do not mandate a subgingival margin, the lingual aspect of the tooth crown margin may be supragingival and on enamel. In addition to reduced risk of decay, lingual tooth sensitivity is reduced by avoiding dentine exposure from cementum removal for crown margin preparation and final crown margins short of the prepared margin. In addition, the final impression may more easily capture the lingual crown margin preparations because soft tissue retraction is unnecessary and a reduced risk of sulcular bleeding is observed.

Caries of the natural tooth crowns and abutments may be reduced further by regular topical applications of fluoride by a professional and in the daily home care regimen. The restoration of a mouth usually involves two to four clinical appointments, during which prepared teeth are accessible to topical medications. These appointments represent an opportunity to apply fluoride directly on the surfaces of the prepared teeth with the dual benefit of decreased tooth sensitivity and vulnerability to decay.[18]

A daily application of neutral fluoride and fluoride in toothpastes to crown margins after treatment also helps prevent caries on the abutment teeth and is prescribed as part of the normal home care regimen. Because decay is the primary cause of complications for natural teeth–supported fixed prostheses, fluoride rather than chlorhexidine is used on natural teeth. In patients with implants and natural tooth abutments, the combination

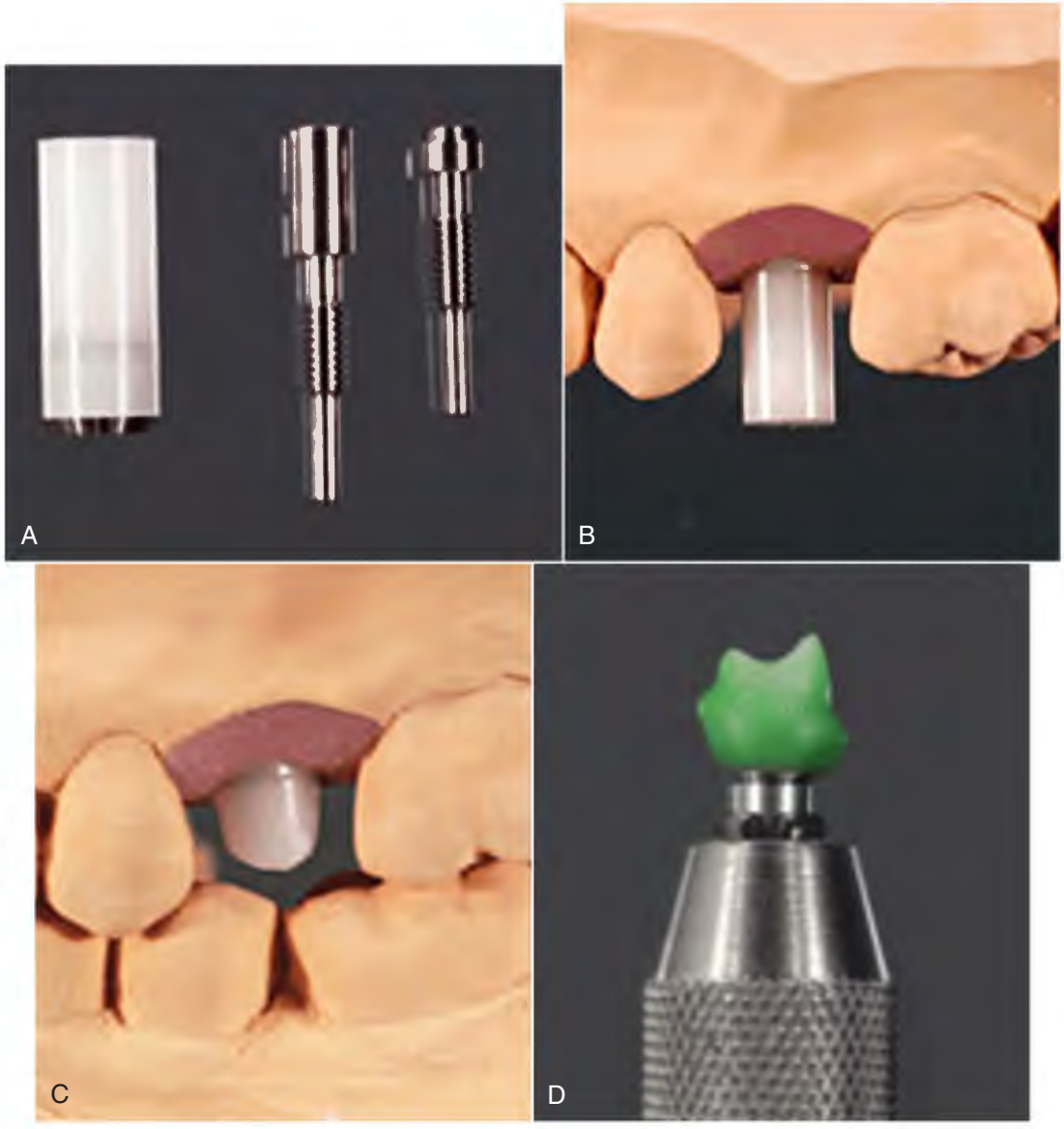


FIGURE 26-56. **A,** Gold–plastic combination abutment. **B,** Abutment placed on soft tissue stone model. **C,** Necessary modifications are made to plastic sleeve. **D,** Wax-up on abutment to create the proper emergence profiles.

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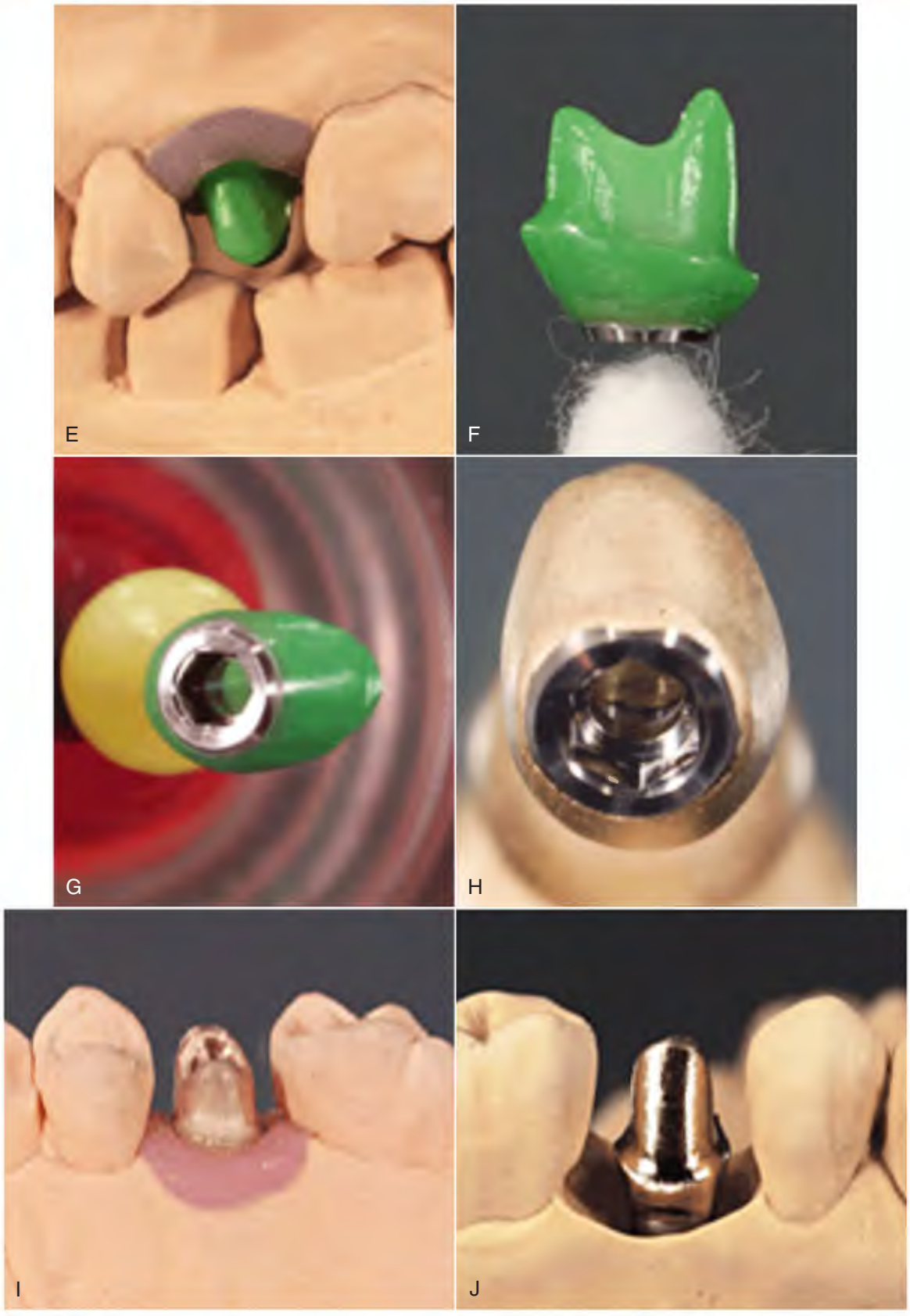


FIGURE 26-56, cont'd. **E,** Wax-up tried on the stone model. **F,** Final wax-up. **G,** Wax-up prepared for investment. **H,** Cast abutment is divested; chemical divestment ensures that the implant interface geometry is maintained within the manufacturer's tolerance. **I,** Cast try-in on the soft tissue stone model. **J,** The final cast is polished, and the implant interface and abutment margins are checked.

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FIGURE 26-57. **A,** A custom abutment with pink porcelain added to the subgingival region is fabricated to enhance the cervical esthetics. **B,** The patient has an implant replacing the left canine. A custom abutment with pink porcelain is placed after an implant body impression is obtained. **C,** The custom abutment and crown are seated. The subgingival pink porcelain is advantageous in situations in which the soft tissues are thin and the grayish color of the titanium abutment may affect the esthetic outcome.

of these two products may make both less effective. Therefore, alteration of fluoride and chlorhexidine applications (e.g., one in the morning, the other at night) is suggested.

Fluoride also may be found in glass ionomer cements used for final cementation, which may provide an increased fluoride uptake in the tooth structure around the margins. However, this cement is less indicated for metal-to-metal luting of surfaces, as for dental implants.

Caries are also a result of a partially uncemented restoration. The combination of natural and implant abutments in the same prosthesis often is not advocated because of potential biomechanical complications. Most often, the most rigid abutment in the prosthesis will become uncemented. In a tooth and implant–combined prosthesis, the uncemented portion of the restoration is most often the implant abutment. However, when an implant serves as a pier abutment, the natural tooth may become uncemented because the implant may act as a fulcrum. Retention and resistance forms of the abutments are critical to minimize such a complication. The insertion of an additional implant to permit the fabrication of an independent implant restoration is the treatment of choice rather than the use of the implant in the intermediate position.



FIGURE 26-58. Caries is the most common complication of crowns on the natural teeth. Guidelines indicate that the crown margin not only should be supragingival but also should be placed on enamel. This not only facilitates access for hygiene but also decreases the risk of caries because enamel is more resistant to decay.

Crown Margin Position for Implants

The indications for subgingival margins described for teeth may be adapted to implants and are therefore only indicated for two reasons: increased retention and esthetics. Hence, the advantages of supragingival margins suggest their use on implants in the majority of situations that are out of the esthetic zones.

The subgingival margin for teeth or implants should not proceed further than 1.5 mm below the free gingival margin even in the interproximal region. It is important to note that the implant abutment flare is often 1 mm above the implant body connection, which is often at the crest of the bone. Hence, when the tissues are 2.5 mm thick (or more), the abutment flare is apical to the crown margin location.

Knife-Edge Abutment Margin Design

Traditional preparations on teeth usually restrict the use of knife-edge margins (minimum tooth preparation) to avoid overcontouring of the final restoration. No scientific studies have stated that chamfers or chamfer and aprons are superior to other finish lines, but the ease of preparation has made them desirable and avoids excessive bulk of restoration. However, whenever minimum implant abutment or tooth preparation is indicated, a knife-edge finish line should be considered. Several common indications exist for a knife-edge margin preparation in prosthodontics because of the minimum reduction required. These indications include (1) implant abutments, (2) furcation regions of molars or premolars, (3) the interproximal region of the mandibular incisors, (4) lingual surfaces of mandibular posterior teeth, (5) a very convex axial surface, and (6) a surface toward which an abutment is tilted more than 15 degrees[18] (Box 26-6).

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BOX 26-6 Indications for a Knife-Edge Margin

1. Implant abutments
2. Furcation regions
3. Interproximal region mandibular incisors
4. Lingual surface of mandibular posterior teeth
5. Convex axial surfaces
6. Abutment tilted more than 15 degrees



FIGURE 26-59. An implant crown often has a knife-edge margin because reduction or preparation of the abutment is not necessary.

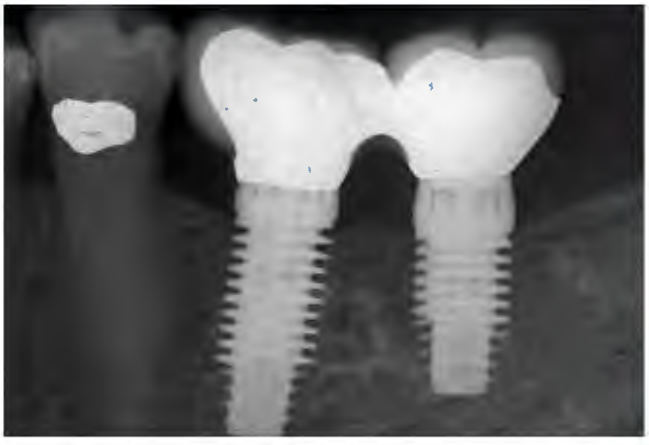


FIGURE 26-60. Knife-edge margins are at or within 1 mm ± 0.5 mm of the free gingival margin.



FIGURE 26-61. Porcelain may be bonded to the knife-edge margin when additional bulk and contour are necessary to develop the emergence of the crown. The porcelain applied to the knife-edge margin may extend from the metal coping to any emergence contour desired.



FIGURE 26-62. The facial position of two of these implant abutments requires a chamfer preparation to provide greater room for porcelain.

Implant abutments are a common indication for minimum abutment margin reduction because they are usually smaller in diameter than a prepared natural tooth for a crown and 5 mm or less in diameter. Reduction of the abutment diameter to achieve room for porcelain or a beveled margin further decreases the surface area for retention. Additional space for metal and porcelain in the region of the margins typically is not required because the implant is already smaller in diameter than the cervical aspect of the tooth and sufficient volume is available for the restorative materials (Figures 26-59 to 26-61). Therefore, a knife-edge margin is the most common implant abutment preparation. In fact, often an impression may be made with no preparation of the implant abutment, and the laboratory technician trims the stone die at the tissue level of the abutment.

An exception to a knife-edge abutment margin is when the implant is too facial or too close to an adjacent tooth and a porcelain crown margin is desired. Crown margin designs such as a shoulder or chamfer can be selected in cases in which the implants are placed too facially so as to create sufficient space for the restoration and avoid overcontouring (Figure 26-62). Another indication for greater reduction is to allow for sufficient space in a mesiodistal dimension for the prosthesis when two implants are too close to each other.

A knife-edge finish line also is indicated on the side of the implant or natural abutment tilted more than 15 degrees. The amount of material removed for parallelism jeopardizes the width of the implant abutment or encroaches on the pulp horn of the tilted tooth. Minimum structure removal of the implant or natural tooth on the side toward the angulation is suggested to reduce these complications.

A third indication for a knife-edge margin is for molars (or on occasion maxillary first premolars) with past periodontal

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bone loss, which may be included in an implant reconstruction. The furcation area of a molar is often closer to the pulp chamber. Excessive removal of dentin in this region increases the risk for endodontic therapy. As a result, a knife-edge margin may be used in the furcation areas to improve hygiene yet decrease the risk of pulpal damage (Figure 26-63). About 30% of the root surface area for a maxillary first molar is found above the root trunk. Values for the mandibular first molar are similar.[95,96] In addition, periodontal disease is more likely under these conditions. When a furcation is exposed by bone loss, these molars are less suitable as abutments for a fixed prosthesis. As a result, an independent implant prosthesis is usually indicated in these conditions.

A knife-edge margin also may be indicated for lower anterior teeth, which may be splinted or crowned to decrease mobility or correct the incisal edge position. The lateral pulp horns project toward the interproximal areas, and knife-edge margins in these areas reduce the risk of pulp exposure (Figure 26-64). The knife-edge margin more often is necessary when the incisal edge is wide and the cervical region is narrow, such as on periodontally treated teeth. The knife-edge margin is also acceptable on teeth with very convex axial surfaces for similar reasons. Therefore, for an implant or natural tooth abutment, the dentist prepares a knife-edge margin whenever the need for minimum reduction of the abutment is a primary concern.



FIGURE 26-63. The maxillary first molar had a buccal furca exposed. The knife-edge preparation reduced the furcation undercut and decreased the risk of pulpal exposure.



FIGURE 26-64. In the interproximal region of lower anterior teeth, a knife-edge preparation may be indicated, especially when the incisal edge is wide and the cervical region is narrow in diameter.

Splinted Crowns

Natural Teeth versus Implants

The most common complication of splinted crowns on natural teeth is caries. The pontic between abutments acts as a plaque reservoir and one of four adjacent teeth decays within 10 to 15 years. When adjacent teeth are splinted together, interproximal hygiene is restricted. As a result, whenever possible, the natural teeth should not be splinted together.

The primary disadvantage of splinting implants together is interproximal hygiene. However, most implants are 3 mm or more apart, rather than adjacent teeth, which may be 0.5 mm apart. When adjacent crowns on natural teeth are splinted together, the interproximal hygiene aids are often insufficient. However, almost any interproximal hygiene aid may be easily used for daily hygiene with adjacent implants.

Implant abutments do not decay (or require endodontic therapy). The most common complications are related to biomechanical stress. As a consequence, methods to decrease the cause of most complications are in order.

To reduce biomechanical stress and maximally benefit from adjacent implants to replace multiple missing teeth, the implants should be splinted together. There are many advantages to splint implant together. Splinted implants (1) increase the functional surface area of support, (2) increase the A-P distance (A-P spread) to resist lateral or cantilevered loads, (3) increase cement retention of the prosthesis, (4) have greater ease to remove the prosthesis for treatment or repair of complications, (5) decrease the risk of marginal bone loss, (6) decrease the risk of porcelain fracture, (7) decrease the risk of abutment screw loosening, (8) decrease the risk of implant component fracture, and (9) make the complications of implant failure easier to treat. In other words, the entire implant system benefits[18] (Box 26-7).

1. Splinted implants increase the functional surface area to the support system. When implants are independent, they cannot share the occlusal load from one implant to another. As a consequence, with splinted implant crowns, the risks associated with the biomechanical overload to the implant system are reduced (occlusal porcelain, cement or screw that retains the prostheses, marginal bone, implant–bone interface, and implant components). If a maxillary second molar implant is connected to a maxillary first molar implant, it can share an occlusal load to the second molar even when the second molar has no direct occlusal load (Figure 26-65). As a consequence of splinting, implant survival may be greater. For example, success rates of 90% for single implants, 97% for two splinted implants, and 98% for three splinted implants are found in several studies.[14,15,92]

BOX 26-7 Advantages of Splinting Implants

1. Increased functional surface area
2. Increased anteroposterior distance
3. Increased cement retention
4. Ease of prosthesis removal
5. Decreased marginal bone loss
6. Decreased porcelain fracture
7. Decreased abutment screw loosening
8. Decreased component fracture
9. Complications easier to treat

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2. An A-P distance between two or more implants is a benefit for any angled load or cantilever, especially when three or more implants are not in a straight line[58] (Figure 26-66). The biomechanics of an arch is of most benefit because there are five different planes connected together (bilateral molar, and premolar, bilateral canines, and an anterior implant).[17] Rotational forces, angled forces, and cantilevers to the facial or lingual (offset loads) are all reduced when splinted implants are not in the same plane and receive a load compared with individual units.
3. Splinted dental units provide greater abutment surface area and resistance form so the prosthesis has more retention and resistance. In addition, there is less force transferred to the cement interface. As a result, the restoration is less likely to become uncemented (Figure 26-67). This is especially significant when the abutments are short or lateral forces are present. The prosthesis is less likely to become uncemented, so less hard cements may be used. This allows the restoration to be more easily removed when necessary.
4. If a prosthesis does become partially retained or an abutment screw becomes loose, a splinted restoration is much easier to remove than individual units. The impact force to an individual crown that is mobile as a result of a loose abutment screw decreases the force to the cement seal and is difficult to remove the crown. In addition, attempting to engage a single crown margin is often difficult for the crown remover, especially when a subgingival margin is present. As a consequence, the crown may need to be cut off and destroyed to gain access to a loose abutment screw (Figure 26-68). Rather than attempting to engage a single crown margin, the crown remover needs only to engage the interproximal space of the prosthesis when crowns are splinted together. This position for the crown and bridge remover is above the tissue and has a large undercut region (Figure 26-69).
5. Splinted implants have less stress transmitted to the crestal marginal bone. Stress may be related to marginal bone loss around an implant. As a consequence, there is less risk of marginal bone loss (Figure 26-70).
6. Splinted crowns have less risk of porcelain fracture. The marginal ridges of implant crowns usually are unsupported by the underlying metal work. As a consequence, the load on a marginal ridge is a shear load, with porcelain weakest to shear loads. In a report by Kinsel and Lin, porcelain fractures may occur in 35% of patients with implant crowns, especially when bruxing patients are restored in group functions.[93]

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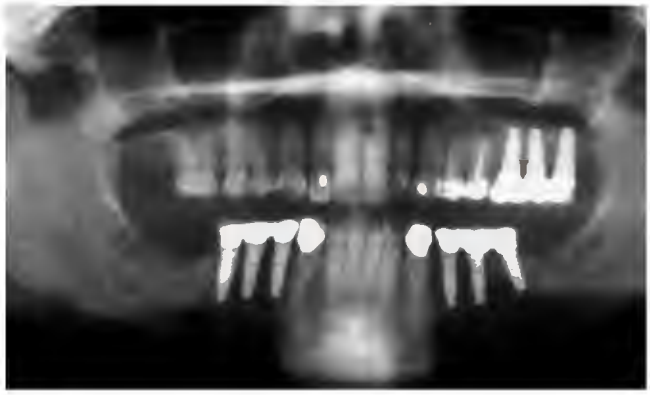


FIGURE 26-65. The maxillary implants are in D4 bone. The patient has parafunction and is opposing an implant prosthesis. Three implants splinted together in the posterior maxilla support the two crowns in occlusal load.

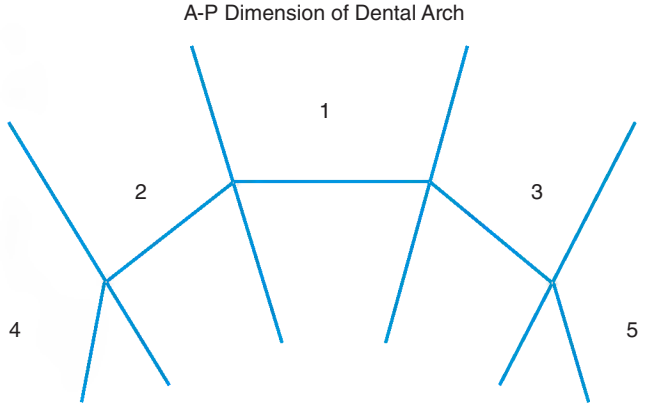


FIGURE 26-66. A dental arch has five different directions of movement: central and lateral incisors, bilateral canines, and bilateral posterior teeth. Splinting two or more components results in an anterior-posterior (A-P) distance to resist horizontal loads.

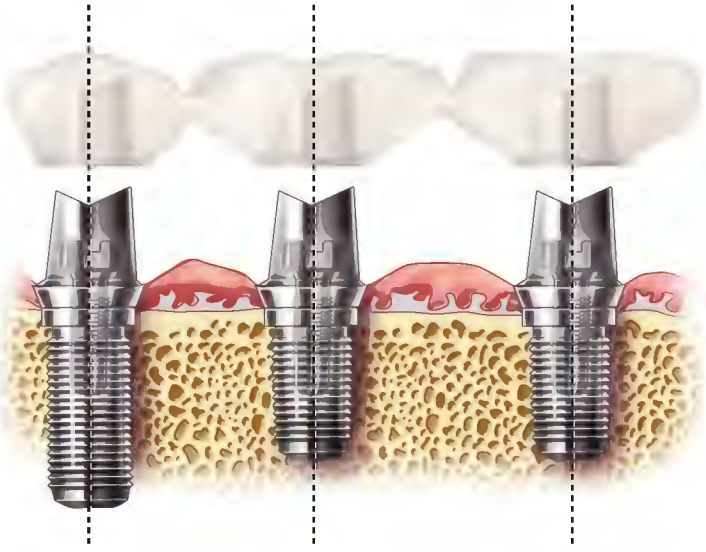


FIGURE 26-67. Splinted implants have more retention for the restoration.

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FIGURE 26-68. Individual crowns cemented on implants may need to be destroyed in order to remove the crown when fixing implant complications.

Splinted implant crowns have the metal connectors of the casting below the marginal ridges. Hence, the interproximal porcelain is supported by metal and has a compressive force applied to the porcelain-to-metal interface during load and porcelain is strongest to compressive loads (Figure 26-71).

7. Splinted implants reduce the risk of screw loosening. One of the highest prosthetic complications with single-tooth or independent implant crowns is abutment screw loosening. In a review of the literature by Goodacre et al., independent crowns had a screw loosening rate of 8%, with a range as high as 22%.[56] In a report by Balshi, single-tooth implants replacing a molar had 48% screw loosening over a 3-year period.[21] When two implants were splinted together to replace a molar, the incidence of screw loosening was reduced to 8% over the same time period.
8. Splinted implants distribute less force to the implant bodies, which decreases the risk of implant body fracture. In a report by Sullivan, a 4-mm single implant replacing a molar had implant body fracture in 14% of the cases.[94] In comparison, multiple implants splinted together report a 1% implant body fracture rate[23] (Figure 26-72).

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FIGURE 26-69. To remove splinted crowns, the bridge remover only needs to engage an interproximal region rather than a crown margin.



FIGURE 26-71. Marginal ridges of implant crowns are often unsupported porcelain, which loads them in shear. Splinted implants have the porcelain marginal ridges supported by the metal framework, so the porcelain is loaded in compression.

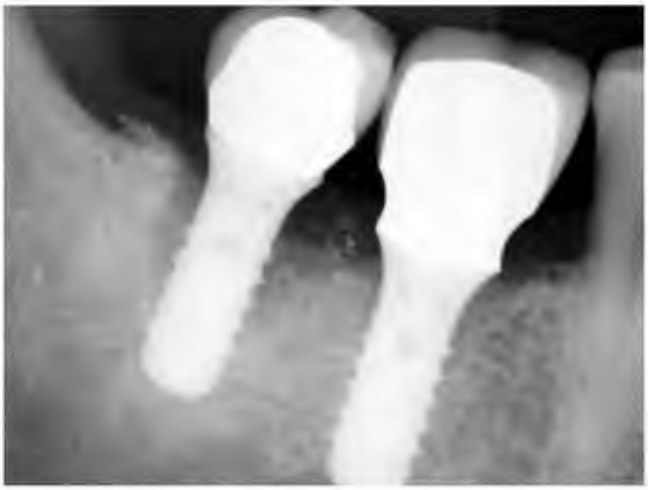


FIGURE 26-70. Individual crowns have greater occlusal loads to the bone and increase the risk of marginal bone loss.



FIGURE 26-72. Individual crowns have greater stresses and may result in implant component or body fracture.

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9. If an independent implant fails over time, the implant may be removed, the site of bone grafted, and the site reimplanted. This may require multiple surgeries over a year period of time. In addition, a new crown must be fabricated.

When multiple splinted implants have an implant that fails, the affected implant may often be removed, and the implant crown converted to a pontic using the same prosthesis (Figure 26-73). As a result, rather than several surgical and prosthetic procedures over an extended period when independent units are restored, the problem may be solved in one relatively short appointment.

As a consequence, of all the advantages of splinted implant crowns compared to individual units, the rule is to, whenever possible, keep natural teeth as independent units and whenever possible, splint implant crowns together.

An exception which favors splinting natural teeth is when mobile teeth surround implant crowns. Anterior teeth may be mobile after successful periodontal therapy. When implants are surrounded by mobile teeth, the implants bear most of the occlusal load of the entire arch. This may be excessive when parafunction is present. One method to reduce mobility is to splint natural teeth together. When this is being considered to reduce mobility, the terminal aspect of the splint should not end on the most mobile tooth.

The exception to the splinted implant rule is a full-arch mandibular implant prosthesis. The body of the mandible flexes distal to the foramen upon opening and has torsion during heavy biting with potential clinical significance for full-arch implant prostheses.[97] As a result, a full-arch mandibular implant prosthesis should not be splinted from molar to molar on the opposite sides. Therefore full-arch mandibular restorations should have a cantilever or be made in two or three sections to accommodate the mandibular dynamics during function. The concept of flexure and torsion does not affect the maxilla, where all implants often are splinted together, regardless of their positions in the arch.

Path of Insertion

Parallelism for Natural Teeth

The anterior natural teeth often are crowded or rotated. As a consequence, when splinting these teeth to decrease mobility several natural abutments may need endodontic therapy to achieve a restorative goal. If this is not explained to the patient before treatment begins and endodontic therapy is required, the patient often feels that inadequate treatment has been rendered. Endodontic therapy or posts and crowns for overlapping anteriors still may provide inadequate embrasures for hygiene. This condition not only compromises esthetics but also may result in the loss of more than one tooth because of periodontal disease. Selective extraction of incisors may even be indicated if rotations or overlapping of teeth that are splinted together creates an unfavorable environment for daily maintenance.

One of the indications for attachments in a fixed or removable partial denture includes joining nonparallel teeth or splinting anterior and posterior teeth in the same prosthesis. The attachment should usually be rigid in design, size, and fabrication. All of these factors limit the path of insertion of the final prosthesis.



FIGURE 26-73. **A,** A three-unit splinted implant prosthesis with severe bone loss of the middle implant. Exudate is present. **B,** The prosthesis was removed along with the middle implant. **C,** The middle splinted crown is converted to a pontic.

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When adjacent teeth have been missing for a long time, the remaining natural abutment often has drifted from its ideal position and frequently exhibits tipping, tilting, rotation, or extrusion. The dentist should consider correction of the natural abutment position in the original treatment plan for the partially edentulous patient, whether or not the natural abutment is joined to the implant. If the tilted tooth adjacent to the implant restoration is not modified, a large triangular space will be present in the interproximal region, which will be a food trap (Figure 26-74).

A good clinical habit is to evaluate and correct any dental unit that will contact the new restoration. Enameloplasty to improve the occlusion or change the contact shape and position next to the implant prosthesis is not unusual. The path of insertion of the implant prosthesis and the size and shape of the interproximal space often require modification. Treatment also may consist of an individual crown to change the contour, when beyond the ability merely to reshape the tooth.

Orthodontic movement to correct interarch or gross occlusal correction, especially when skeletal patterns require improvement, may be indicated. One can plan orthodontic treatment along with the healing phase for rigid fixated implants. Orthodontic treatment may also develop available bone for an implant site next to a natural tooth. Moving the tooth slowly through the bone to a more remote position generates bone growth and an improved implant site adjacent to the orthodontically removed tooth.

Implant Abutments

Ideally, a similar path of insertion and occlusal load direction permit the use of straight implant abutments and assist the laboratory in designing a prosthesis that directs the forces along the long axis of the implant bodies, which is most desirable for crestal bone maintenance, and reduces the risk of abutment screw loosening. However, whenever the FPD path of insertion is identical to the direction of the occlusal forces, greater tensile forces are placed on the cement while chewing sticky foods. Therefore, under ideal conditions the path of insertion of the restoration should be slightly different than the direction of the load during mastication.

Ideally, one suggestion is that the path of prosthesis insertion should be about 10 degrees divergent from the axial load of the implant during occlusion to improve resistance to bridge uncementation. A straight abutment may still be used, but the preparation and path of insertion of the restoration, flat sides, and grooves in the abutment diverge 10 degrees from the long axis of the implant bodies while still allowing axial occlusal loading to the implant bodies (Figure 26-75).

For example, the posterior abutments for cement (not implant body) should be angled mesial to the axial load of the implant body. The forward path of insertion permits easier preparation, impression removal, and prosthesis seating as it corresponds to the approach of the operator to the mouth. The occlusal loads may be longitudinal to the implant body, yet the prosthesis path of insertion (and removal) is more angled to the anterior.

Nonparallel Abutments

The implant abutment diameter is narrower than most natural teeth; thus the dentist does not have as much latitude to correct unparalleled abutments by preparing a straight abutment. For a cement-retained prosthesis, the unparalleled, posterior implant abutment can be corrected several ways, depending on the degree of divergence.

1. If the divergence of the abutment for cement is less than 20 degrees, the dentist may prepare a straight two-piece abutment initially with a crosscut fissure bur, copious amounts of water, and intermittent contact (Figure 26-76). The resulting abutment should not be round in cross-section, should have a flat side to create resistance against loosening, and should remain as long as possible (Figure 26-77). The dentist then finishes the abutment with a coarse diamond to increase the surface roughness and then uses a crosscut fissure bur to add grooves parallel to the path of insertion. Although this approach is the most familiar to a restoring dentist, the disadvantage is the decrease in surface area of the implant abutment when it is prepared for parallelism. Also, the intra-



FIGURE 26-74. An implant positioned between tilted adjacent teeth results in a large triangular space between the crowns. Therefore, the interproximal regions should be modified by enameloplasty or orthodontics.

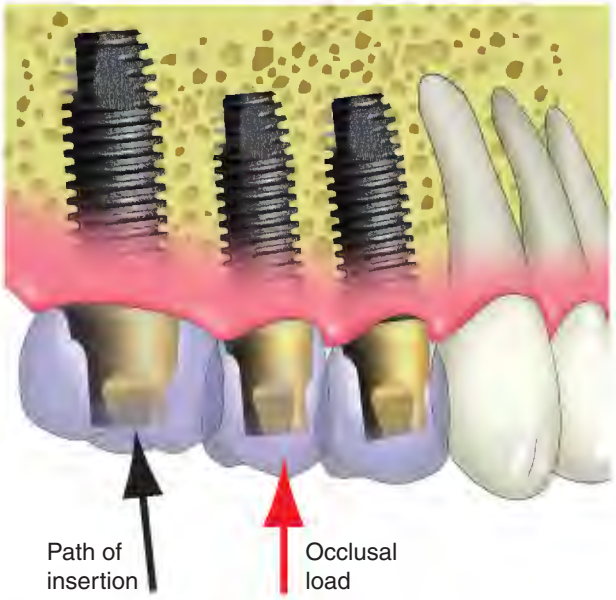


FIGURE 26-75. When the path of insertion is similar to the forces of mastication, sticky food may place shear and tensile forces on the restoration and contribute to uncemented prostheses. The implant body should receive a long-axis load to reduce crestal stress. A path of insertion different from the occlusal force direction is selected to decrease the shear loads to the cement seal from sticky foods. A path angle to the mesial facilitates preparation of the abutment and seating of the restoration.

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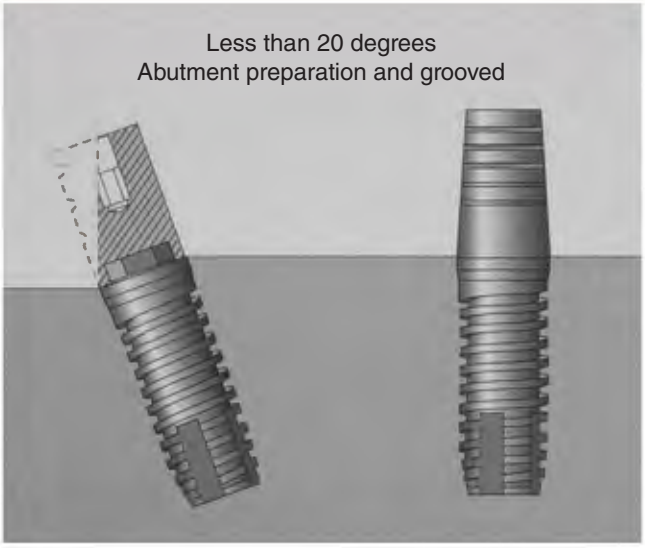


FIGURE 26-76. When the abutment angle needs a correction of less than 20 degrees, a straight abutment may be used and prepared intraorally (one- or two-piece abutment) or in the laboratory (using an implant body transfer impression and a two-piece abutment).

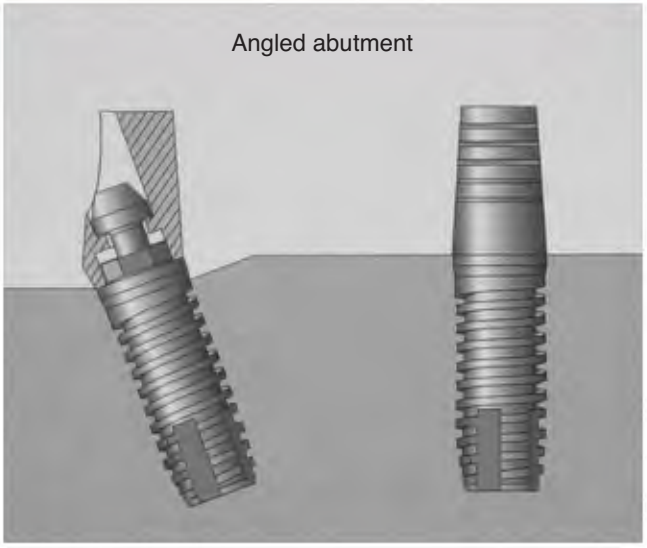


FIGURE 26-78. When the implant body is between 15 and 35 degrees from ideal, a prefabricated two-piece angled abutment may be used to improve the path of insertion.

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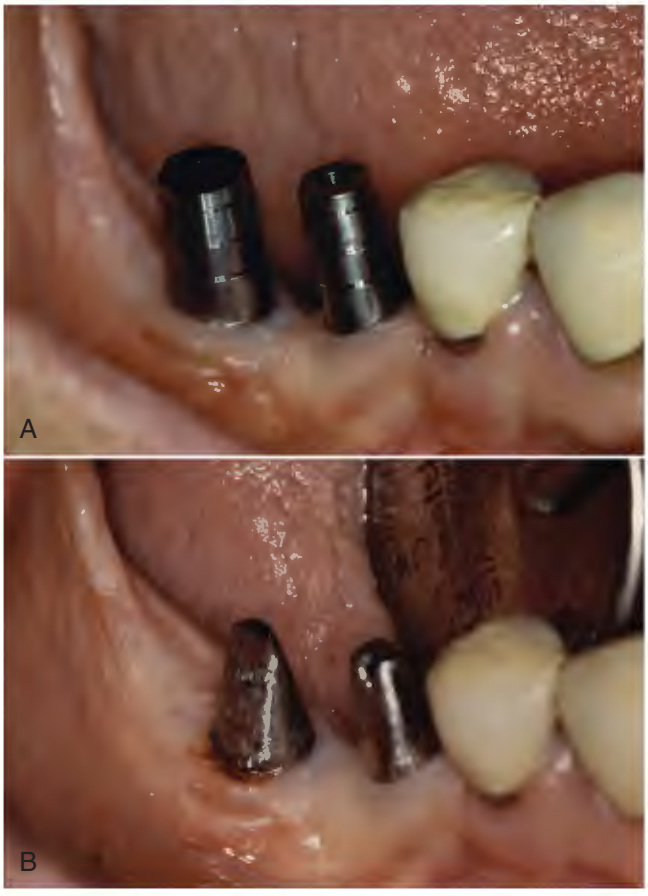


FIGURE 26-77. **A,** Abutments for cement were placed on these two implant bodies. The distal implant is angled buccally. **B,** A high-speed handpiece is used to prepare the abutment and correct the path of insertion.



FIGURE 26-79. Angled abutments have less metal next to one side of the abutment screw.

oral direct approach is less precise than preparing an abutment in the laboratory on a laboratory analog.

2. A second option for an unparalleled abutment for a cemented prosthesis is to place an angled implant abutment (Figure 26-78). Several designs are available, depending on the manufacturer, with varying angle values (15–30 degrees). A two-piece angled abutment that engages the hexagon or antirotational feature of the implant body offers the most advantages. This option most often is selected for anterior implants.

   Most angled abutments are weaker than the implant body, especially on the cervical side of the angle. The abutment resistance to fracture decreases as the angle increases because of the increased angular load and the decreased metal thickness lateral to the abutment fixation screw (Figure 26-79). Manufacturers often have more abutment flare on the side of the angle. This feature permits more metal around the abutment screw (Figure 26-80). The increased diameter of the cervical region of an angled abutment is below the

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crown margin. Hence, the metal color of the abutment may show through thin tissue or become exposed if gingival recession occurs.

3. A third option to improve the path of insertion of a posterior implant abutment is to use a coping (Figure 26-81). The implant abutment remains unparallel to the other abutments. The straight abutment may be roughened and may incorporate grooves into its walls parallel to its own path of insertion but different from the path of insertion of the prosthesis. A coping is then fabricated with walls parallel to the path of the fixed prosthesis. The dentist cements the coping with a permanent cement (i.e., zinc phosphate) onto the abutment for cement retention with a different path of insertion than that of the final prosthesis (Figure 26-82). Soft access or temporary cement (i.e., polycarboxylate) may be



FIGURE 26-80. The cervical region of an angled abutment is often larger in diameter to increase the metal thickness on the side of the abutment screw hole. This portion of the abutment is placed subgingivally but may become exposed after gingival recession.



FIGURE 26-81. A coping may be cemented over the straight abutment. The contour of the coping is made to parallel the path of insertion for the prosthesis.



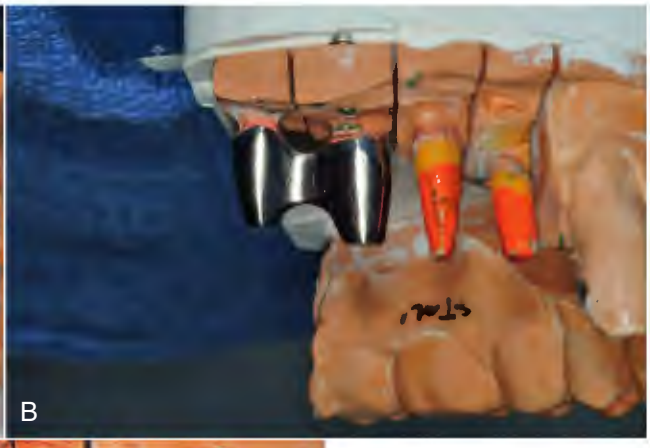




FIGURE 26-82. **A,** Four posterior implants are not parallel to each other. **B,** A coping is made over the distal two implants and is made parallel to the anterior two implants. **C,** The fixed prostheses may now splint the implants together.

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used on the fixed prosthesis for retrievability. The coping remains in place during removal of the prosthesis because of its diverging path of insertion and harder cement (Figure 26-83).

This technique has several advantages. The diameter of the coping is larger than that of the original abutment, so retention is greater. In addition to the greater surface area, the laboratory may prepare the coping with an ideal taper simultaneously to improve the retention and resistance forms. Parallel grooves also may be added by the laboratory to the coping. This procedure is indicated least often for a facially placed anterior implant and most often for a posterior implant distally inclined.

The coping procedure may be used when a final impression is made but the abutments are not parallel to each other. In this way, rather than repreparing the abutments and making another final impression, the case may proceed onto the metal try-in (and coping try-in) appointment.

4. A fourth option is to design a custom abutment. The abutment may be fabricated at most any length or angulation. Precious metal should be used to limit corrosion because the abutment will be cemented or screwed within the implant body. Advantages include a proper angulation, form, bulk, improved emergence profile and facilitated crown usage, allowance of easy preparation of subgingival margins, overcoming interarch space conditions, precision fit, and accurate fabrication. Disadvantages include the sensitivity of the laboratory procedure, additional cost, and accuracy when the hexagon of the implant should be engaged.

Prostheses Fabrication

Direct Prosthetic Option

The implant abutment may be restored as a natural tooth restoration. The two-piece abutment for cement (straight or angled, usually prefabricated) is inserted into the implant body. The abutment screw is tightened, loosened, and tightened again to 30 N-cm or more (for most systems). A counter torque is used during this process on the abutment (Figure 26-84).

A clear prosthetic template may be fabricated before the appointment on the pre-prosthetic wax-up to represent the contours of the final restoration. If the abutments are within 15 degrees of each other, the abutments are prepared intraorally with a #703 crosscut fissure bur under copious irrigation. The crosscut carbide removes metal more efficiently than a diamond (Figure 26-85). The shank of a #703 bur is thicker than a #557, so fracture of the bur during abutment preparation is reduced. The most common finish line is a knife-edge margin (Figure 26-86). The occlusal surface and flat opposing axial surfaces are prepared. A rough diamond is used to increase surface roughness above the finish line (Figure 26-87).

After preparation of the abutment (when necessary) in the mouth, a cotton pellet may be placed over the abutment screw head, and the abutment screw space obturated with composite or endodontic temporary stopping (i.e., Cavit or Fermit) (Figure



FIGURE 26-83. **A,** Six implants with straight abutments not parallel to each other. **B,** Copings are made that have a similar path of insertion for a prosthesis. **C,** A full-arch cemented fixed prosthesis. **D,** The copings are cemented with a definitive cement (i.e., zinc phosphate) and the prosthesis with a softer cement (i.e., polycarboxylate).

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FIGURE 26-84. The abutment for cement retention positioned on the implant and torque applied to the abutment screw with a counter torque on the abutment.



FIGURE 26-87. A rough diamond increases the surface roughness above the finish line.

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FIGURE 26-85. A cross-cut fissure bur grossly prepares the abutment.



FIGURE 26-88. The abutment screw hole is obturated, and sharp edges are rounded.



FIGURE 26-86. A knife-edge finish line is the most common margin preparation.

26-88) The abutment edge contours of the preparation should not be thin or sharp, so the stone die poured after the impression will not fracture at the preparation edges.

If the crown margin is not subgingival, a crown or bridge impression is made. If the crown margin is for esthetics or subgingival (to increase abutment height for retention), a retraction cord is inserted 1.5 mm or more into the sulcus (Figure 26-89). The retraction cord is easier to insert than into the sulcus of a tooth because there is no connective tissue attachment zone. An impression is made of the abutment (with the impression cord in place). These steps are similar to the preparation of teeth for fixed prostheses.

Transitional Prostheses

The need for a transitional restoration for cemented prostheses varies depending on the option of final restoration fabrication (direct or indirect), the bone density, the soft tissue contours, and the location in the esthetic zones.

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FIGURE 26-89. A retraction cord is used to capture a subgingival margin in the impression (for esthetics or to increase abutment height for retention).



FIGURE 26-90. In softer bone types, a temporary prosthesis out of occlusion is fabricated.

After the final impression for the direct technique is obtained, when the implant is not in the esthetic zone, no transitional restoration is required, when the bone density is type D1 or D2 bone. Unlike a natural tooth, the implant is not sensitive to temperature or function.

When the implants are placed into poor-quality bone (D3 or D4 bone), a progressive bone loading protocol is strongly suggested. A transitional restoration is used as a treatment prosthesis under these conditions. The first temporary restoration is completely out of occlusion, and the patient's diet is restricted to soft food (Figure 26-90). After 3 or 4 weeks (or more), the temporary prosthesis is placed into occlusion with no cantilevers (if present). This appointment is in conjunction with the metal try-in procedure. After 3 to 4 more weeks, the final restoration is delivered to the patient.

For a FP-1 implant restoration in the esthetic zone, a transitional restoration is used to evaluate and assist in soft tissue contour around the implant crown(s). This restoration may remain in place for 2 months or more while the soft tissues mature and the interdental papilla regions evolve into their final contour.

Master Casts

Cement-retained prostheses on implants often are fabricated on stone casts, similar to those on natural teeth. A stone cast is poured and an individual die of the abutment is trimmed. However, the abutment post diameter is small (3.5 to 5 mm) and may break off the master cast when the impression is removed after setting of the stone. Several strategies can reduce this complication.

Die stone is used for natural teeth or implant abutments. The greatest compressive strength die stone should be used. As a general rule, the greater the strength, the more the stone expands. Stone expansion compensates for some of the impression material shrinkage. The compressive strength of dry die stones, after 48 hours of setting time, can range from 10,000 to 17,000 psi. This strength increases when allowed to set for up to 1 week. Rather than pouring the impression on the first day and separating the impression/cast the same day, the cast should be allowed to set for several days (up to 1 week).[95] The strength of the die stone may increase by more than 30% by this delay.

The impression tray may be cut and destroyed to remove the impression. This can reduce stone die breakage, but is risky in case the impression needs to be repoured because of bubbles in the mold. Destroying the tray also precludes a second pour if the first pour breaks the dies off the master cast.

An epoxy resin may be poured into the abutment for cement retention regions of the cast. However, epoxy resin shrinks rather than expands when setting. Impression materials shrink, so the master cast should expand to compensate for the shrinkage. When epoxy resins are used, several conditions should be met to compensate for their inherent shrinkage.[96,98] Addition silicone (polyvinyl siloxane) exhibits the lowest impression material shrinkage and is the material of choice when epoxy is used for the dies.[99] Material dimension shrinkage is related to its volume. Therefore, rather than pouring the entire impression in resin, only the abutment posts are poured in resin, which is especially important in full-arch implant restorations. Methylmethacrylate or ethylmethacrylate resin shrinks too much (up to 17%) to be used as a die for cement-retained prostheses. Instead, an expoxy designed for dental dies is indicated.

A die spacer (40 microns) is used on the stone master dies to allow for cement space and improve the passive casting fit.[97] For natural teeth the spacer is usually 25 to 40 microns, but because implants do not decay and passive castings are desirable to reduce crestal bone loss and early implant failure, a 40-micron space is preferred (Figure 26-91). An additional thickness of die spacer should be used with epoxy resin materials because it exhibits shrinkage rather than expansion as with dental stone.

The cemented restoration is often fabricated very similar to a crown on a tooth, with some modification (see Chapter 31). This prosthetic approach may be called a direct prosthetic option (Figure 26-92).

The advantages of placing and preparing the abutment for cement retention in the mouth and leaving it in place for the entire prosthetic steps are many:

1. Familiar to restoring dentists (similar to natural teeth).
2. The preparations are made by the doctor, not the laboratory technician. Hence the amount of preparation, type, and location of the margin are under the doctor's control.
3. No laboratory analog components are required.

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4. Splinting crowns together are less complicated because manufacturer precision for analogs are not required and transfer of components are not required.
5. Reduced cost because analogs and laboratory fees for abutments are eliminated.
6. A fixed transitional prosthesis may be fabricated on the final abutments and initiate the progressive bone loading process at the first prosthetic appointment.

The disadvantages of the direct prosthetic option is that (1) the abutments are prepared in the mouth, (2) retraction cord placement is required in esthetic zones or when additional abutment height is required for prosthesis retention, (3) an accurate impression of the abutment margins are necessary, and (4) a different transitional restoration is often fabricated than the restoration which was used during implant body healing because the abutment(s) is inserted.

Indirect Prosthetic Option

The generic terminology and step-by-step pictures of the indirect prosthetic options were presented in Chapter 2.



FIGURE 26-91. A die spacer is applied to the stone dies.

Option 1

The indirect technique uses a laboratory to select and prepare the abutment. The laboratory wax-up and casting then may be fabricated directly on the abutment that will be used for the prosthesis. Two different indirect implant restorative techniques may be used to make a master impression, and each uses a different design transfer coping, based on the transfer technique performed. To use the indirect laboratory procedure, the dentist makes an implant body impression with an indirect or direct impression transfer coping.

A *transfer coping* may be used in traditional prosthetics to position a die in an impression. Most implant manufacturers use the terms *transfer* and *coping* to describe the component used in the implant body for the final impression. A transfer coping is used to position an *analog* of the *implant body* in an impression or cast and is defined by the portion of the implant it transfers to the master cast.

The first indirect option uses an *indirect transfer coping* and a "closed tray" with an impression material requiring elastic properties. The *indirect transfer coping* is screwed into the implant body and remains in place when a traditional "closed tray" impression is set and removed from the mouth. The *indirect transfer coping* is then removed from the *implant body* in the mouth and connected to an *implant body analog* and then reinserted into the closed-tray impression, hence the transfer is "indirect." The *indirect transfer coping* usually has undercuts to engage the elastic impression material when reinserted, slightly tapered to allow ease in removal from the impression, and often has flat sides or smooth undercuts to facilitate reorientation in the impression after it is removed (Figure 26-93).

The second indirect prosthetic option uses a *direct transfer coping* and consists of two pieces, which includes a hollow transfer component (often square) and a long central screw to secure it to the *implant body*. The direct-impression transfer coping is used with an open-tray technique. A two-piece impression transfer coping engages the antirotational hexagon of the implant body, and an abutment-like screw engages the implant body and extends several millimeters above the impression transfer coping. The dentist verifies proper position with a radiograph or visually. The "open" impression tray is placed over the impression transfer so that the abutment-like screw extends above the tray.



FIGURE 26-92. **A,** Two implant abutments with knife-edge margins and retraction cord ready for a final impression. **B,** A three-unit fixed prosthesis replaces the canine and first and second premolars.

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After the impression material is set, the *direct-transfer coping screw* is unthreaded (hence an "open tray" is necessary) to allow removal of the impression from the mouth. The square impression coping remains in the impression, hence the transfer is "direct." *Direct transfer copings* take advantage of impression materials having rigid properties and eliminate the error of permanent deformation of impression materials, or incorrect seating of the impression coping because the transfer coping remains within the impression until the master model is poured and separated (Figure 26-94). The dentist attaches an analog, engages the antirotational feature (i.e., hexagon), and tightens the abutment screw into position. The direct transfers are also less likely to be rotated or moved during the model pouring in a vibrator and fabrication compared to the indirect techniques.

The dentist makes an impression of the opposing arch and obtains a centric relation occlusal recording or closed mouth bite rejustification.

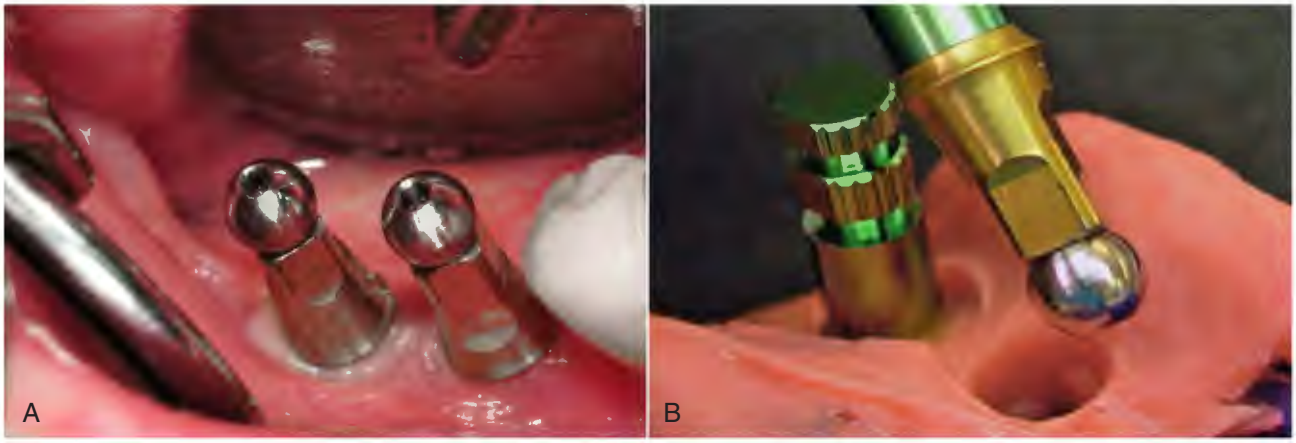


FIGURE 26-93. **A,** Indirect transfer impression copings are inserted into the implant bodies. The two-piece transfer engages the hex of the implant. **B,** The indirect transfer is removed from the mouth and connected to an implant body analog. **C,** It is then repositioned into the impression.

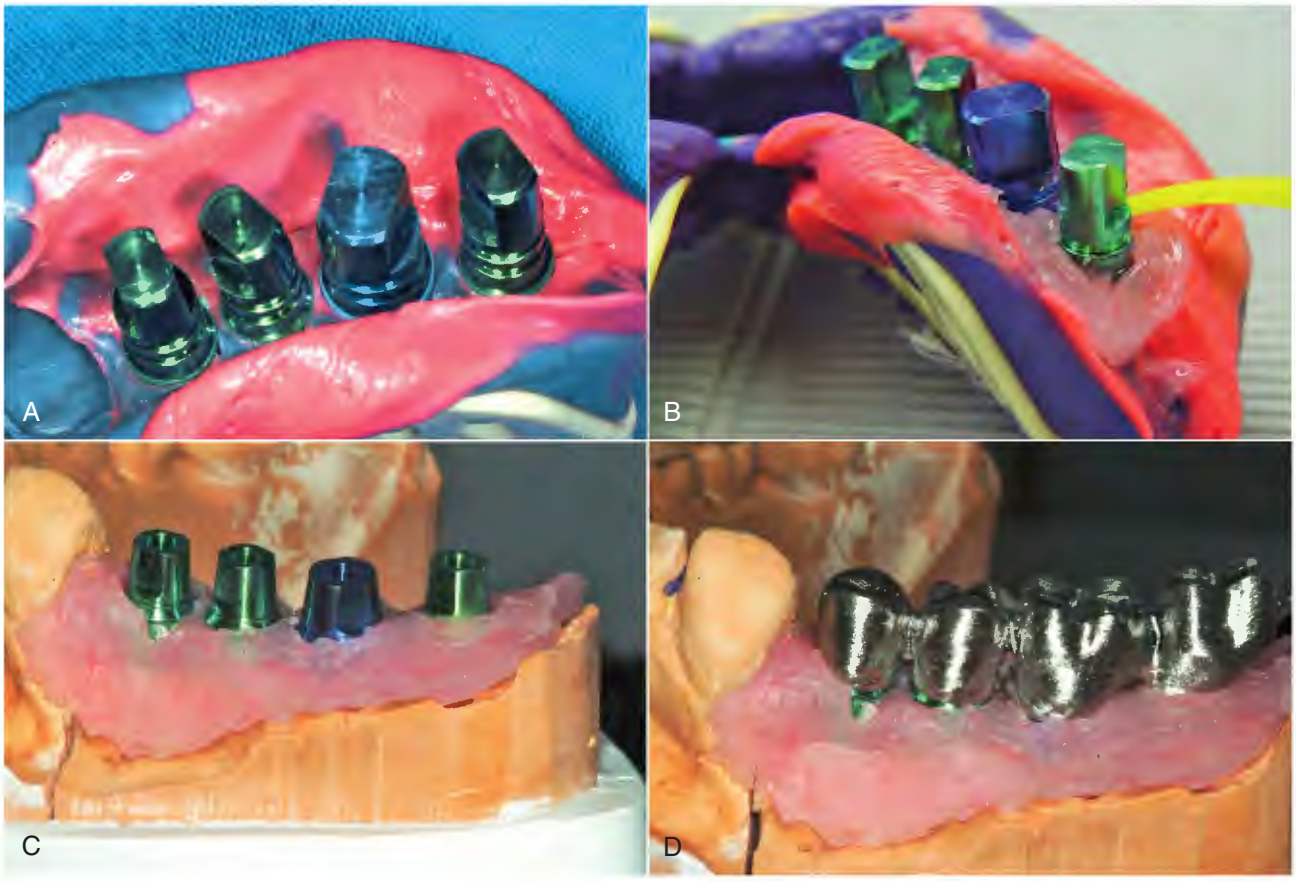


FIGURE 26-94. **A,** The implant analogs are inserted into the impression. **B,** A soft, resilient material is placed around the analogs when a subgingival margin is desired. **C,** The master model is poured and the abutments prepared. **D,** The framework of the prosthesis is cast. *Continued*

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FIGURE 26-94, cont'd. **E,** The abutments prepared in the laboratory are placed in the mouth and torqued into position. **F,** The metal work is evaluated in the mouth. **G,** A new bite registration is usually made. **H,** The laboratory adds the porcelain to the framework. **I,** The final restoration is delivered to the patient.

Laboratory Fabrication

The laboratory then pours a working cast with analogs. An *analog* is defined as something that is analogous or similar to something else. An *implant analog* is used in the fabrication of the master cast to replicate the retentive portion of the implant body *(implant body analog)*. After the master impression is obtained, the corresponding analog is attached to the *transfer coping* and the assembly is poured in stone to fabricate the master cast (Figure 26-94, *B*).

In either the indirect or direct impression method option the laboratory pours and mounts the final impression with an implant body analog. Two-piece abutments are inserted into the implant bodies and the abutments are prepared in the laboratory for parallelism (Figure 26-94, *C*). If custom posts are required, they also may be fabricated at this time. The laboratory also waxes and casts the framework for the final prosthesis in precious metal (Figure 26-94, *D*). A transfer jig may also be made to allow the dentist to position the prepared abutments properly in the mouth (Figure 26-94, *E*).

In larger-implant prosthetic cases a metal try-in is suggested, along with a new centric relation bite registration (Figure 26-94, *F* and *G*). In the restoration of one or two teeth, the laboratory often finishes the prosthesis, and at the following appointment,

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the dentist inserts the abutments into the implants and delivers the final prosthesis (Figure 26-94, *H* and *I*). In good bone quality, out of the esthetic zone, using the indirect laboratory fabrication procedure, no transitional restoration is required.

Using indirect laboratory techniques has several advantages:

1. The primary advantage of the indirect option is that the laboratory can prepare multiple abutments for parallelism and can fabricate single crowns to full-arch prostheses.
2. The impression requirements are less demanding because small bubbles or voids do not affect abutment transfer and margins are not important to capture or record.
3. If an angled abutment is required, the laboratory may choose the right component. A custom abutment may be fabricated (e.g., for a short crown height when a greater diameter would help with retention). As a result, less inventory is required in the doctor's office.
4. A framework may be fabricated directly on the implant abutments, allowing for a more accurate margin fit.
5. Chair time is decreased because the preparations, and transitionals are fabricated by the laboratory.

Additional advantages of the laboratory-assisted abutment preparations can be summarized as (1) more accurate dies to fabricate the prosthesis, (2) improved margins and emergence profile of the transitional or final prosthesis, and (3) subgingival margin preparations without risk of tissue trauma or shrinkage.

Disadvantages of the laboratory-assisted approach include the following:

1. Implant abutment transfers may not be timed or transferred accurately. When an impression is made and the abutments are first removed and inserted into a laboratory model, the rotation of the implant analog may be different by several degrees than in the implant body in the mouth. As a consequence, splinted implant prosthesis may not seat passively.
2. No fixed transitional prosthesis is used to load the bone gradually during fabrication of the metal framework. This increases the risk of early bone loss or early implant failure in softer bone types. This risk can be alleviated by delivering the prosthesis on a temporary abutment with the added disadvantage of increased chair time and laboratory cost.
3. The laboratory decides on the margin location and preparation style.
4. The laboratory cost is increased.
5. The casting is made directly on the implant post and may fit the abutment so accurately as to produce a nonpassive casting. The stone expansion and die spacers of 40 microns help ensure passive castings.

The indirect impression technique may begin the day of surgical implant placement. In this way the laboratory may perform their procedures while the implant-to-bone interface is developing. As a result, the first prosthetic appointment is combined with the implant surgery appointment. Another option is to make the implant body impression at stage II uncovery. This is a safer option because the implants are rigid and their dislodgement or movement is less likely when the impression is removed from the mouth. In addition, impression material is less likely to be trapped between the bone and the implant because the crestal bone has remodeled next to the implant crest module.

Occlusal Materials

The occlusal surface materials affect the transmission of occlusal forces and the maintenance of occlusal contacts. In addition, occlusal material fracture is one of the most common complications for restorations on natural teeth or implants. Therefore, it is suggested the dentist considers the occlusal material for each individual restoration. Occlusal materials may be evaluated by esthetics, impact force, a static load, chewing efficiency, fracture, wear, interarch space requirements, and accuracy of castings (Table 26-1). The three most common groups of occlusal materials are porcelain, acrylic, and metal. These materials for fixed prostheses on implants are reviewed with relevance to the previous eight criteria.

Esthetics

Esthetics is a primary concern for patients. The most esthetic material available today is porcelain (Figure 26-95). Acrylic is acceptable for esthetics, and metal is a poor choice when esthetics is the chief criterion. However, in many situations esthetics is not an important aspect of the restoration. For example, when a maxillary or mandibular second molar is restored, most patients do not expose this area when smiling or laughing. Yet, most of the time the dentist restores the second molar crown with porcelain on the facial and occlusal surfaces and increase the risk of porcelain fracture.

Porcelain fracture is the second most common cause of prosthesis failure. Bite forces are greatest in the second molar region. Instead of increasing the risk of a complication, nonesthetic

TABLE 26-1
Occlusal Material Characteristics

	Porcelain	Gold	Resin
Esthetics	+	–	+
Impact force	–	+	+
Static load	+	+	+
Chewing efficiency	+	+	–
Fracture	–	+	–
Wear	+	+	–
Interarch space	–	+	–
Accuracy	–	+	–

+, Favorable; –, unfavorable.



FIGURE 26-95. Metal occlusals on implant crowns have the poorest esthetics *(right)*. Porcelain is the most esthetic occlusal material *(left)*.

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FIGURE 26-96. In the mandibular second molar region, metal occlusals have less fracture.

regions may consider an occlusal surface based upon other criteria (Figure 26-96). Use of porcelain is suggested primarily when esthetics is the primary criterion for choice of the occlusal material.

Impact Forces

The materials on the occlusal surface affect the transmission of force to the implant system. Impact loads give rise to brief episodes of increased force, primarily related to the speed of closure and the dampening effect of the occlusal material. The hardness of a material is related to its ability to absorb stress from impact loads. An all porcelain occlusal surface exhibits a hardness 2.5 times greater than that of natural teeth. On the other hand, acrylic resin has a Knoop hardness of 17 kg/mm^2, and enamel has a 350 kg/mm^2 hardness.[81] A composite resin may exhibit a hardness of 85% that of enamel. Therefore, impact loads are lowest with acrylic, increase with composite and metal occlusals, are greater with enamel, and further increase with porcelain. As a result, the use of resin occlusal surfaces on the implant prosthesis was originally suggested, because of its dampening characteristics.[1,2]

Acrylic transitional prostheses provide progressive bone loading. Acrylic may reduce the impact force on the early implant-to-bone interface. As the bone matures and its density increases, the need for force reduction decreases.

Chibirka et al. found no statistical difference in the mandible for stress to the implant-to-bone interface using strain gauges with the force to crush a peanut between occlusal surfaces of gold, porcelain, or resin.[100] Also, in the authors' experience and in clinical studies, fewer adverse effects occur to the implant system with the use of occlusal porcelain compared to acrylic.[101]

For a patient without parafunction, the dentist may select any occlusal material with minimal risk. Patients without parafunction occlude less than 30 minutes each day, with a force lower than 30 psi. However, bruxism may increase the duration, speed, and amount of force by 10 times or more. Therefore the type of occlusal materials selected can affect the implant system under such abnormal loading conditions. For the patient with problems of bruxism, the dentist may reduce the impact force with metal or acrylic versus porcelain occlusal materials. However, impact force is not the only issue. Material fracture is greatest for acrylic, followed by porcelain, and metal is the least likely to have this complication.

A hybrid restoration may use porcelain denture teeth, surrounded by acrylic, which binds to a metal substructure. The damping effect of acrylic to decrease the impact force is still present, yet the risk of occlusal porcelain fracture is reduced. This construction is also easier to repair if the fracture does occur long term.

Static Occlusal Forces

Continued or static occlusal forces (e.g., with clenching), are affected minimally by the occlusal material. A static or constant load on occlusal materials results in a similar amount of stress on the implant system, regardless of occlusal material type. Hence, clenching patients do not have a considerable amount of stress reduction when acrylic materials are used on the occlusal surfaces instead of porcelain.

Chewing Efficiency

The chewing efficiency related to the type of occlusal surfaces of the prosthetic teeth is controversial. Fixed prostheses exhibit an improved efficiency compared with removable soft tissue–borne prostheses, regardless of the occlusal material. Shultz compared the difference of acrylic, gold, and porcelain on identical dentures in two patients.[102] Acrylic was 30% less efficient than porcelain or metal, whereas no difference was found between gold and porcelain.

Wear

The maintenance of an occlusal scheme is related in part to the wear of the material. Dramatic changes in occlusal contacts in centric relation and excursions, occlusal vertical dimension, and esthetics may occur because of significant occlusal wear.

The definition of wear is the deterioration, change, or loss of a surface caused by use.[103] The factors affecting the amount of wear include magnitude, angle, duration, speed, hardness, and surface finish of the opposing force and surface, together with the lubricant, temperature, and chemical nature of the surrounding environment.[104] Most occlusal wear occurs as a result of bruxism.[105]

An intuitive feeling is that the harder the occlusal material, the less the wear. However, surface hardness has been shown to be a poor indicator of wear rate.[106,107] Total volume wear is more significant than the wear rate of a particular material. In other words, when two occluding surfaces occlude, the sum of both surfaces is more relevant to maintain stable occlusal contacts than understanding which particular surface wears more. For example, acrylic resin wears 7 to 30 times faster when opposing gold, resin, enamel, or polished porcelain, compared with gold opposing gold, enamel, or porcelain. Gold occlusal surfaces exhibit less volume loss (sum of loss of opposing occlusal surfaces) than any other combination of materials. Porcelain opposing porcelain wears more than porcelain opposing gold or metal.

Ideally, the wear rate of occlusal materials, especially in the partially edentulous patient with unrestored teeth, should be similar to enamel. In this way, occlusal changes will not dramatically change the occlusal scheme. An in vivo investigation reported vertical wear of premolar and molar tooth enamel to be 20 to 40 microns per year when opposing the enamel of natural teeth, but the wear may be four times greater than this according to Ramp et al.[108]

The total volume loss of opposing occlusal surfaces is most significant related to occlusal maintenance, rather than evaluation of which material wears more or less.[109] A total mean

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volume loss has been determined for enamel, acrylic, gold, and porcelain opposing each other[104] (Figure 26-97). Ceramics are susceptible to fatigue wear, rather than abrasive wear, which typically occurs from a harder material rather than a softer material. Fatigue wear causes microcracks, which lead to fracture, leaving large, irregular pits in the surface.[110] As a result, occlusal surfaces of opposing porcelain may have greater wear.

Adhesive wear occurs when one hard surface slides over a surface of lesser hardness. As a result, wear fragments of one material adhere to the other material, such as gold particles from gold occlusal surfaces adhering to enamel.[111] The use of gold, regardless of the opposing combination, always provides the least total volume loss. Adhesive wear may account for less total volume loss when metal opposes other materials. It is interesting to note in this study, the opposing materials with one of the total greatest volume loss is enamel opposing enamel.[104] As a result, bruxism on the natural teeth may be easily identified.

In principle, for the partially edentulous patient to have greater occlusal wear on implants, rather than less, would be preferable because the additional forces placed on the teeth are better tolerated than on implant prostheses. As a result, total volume wear may favor porcelain opposing enamel for the implant prosthesis opposing teeth in the partially edentulous patient and metal opposing enamel in the other regions of the mouth that require restoration of natural teeth.

The rougher the porcelain surface, the more rapid the rate of tooth wear. Polishing of the porcelain may occur with opposing teeth over time but occurs slowly or not at all when roughened porcelain opposes gold.[109]

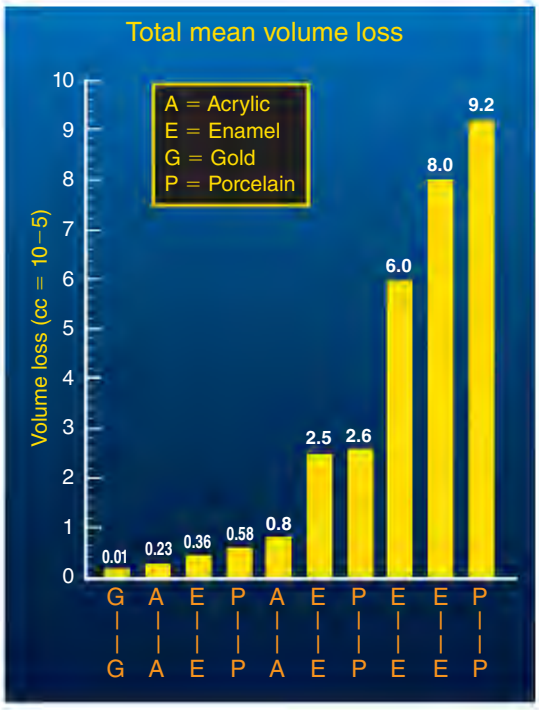


FIGURE 26-97. When metal occlusal surfaces oppose any other material, the total volume loss is less than any other combination of opposing materials. Enamel opposing enamel has one of the greatest amounts of total volume wear. Whereas the natural tooth may erupt as the enamel wears, the implant crown stays in a more constant position as the occlusal material wears.

For full-arch implant-supported prostheses the restoring doctor may consider metal occlusals in nonesthetic areas to minimize wear and prolong the accuracy of occlusal schemes long term. Porcelain in esthetic regions opposing gold in the nonesthetic areas or metal occlusals in both arches when parafunction or marginal CHS is present are the materials most often selected for implant prostheses. Improved composite resin materials are available with less wear than acrylic and close to enamel. However, the long-term performance of those materials on implants has not yet been established.

Occlusal Material Fracture

Material fracture is one of the more common factors that leads to refabrication of a prosthesis.[23] Porcelain, acrylic, and composite fractures occur under excessive loads or even with a lesser load of longer duration, angulation, or frequency (Figure 26-98). Acrylic or composite materials fracture more easily than porcelain, metal, or enamel. The compressive strength of acrylic resin is 11,000 psi compared with 40,000 psi for enamel.[99] Composite resin is three times stronger than acrylic. Acrylic fractures more often when used as a crown and bridge occlusal veneer than does porcelain fused to gold.

Acrylic fracture is a much more common complication for fixed reconstructions than for removable prostheses. Acrylic denture teeth on traditional dentures do not sustain the forces developed in implant-supported restorations. In addition, unlike porcelain, acrylic obtains its strength by bulk. Mechanical retention must be incorporated in the metal superstructure with proper resistance to the forces of occlusion. Posterior acrylic or composite facings often fracture because of the inadequate bulk and inadequate yield and fatigue strengths compared with the bite force developed under parafunction or on cantilevers for fixed restorations.

Porcelain opposing porcelain is not suggested with severe parafunction because it may fracture more often than porcelain opposing metal. Metal occlusals do not fracture easily, provide good wear resistance, and have less impact load compared with porcelain (Figure 26-99). When the patient is concerned with esthetics, metal occlusals in the mandible and porcelain in the maxilla is suggested (Figure 26-100).

In a report by Kinsel and Lin in 2009, when a porcelain-to-metal implant crown opposed another porcelain-to-metal



FIGURE 26-98. Porcelain fracture is one of the more common causes of failure of restorations supported by natural teeth. Implant crowns have higher impact forces and are more at risk of fracture. Unsupported porcelain on an implant crown places additional risk on these restorations.

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FIGURE 26-99. Metal occlusals are suggested for patients with severe parafunction.



FIGURE 26-100. When implants oppose each other, the mandibular restoration is usually designed to have metal occlusals, at least in the posterior region.

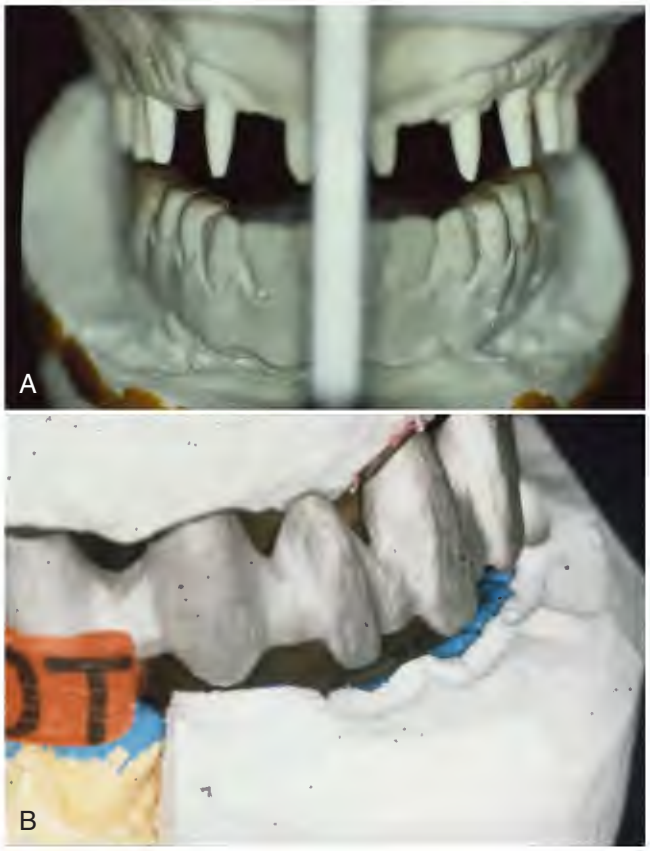


FIGURE 26-101. **A,** The anterior maxilla is restored with an implant restoration. **B,** The incisal edge is first determined, so the metal work will only have 2 mm of porcelain thickness.

implant crown, the incidence of fracture was 16.2%.[93] When the implant crown opposed a crown on a tooth, the fracture rate on the implant crown was 5.7%. Opposing a natural tooth the incidence of fracture in the implant crown was 3.2%, and when opposing a denture, there was no fracture reported. The fracture rate was greatest for bruxism patients or group function occlusal patients with 34.9% and 51.9% of patients, respectively, affected. The percentage of porcelain units that fractured in these two conditions were 18.9% and 16.1%, respectively.

Implants, components, and the prosthesis are subjected to loads with a broad range of magnitude, duration, direction, and frequency. As a result, permanent deformation may result, and fatigue fracture and creep are expected conclusions after years of service. These effects relate to factors of force. A long-term view of these complications associated with implants is not yet appreciated by the profession. Porcelain fracture is one of the three most common conditions requiring the replacement of a fixed prosthesis supported by natural teeth. It is likely to be more common in implant prostheses because the biomechanical stresses are greater.

The ideal thickness of porcelain to prevent breakage is about 2 mm.[112] Unsupported regions of porcelain may occur in porcelain fused to metal FP-2 or FP-3 prostheses because of their large volume when the metal superstructure is not designed properly. Many dental laboratories fabricate thin metal copings over the implants and teeth and then add porcelain to the final contour and occlusal table. As a result, FP-2 or FP-3 restorations may have more than 6 mm of unsupported porcelain. To limit the amount of unsupported porcelain, the incisal edge and occlusal table position of the prosthesis must be planned before fabrication of the metal superstructure (Figure 26-101). The technician then may fabricate a full-contour wax-up of the final prosthesis and afterward reduce the contour by 2 mm in the regions where porcelain is to be added.

Accuracy

Metal shrinkage during cooling of the casting is 10 times less than porcelain or acrylic shrinkage and therefore permits the fabrication of a more passive casting. When accuracy of the casting is paramount, as with screw-retained restorations, the occlusal material may make a significant difference. If porcelain is selected as the material of choice for a particular prosthesis, baking several increment layers will result in less dimensional change compared with just one baking cycle for the porcelain. Accuracy is most important in regions of long spans or with a large volume of material (or screw-retained prostheses).

Interarch Space

Metal occlusals require the least amount of interarch space; therefore, the abutment height may be greater when metal occlusals are used. When increased retention of a

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FIGURE 26-102. **A,** Crown height space is minimum. **B,** Metal occlusals allow the abutment to be greater in height for retention.

cement-retained prosthesis is required, a greater abutment height and greater retention may be achieved with a metal occlusal prosthesis because the amount of occlusal clearance over the abutment is 1 mm rather than 2 mm for porcelain (Figure 26-102). Porcelain is intermediate in the interarch space abutment height requirement. Acrylic restorations receive their strength from bulk and therefore require greater interarch space.

Conclusion for Occlusal Materials

When all seven criteria for occlusal materials are evaluated, metal is an excellent occlusal material, with improved properties in accuracy, wear, fracture resistance, abutment retention, and good qualities for impact or static force. Esthetics is best satisfied with porcelain, which has improved properties compared with acrylic concerning fractures and retention.

Types of Cements for Implants

Cements for fixed prostheses may adhere chemically to the dentin of natural teeth. In addition, almost all tooth preparations present undercut or irregularities from previous restorations or decay. As a result, attempts to remove a cemented prosthesis on natural teeth may result in involuntary tooth fracture.

Crown and bridge cements do not adhere as tenaciously to titanium abutments, which are free of undercuts or decay. As a result, a harder cement may be used on implants than on teeth yet still be readily removed. Fixed prostheses on implants may be luted with cements of varying hardness that can be selected in function of the number and location of the abutments and their height, width, degree of taper, retention, resistance form, and design. The transitional restoration may be used as a guide to find a cement that is retrievable yet will not come loose during function. The initial delivery of the prosthesis before final evaluation and hygiene appointment 1 month later further allows the dentist to fine-tune the hardness of cement required without automatically using the definitive cements indicated for natural teeth.[18]

The harder the cement, the more likely the implant abutment may be scratched during removal of excess cement. Zinc phosphate cement is easier than glass ionomer to remove from titanium and its alloy, and resin cements are the most difficult to remove the excess without altering the implant components below the metal margin of the restoration.[113] Plaque has been shown to follow the direction of scratches on the surface of titanium. Hence, scratches from the scalers should not be vertical, toward the crest of bone, because plaque forming at the crown margin may migrate more rapidly down the scratches to the crestal bone region.[114] Titanium alloy components are preferred to grade 1 to 4 titanium to decrease the effect of implant surface scratching because of improved mechanical properties.

Provisional Cementation

At the delivery of the final restoration, the fixed implant prosthesis often is cemented with a "soft access" or temporary cement. The implant differs from a natural tooth in that it does not provide early symptoms of occlusal disharmony, such as hyperemia. Therefore, a second evaluation of the occlusion at a follow-up appointment provides additional safety. In addition, the soft tissue health and hygiene may be evaluated at the follow-up appointment and may mandate the modification of embrasures or pontics to improve access.

The disadvantage of transitional cements on natural teeth is the risk of cement failure and decay as a consequence. Because implants do not decay, a temporary cement often may be used as the definitive cement and permit an easy retrieval of the prosthesis if intermediate or long-term complications develop.

The most common soft access cement used for the definitive restoration with multiple abutments splinted together and no cantilever is a zinc oxide eugenol with EBA (2-ethoxybenzoic acid) (Figure 26-103). This cement combines the properties of its compressive and tensile strengths to be similar to a polycarbonylate cement yet as a shear strength similar to zinc oxide eugenol. Hence, the restoration may be removed but does not become unluted during regular function. This cement is inappropriate when cantilevers or significant offset loads are present. Its use in cementation is limited to implant abutments with the final prosthesis as a temporary cement used with acrylic restorations, the eugenol prevails modifications with acrylic because the reline or repair procedure will not adhere.

Definitive Cementation

Final cementation for an implant prosthesis should be done in a dry environment. If the patient has a profusion of saliva at the initial prosthetic appointment, an antisialagogue such as glycopyrrolate (Rubinol) is suggested 1 hour before the final delivery appointment. Medical contraindications are fewer with drugs that do not cross the blood–brain barrier, but a few

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FIGURE 26-103. The most common soft access cement used for the final restoration with multiple splinted abutments and no cantilever is EBA (2-ethoxybenzoic acid) cement.



FIGURE 26-105. Zinc polycarboxylate cement is often used for individual implant crowns when a "soft access" cement is desired.

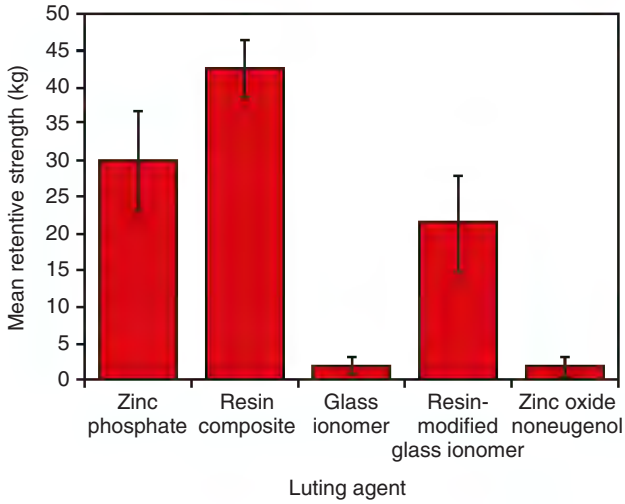


FIGURE 26-104. Retentive strengths of dental cements were evaluated for metal-to-metal connections by Squier et al.[115] (From Squier RS, Agar JR, Duncan JP, et al: Retentiveness of dental cements used with metallic implant components, Int J Oral Maxillofac Implants 16:793-798, 2001.)

contraindications exist, so the dentist must take care to avoid prescribing this drug for patients with a medical risk.

The choice of a final cement in implant dentistry is more broad and varied than for natural teeth. Traditional dental cements can be used for cast restorations. The luting properties of cements traditionally used in dentistry have been reevaluated for implant dentistry when the adhesion occurs between two metallic components[115] (Figure 26-104). However, transitional cements or definitive luting agents may be used to decrease or increase the retention of the crown or implant components. Hence, one of the first requirements in the selection of a class of luting agents is the type of cementation desired.

The cements used most often in implant dentistry for the final prosthesis include zinc oxide and eugenol with EBA, polycarboxylate, zinc phosphate, and rarely composite resin cements. Zinc oxide eugenol provides an excellent seal, but it exhibits the lowest compressive strength and a high solubility. The cement often is used as a transitional cement at the initial delivery of the final prosthesis.[116-119] A range of tensile bond strength has been measured based on the different manufacturers. The addition of EBA modifier increases the compressive strength, almost to the value of polycarboxylate cement. EBA often is used for the final restoration when the transitional prosthesis was retained adequately with a temporary cement without eugenol yet a slightly harder and less soluble cement is desired long term for a still retrievable prosthesis.

Zinc polycarboxylate cement may adhere to teeth because it chelates the calcium ions. However, zinc polycarboxylate does not adhere to a gold casting or to a titanium abutment post. The working time is 50% shorter than for zinc phosphate cement ($2^1/_2$ minutes compared with 5 minutes).[69] This is a problem when cementing multiple abutments. If the cement is removed before final hardening, it may pull material from under the margin and cause marginal openings for plaque retention. After it is set, the residual cement is more difficult to remove than most other options, and scratching of the abutment may occur along the margin. The compressive strength of zinc polycarboxylate is inferior to zinc phosphate cement, its tensile strength is higher, and the overall retention is inferior to zinc phosphate cements. As a result, zinc polycarboxylate is not used often on implant abutments as a definitive cement.

The most common usage of polycarboxylate cement is when multiple splinted abutments are present, no cantilevers or significant offset loads are present, and a "soft access" cement is desired, but zinc oxide with EBA was not retentive enough for this application (Figure 26-105). It is also used for individual implant crowns when the acrylic transitional crown was retentive enough with zinc oxide noneugenol cement. Zinc polycarboxylate also may be used as a stronger provisional cement for the transitional prosthesis when zinc oxide eugenol appears insufficient.

Zinc phosphate cement exhibits good compression and tensile strengths when in a 25-micron film thickness. A cooled glass slab allows the incorporation of more powder in the mix, which increases the compressive strength and reduces solubility after setting. In addition, the cooler the slab, the longer the working time. Multiple abutments have more than adequate working time for proper cementation with this material and technique. Excess material is easy to remove without scratching the implant surface.

The phosphorous acid or zinc phosphate cement is not a disadvantage, as with natural teeth. Zinc phosphate on an implant does not require a cavity varnish (as with teeth to protect the pulp), which reduces retention. Zinc phosphate often is the cement of choice for definitive cementation of an

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FIGURE 26-106. Zinc phosphate cement has many favorable qualities for implant restorations that require a definitive cement.

implant restoration (Figure 26-106). In general, most cements do not reach their final strengths for 24 hours.[69]

Glass ionomer cements may adhere to enamel or dentine and release fluoride for an anticariogenic effect. Their properties for luting fixed restorations to natural teeth are excellent. However, their performance as luting agents on metallic abutments has raised controversy because it is less retentive than most definitive cements.[115]

Composite resin cements have the highest compressive and tensile strengths of all cements, five times greater than zinc phosphate.[69,120] When these cements are used in implant dentistry, the intent is to not remove the restoration in the future. These cements most often are used to cement a post into an implant body to serve as an abutment for a cemented prosthesis. A secondary indication is when the abutment post is too short for adequate retention and prosthesis removal is not planned at a later date. Unlike polycarboxylate cement, the excess cement should be removed before final setting; otherwise, a rotary bur may be required to eliminate any excess.

Radiopacity

The luting agent of an implant crown should be radiopaque, so it may be seen on a postinsertion radiograph. Many cements designed for implants are radiolucent (i.e., composite resin cement). Zinc in a luting agent renders the material radiopaque. Hence, zinc oxide (with or without EBA), zinc polycarboxylate, and zinc phosphate cements have an advantage, especially when subgingival margins exist on the restoration. Retrieval studies of 25 years at the University of Alabama at Birmingham have shown no corrosion or complication related to the zinc in dental cements in contact with titanium or titanium alloy.

Cementation

Almost all cements are soluble in oral fluids. The precision of the crown margin not only minimizes plaque retention and enhances soft tissue health but also minimizes the effects of cement solubility. Marginal gaps greater than 75 microns lead to accelerated cement washout and retention failure. To reduce the cement margin thickness, several approaches have been suggested.[97,100-114,121,122] A groove may be placed in the preparation or the casting to act as an additional spacer or vent for the cement. In implant prostheses, the casting is often thicker than on natural teeth. As a result, a groove may be placed inside the casting from the occlusal (incisal) to a few millimeters above the margin. The cement seal may be reduced to almost half its thickness with this technique.

Another method to reduce film thickness is the timing of the prosthesis insertion. Film thickness may increase by 10 microns or more for every additional 30 seconds after the cement is properly mixed. As a result, although most definitive cements may exhibit a cement thickness between 10 and 25 microns, thickness may increase dramatically because too much time has elapsed before cementation.

The amount of cement and its location is an important process to decrease the risk of excess residual cement after the cementation process of a prosthesis. When there is a 40-micron cement space around the implant abutment die, the amount of cement to completely fill the space and margin is minimal compared with the volume of cement a crown may hold. In other words, if the volume of space a crown may hold when filled is 100%, only 3% of that volume is necessary to fill the cement space and margin after the crown is completely seated. Wadhwani et al. found, in a report of 401 dentists, that 36% filled a crown with cement one third to two thirds of the volume before cementation.[123] As a result, the excess cement is considerable and increases the risk it may extrude beyond the margin and into the undercut of the abutment flare, especially when it is subgingival.

As the crown filled with cement is seated, it flows toward the top of the abutment and then begins to express the excess cement from the margin when it occupies the space between the abutment and crown (Figure 26-107). Hence, it is logical to apply the cement at the marginal region of the crown and rim the crown margin for approximately one fourth the axial wall dimension. In the Wadhwani et al. report, fewer than 20% of dentists used the marginal application approach.[123] The most important aspect of the crown margin to seal for an implant abutment is the margin region because bacteria may accumulate in the crevice if it is not sealed. Hence, the margin application technique appears prudent.

Another method advocated by authors is to brush the cement into the intaglio surface of the crown, usually including the occlusal surface. Almost 50% of dentists in the Wadhwani et al. report used this technique. There was not a statistical difference in the amount of cement used to fill the crown between the group of dentists with the marginal application process or the brush cement placement method. However, when multiple abutments are splinted together, the brush-on technique may increase the cement thickness because of the additional application time.

To prevent excessive cement from extruding from the crown margin, the abutment for cement may be modified before cementation. The abutment screw opening in the abutment is obturated before making the final impression. This is necessary so the thin metal marginal region in the stone die is not fractured when it is removed from the impression when the stone model is fabricated. Before cementation, a portion of this obturation material may be removed in order to leave a recess region or void for excess cement (Figure 26-108). This aspect of the crown is least responsible for retention or resistance of the crown. In fact, if cement is captured on the occlusal surface, it

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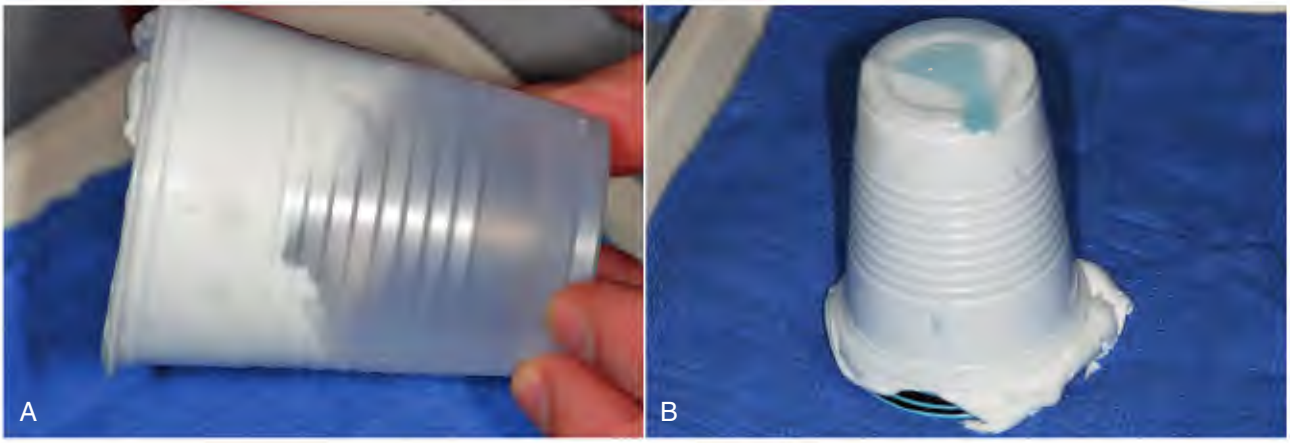


FIGURE 26-107. **A,** A clear cup with the cervical third coated with a cement. **B,** The cement proceeds up the sides while it is seated on the abutment, and then the excess extrudes out the margin of the cup.



FIGURE 26-108. The obturation material over the abutment screw may be partially removed to act as a reservoir for the excess cement.

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will prevent the crown from completely seating. Hence, a crown with no die spacer on the occlusal does not seat as far on the abutment preparation as when several layers of the die spacers are used on the die before fabricating the crown.[124]

Packing the implant sulcus with a retraction cord placed below the margin before cementation is an excellent protocol to follow when using a harder cement. However, one must take care not to capture any of the retraction cord under the crown, which will make cement removal more difficult.

Summary

Fixed prostheses are the most common restorations required of implant dentists. More than 60 million partially edentulous patients in the United States are missing posterior teeth in at least one quadrant or have long spans between natural teeth. A common axiom used in dentistry is to perform a fixed restoration for partially edentulous patients whenever possible. Implant dentistry permits the placement of additional abutments, so this axiom may be expanded to include most patients. A cemented restoration presents several advantages for fixed implant prostheses. The concepts of retention, resistance, and fundamentals of abutment preparation include taper, surface area, height, roughness, shear forces, path of insertion, nonparallel abutments, and knife-edge margins. With some variations, these same parameters dictate the principles of fixed, cemented implant prosthodontics. Particular attention is given to the limitations of implant abutment diameter and angulation.

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CHAPTER **27**

Digital Technology in Implant Dentistry

Lee Culp, Natalie Y. Wong, and Carl E. Misch

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The Harmony of Function and Esthetics with Digital Technology

The ultimate goal to replace the natural dentition is to restore a patient to normal contour, comfort, function, esthetics, and health. The attainment of perfection in the duplication of natural dentition is the ultimate achievement in contemporary esthetic dentistry. Understanding the complex relationship between tooth form and function and how they relate and combine to create the esthetics of natural dentition is the basis of study for achieving predictable success in oral reconstruction. Throughout the years, restorative trends and techniques have come and gone. Some material developments have transformed the face of esthetic dentistry, but other initial concepts have phased out and died.

As patients become more educated to modern dentistry's advances, their motivation and desire for natural esthetic restorative dentistry is increasing at a dramatic rate. Dentists are now more predictably fulfilling these patient demands but still often use dental laboratories and restorative techniques that do not offer predictable efficiency and quality. Digital dentistry is a methodology to expand the predictable aspect of restorative dentistry, especially when replacing part or all of the natural dentition.

The concept of digital dentistry is one that started out small and has progressively increased in momentum until its boundaries appear to have become endless. However, new technologies in dentistry will only be successful if they are combined with a complete understanding of basic comprehensive dentistry. Although new technology and computerization can make procedures more efficient, less labor-intensive, and more consistent, it will not replace education, practical experience, and clinical and technical judgment.

The most exciting factor surrounding these technologies is not, however, only in the potential applications of the technologies that are being hypothesized by dental professionals. The excitement truly lies in the fact that these "hypothetical" applications are currently being developed today, and some are even in the final stages. Implants are now well documented for fulfilling the functional requirements in prosthetic tooth replacement. These new technologies along with evolution of surgical and prosthetic techniques allow the dental team predictable, consistent results in implant rehabilitation. In a relatively short time period, digital technology will revolutionize the quality of dental care that is being delivered in modern practice.

The newest technology to enter restorative dentistry is CAD/CAM (computer-aided design/computer-aided manufacturing). Based on technology adopted from aerospace and automotive and even the watch-making industry, this technology is accepted because of its advantage of increased speed, accuracy, and efficiency. Today's CAD/CAM systems are being used to design and manufacture metal, alumina, and zirconia frameworks, as well as all-ceramic, full-contour crowns, inlays, and veneers that may be stronger, fit better, and are often more esthetic than restorations fabricated using traditional methods. When partnered with predictable implant technology, CAD/CAM offers restorative dentists and technicians an expanding horizon of dental prosthetic options. This success awakens a new focus; esthetics in implant prosthesis is now of major concern in both the surgical and prosthetic phases of treatment.

As dentistry evolves into the digital world, the successful incorporation of computerization and new technology will continue to provide more efficient methods of communication and fabrication while at the same time retaining the individual creativity and artistry of skilled dentists and dental technicians. The utilization of new technology will be enhanced by a close cooperation and working relationship of the dentist–technician team. The evolution from hand waxing to "digital waxing" using the diagnostic wax-up and provisional restorations and their digital replicas to guide us in the creation of CAD/CAM restorations will be presented. The utilization of these new technologies, along with the evolution from "hand" design to "digital' design, with the addition of the latest developments in intraoral laser scanning, materials, and computer milling and printing technology will only enhance the close cooperation and working relationship of the dentist–dental laboratory team.

The Dental Laboratory

The dental laboratory's primary role in restorative dentistry is to perfectly copy all of the functional and esthetic parameters that have been defined by the dentist into a restorative solution. Throughout the entire restorative process, from the initial patient consultation, diagnosis, and treatment planning to final restoration placement, the communication routes between the dentist and the laboratory technician now can provide a complete transfer of information. Functional components, occlusal parameters, phonetics, and esthetic requirements are just some of the essential types of information that are necessary for technicians to complete the fabrication of successful, functional, and esthetic restorations. Today, as in the past, the communication tools between the dentist and the technician include photography, written documentation, and impressions of the patient's existing dentition. The clinical models from these

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impressions may be created and mounted on an articulator, which simulates the jaw movements of the mandible.

The Digital Laboratory

As restorative dentistry evolves into the digital world of image capture, computer design, and the creation of dental restorations through robotics, the dental laboratory must evolve as well (Figure 27-1). To fully understand this concept, a laboratory must be clearly defined. At first thought, it may seem that a laboratory is the place where a dentist sends his or her patient's impressions to be processed into restorations, which are sent back to the dentist for adjustment and delivery. This definition fits well with the traditional concept of a laboratory–dentist workflow. However, just as the Internet has forever changed the landscape of communication through related computer technology, the possibility to use CAD/CAM restoration files electronically has provided the catalyst for a significant change in the way we view and structure the dentist–laboratory relationship.

Imagine that the laboratory is not a physical place but exists only in the talents of those performing the restorative process: the dentist and the technician. The equipment used to create the restoration may be located centrally, remotely, or both. The laboratory is essentially a workflow, which is as flexible as the abilities of the dentist, the technician, and the equipment will allow. The primary decision becomes where the hand-off from one partner to another should occur. The dentist who has the ability to optically scan teeth for impression making and chooses CAD/CAM restorations as the treatment option for his or her patients has enhanced freedom as to where the hand-off to the technician should occur. As a result, the laboratory is no longer a place; it is instead, to a large degree, virtual.

The Digital Process

The new millennium has brought with it a change in digital dentistry because more than 20 different CAD/CAM systems have now been introduced as solutions for restorative dentistry. The introduction of digital laboratory laser scanning technology along with its accompanying software allowed the dental laboratory to create a digital dental environment to accurately present a real three-dimensional (3D) virtual model that automatically takes into consideration the occlusal affect of the opposing and adjacent dentition. This process also includes the ability to design 16 individual full contour anatomically correct teeth at the same time (Figure 27-2). It essentially takes a complex occlusal scheme and its parameters and condenses the



FIGURE 27-1. **A,** Dental digital designers. **B,** CAD/CAM system.

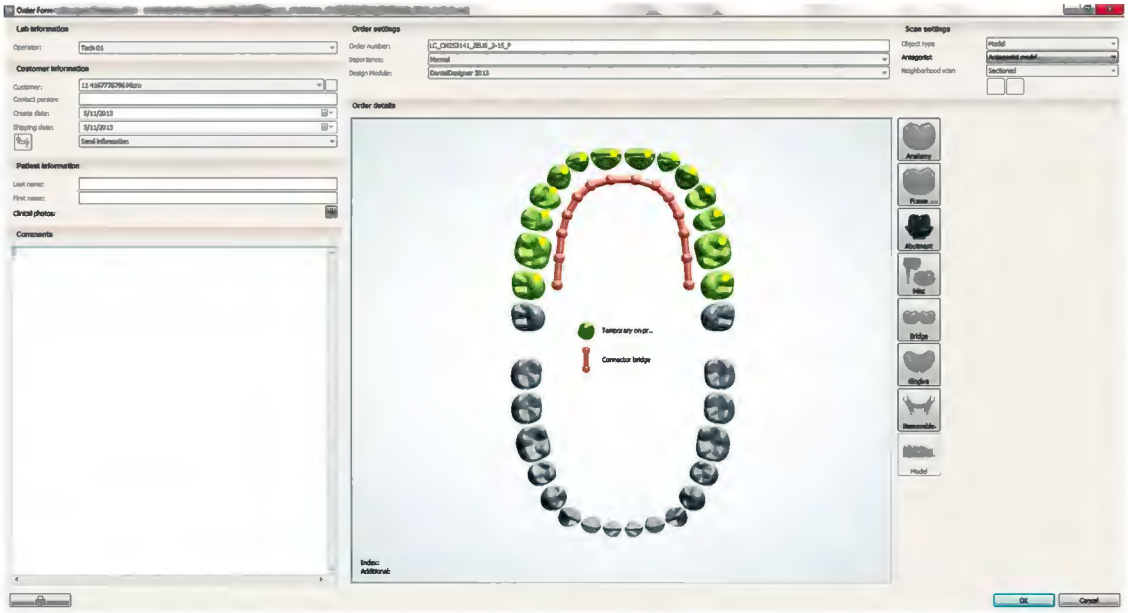


FIGURE 27-2. A three-dimensional virtual model includes the ability to design up to 16 individual full-contour, anatomically correct teeth at the same time.

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information, displays it in an intuitive format that allows dental professionals with basic knowledge of dental anatomy and occlusion to make modifications to the design, and then sends it through to the automated milling unit. For the dental laboratory profession, the introduction of digital technology can effectively automate or even eliminate some of the more mechanical and labor-intensive procedures (waxing, investing, burnout, casting, and pressing) involved in the conventional fabrication of a dental restoration, allowing the dentist and technician the ability to create functional dental restorations with a consistent, precise method.

Linear versus Vertical Manufacturing

The successful laboratory of the future will need to focus not just on quality of the final end product but also more efficient production methods to reduce turnaround time within the laboratory process. Digital technology allows the laboratory production to become vertical rather than linear. The current laboratory fabrication process follows a very linear progression; model fabrication on day 1, waxing on day 2, finishing on day 3, ceramics on day 4, and so on. Average production time for an all-ceramic or porcelain-fused-to-metal (PFM) restoration is approximately 5 to 7 working days based on this fabrication method.

In the digital laboratory, impressions will still be received from the client. But instead of taking days or weeks to go through several processes, the same process can be accomplished in 2 to 3 days. After the impression is received into the laboratory, the impression has the possibility to be scanned, and those data will be sent to several digital production stations at the same time. This will potentially allow the model and the restorations, including the framework, the wax-up, and the final ceramic restoration, to be completed at the same time.

Digital Diagnostic and Treatment Planning

The basis for all long-term success in restorative dentistry is a comprehensive diagnosis and treatment plan. The ability to preview a case from start to finish, communicating and co-diagnosing with other specialists and specialties about dental patients via the virtual world is the true power and capability of digital dentistry.

The emergence of cone-beam computed tomography (CBCT) scanning 3D volumetric imaging systems now provides dentists and specialists complete views of all oral and maxillofacial structures, giving the dental profession improved diagnostic information for a variety of treatment areas. Digital dentistry may allow for more accurate diagnosis and treatment planning, which leads to more predictable treatment outcomes. This includes implant placement and restoration, diagnosis and treatment of temporomandibular joint disorder, and the creation of functionally esthetic all-ceramic restorations. With the ability now to combine high-resolution data that are acquired from intraoral laser scanning, with the amazing global information that CBCT offers, we now have the ability to create a true digital patient. This combination of data sets will offer dentistry the ability to predictably offer accurate diagnosis, treatment planning, and restorative outcomes.

The combination of computed tomography (CT) scanning and laboratory-based laser scanning technology (e.g., 3 Shape, Laserdenta, Dentalwings) along with intraoral digital impression capture technology (e.g., E4D, NEVO, 3M Lava COS, Cerec, and iTero), in harmony with the design capabilities of state-of-the-art software would offer for the first time in dentistry the accurate representation of a virtual patient. This concept will have the ability to preview and even test different treatment options to enhance patient care, combining the data to develop a proper treatment plan for patient analysis and treatment. As a result, one can create solutions that would include all functional and esthetic aspects of oral rehabilitation.

Dental design software is currently available that will allow dentists and technicians and even patients the ability to communicate and create numerous anterior tooth arrangements based on functional and esthetic parameters, as well as the patient's desires. This would encompass both software and output devices to simulate and fabricate intraoral devices for tooth movement, tooth restoration, and tooth replacement.

Digital Fixed Prosthetics

Historically, PFM restorations have been manufactured through the traditional lost wax casting process. The recent proliferation of dental CAD/CAM systems is having little effect on the PFM manufacturing process because machining metal substructures in popular alloys is inefficient and costly. However, now with metal laser sintering technology, dental laboratories can produce bridges and copings directly from CAD data without waxing and investment casting. The technology virtually relieves the dental laboratory of the least valuable tasks in the prosthesis manufacturing chain. The laboratory no longer needs to spend time waxing, investing, and casting but instead can concentrate on core competencies such as the ceramic veneering of the metal framework. The laser sintering process is faster, more economical, and requires only a minimum amount of manual labor while providing the dental laboratory with a scalable technology irrespective of technician availability. At the same time, the cycle times decrease to a minimum, thus resulting in an enormous increase in productivity and a definite technological advance for the dental industry.

The Digital Process

The laboratory technician's primary role in restorative dentistry is to perfectly copy all functional and esthetic parameters that have been defined by the dentist into a restorative solution. It is an architect–builder relationship. Throughout the entire restorative process, from the initial consultation through treatment planning, provisionalization, and final placement, the communication routes between the dentist and the technician require a complete transfer of existing, desired, and realistic situations and expectations to and from the clinical environment. Functional components, occlusal parameters, phonetics, and esthetic information (shade and contour) are just some of the essential information that is required by the technician to complete the fabrication of successful, functional, and esthetic restorations.

Communication of Occlusion

Historically, the transfer of occlusal and functional information from the clinical environment to the laboratory was somewhat limited. There was little, if any, direct communication of the functional requirements for a case beyond the dentist providing an opposing model and an impression and sometimes an interocclusal record with the shade preferences. With limited

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guidance, the technician would mount and articulate the case (most often on a hinge articulator) and restore the case by filling spaces and trying to mimic the existing dentition using his or her own interpretation and experience. The result was a close approximation that the technician hoped would meet or exceed the dentist's and patient's expectations. In situations like this, the dentist expected to spend considerable chair time seating a case, adjusting the occlusion, and recontouring restorations. The results were often a complete removal of anatomy, occlusal form, and sometimes an esthetic and functional compromise of the final restoration.

There were, of course, dentists and technicians who desired more predictable results and sought a solution through advanced continued education courses that encouraged a dentist and technician team approach and sought out the combination of restorative and functional requirements. This group was introduced to the concept of comprehensive dentistry, which took into account optimum oral health, anatomic and functional harmony, and occlusal stability rather than singling in on just the restoration of aspect and tooth.[1] To accomplish this, the dentist–technician partnership became a "diagnostic team" with the dentist and technician both participating in the complete understanding of the cause-and-effect relationship of the problems before initiating treatment.

Computerized Design and Fabrication

With traditional laboratory procedures, after the elastomeric impression of the implant impression coping is obtained, the dental laboratory must pour up a stone or an epoxy working model to fabricate the restoration and implant abutment. The lost wax technique developed in 1907 by Taggart is still currently used in many dental laboratories.[2] Inaccuracies during the laboratory phase can include dimensional instability of the stone material, wax, casting investment, and alloy material, which results in an inaccurate fitting restoration and abutment.[3,4]

CAD/CAM technology originated in the 1950s with numerically controlled machines feeding numbers on paper tape into controllers wired to motors positioning work on machine tools. Advances were made in the 1960s with the creation of early computer software that enabled the design of products in the aircraft and automotive industries. The introduction of CAD/CAM concepts into dental applications was the innovation of Dr. Francois Duret in his thesis titled "Empreinte Optique" ("Optical Impression") in 1973.[5] He developed and obtained a patent for a CAD/CAM device in 1984 and took it to the Chicago Midwinter Meeting in 1989 where dentists witnessed a crown fabricated in 4 hours. In 1980, a Swiss dentist, Dr. Werner Mörmann and an electrical engineer, Marco Brandestini, developed the concept for what was to be introduced in 1987 by Sirona Dental Systems LLC (Charlotte, NC) as the first commercially viable CAD/CAM system for the fabrication of dental restorations—CEREC.[6]

Dental Impressions

As with any conventional laboratory-prescribed restorative process, this procedure begins the same: the clinician prepares the case according to the appropriate preparation guidelines, impressions the case, and sends all critical communication aspects to the laboratory. When the laboratory receives all the materials, the impressions are poured, the models mounted, and the dies trimmed. A bite registration is taken using the mounted models and will be used in a subsequent step.

The overall excellence and marginal fit of any definitive fixed restoration in dentistry depends on the accuracy of the dental impression. The introduction of CAD/CAM to dentistry through digital impression systems has paved the way to a completely digitized design and manufacturing process, which simplifies the creation of restorations and makes them more reliable.[7]

Digital dental impressions have potentially eliminated the need for taking conventional impressions for crowns and other fixed prostheses.[2] In implant dentistry, the goal in the prosthetic phase of treatment is to fabricate an accurate restoration of high quality and an abutment with an appropriate emergence profile, occlusion, and esthetic appeal. In the standard crown and bridge approach, to fabricate a restoration with an ideal fit, the impression material used must capture the details of the abutment margin, the gingival anatomy, and the adjacent and opposing dentition.[3] The accuracy of crown and bridgework is determined by the accuracy of the many steps of the process, including making and extracting the impression, pouring models, cutting and trimming dies, and the properties of the dental stone itself. Each of these steps decreases the accuracy of the clinician's work, which leads to expensive increases in chair time, costly laboratory remakes, and unhappy patients.

To make a good impression, the material used must meet all the ideal properties and requirements (Table 27-1). Such requirements include sufficient working and setting time, hydrophilicity, wettability, tear strength, and elastic recovery.[4] Similar to conventional fixed prosthetics, impression materials used to fabricate a restoration and an abutment for the implant must meet all the requirements to capture a good impression. However, dental impression materials were designed to capture tooth margins and may not be as accurate when used with metal or ceramic abutment materials.[8,9] A survey of laboratory technicians indicated that as high as 90% of conventional dental impressions have incomplete registration of finish lines.[10] Without an accurate duplication of finish lines, the prosthesis becomes little more than an approximation of the properly fitted prosthesis.

Conventional Impression Materials

The purpose of making a dental impression is simply to transfer 3D data from the patient's mouth to a model as accurately and as comfortably as possible. The goal of the material used to make a dental impression must be to replicate hard and soft tissue structures under both wet intraoral and dry laboratory conditions with minimal hygroscopic distortion. A wide variety of impression materials have been developed to help us in achieving this. Rubber base (slow setting and foul smelling) was the most common and best available material into the mid 1970s. In the late 1970s, hydrophobic polyvinyl impression materials were introduced, and they gained popularity. They are the most commonly used impression materials in North America. In the mid 1990s, truly hydrophilic polyvinyl materials that could take accurate impressions of wet intraoral surfaces were introduced. Other enhancements included material strength, tear resistance, repeated pourability, and easy-to-read coloration. Polyvinyl siloxane (PVS) impression materials quickly became the material of choice in conventional impressions because they were accurate; fast; predictable; and last but not least, easy to use.[11] Table 27-1 is a comparison of the advantages and disadvantages of properties of all impression materials. PVS is the most commonly used material for conventional

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TABLE 27-1
Properties of Impression Materials

	Viscosity	Border	Wash	Co-lamination between Viscosities	Hydrophilicity	High Tear Strength	Engage Undercuts	Working and Setting Time	Patient	Operator
Plaster	Light	No	Yes	No	Yes	No	No	Not constant	Sensitive	Sensitive
Impression compound	Heavy	Yes	No	No	No	No	No	Not constant	Sensitive	Sensitive
ZOE	Light and medium	No	Yes	No	No	No	No	Not constant	Sensitive	Sensitive
Alginate	Light and heavy	No	Yes	No	Yes	No	Yes	Not constant	Sensitive	Sensitive
Polysulfide	Light and heavy	Yes	Yes	No	No	Yes	Yes	Somewhat constant	Sensitive	Sensitive
Polyether	Multiple	Yes	Weak yes	Yes	Yes	Weak yes	Yes	Constant	Slightly sensitive	Not sensitive
Condensation silicone	Light and medium	Yes	Yes	Weak yes	No	Yes	Weak yes	Not constant	Not sensitive	Not sensitive
Polyvinyl siloxane	Multiple	Yes	Yes	Yes	Yes	Yes	Yes	Constant	Not sensitive	Not sensitive

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dental impressions, and its properties will be compared with digital impressions.

Dimensional Accuracy

The dimensional accuracy of PVS is excellent if the margins of the preparation are isolated, the impression material covers the preparation adequately and uniformly, and the material is completely set before removal. Otherwise, the accuracy decreases because there is a risk of distortion of the impression material. In comparison, a digital impression technique will have equal or better dimensional accuracy because there is no impression material and thus no risk of any material distortion. Although moisture control and tissue management are required for both, digital impressions require this control for only one image at a time.

Capturing Detail

Capture of detail in a conventional impression is good when there is no movement of the impression tray and no air entrapment and the impression material is allowed to set completely. In the case of the digital impression technique, the images capture detail and are magnified, which allows any problems with the preparations to be visualized immediately. In addition, occlusal clearances are also verifiable (Figure 27-3).

Time

Dental impression materials on the market today require on average 5 to 8 minutes of mixing and setting time. The digital impression technique will have an initial learning curve of approximately five to 10 scans, after which an average quadrant scan is 3 to 5 minutes. This may seem to be just a small savings in time; however, the task in which the digital impression technique shows its superiority is in a remake situation. Remaking of a conventional impression doubles the time as it will require another 5 to 8 minutes for the second impression. In addition, the entire impression needs to be remade. A survey by the Consilium Associates in Irvine, California, states that 36% of dentists have to remake their impressions at least three times or more per month. With the digital impression technique, the only area that needs to be rescanned is the area that was missed.

Intraoral Access

Intraoral access using conventional impression techniques can be a challenge for those with an active gag reflex, excess saliva, small oral cavities, or large cheeks and tongue. With the conventional technique, the entire impression (the tray and the material) needs to be in the mouth and stable until the impression material has set completely. With the digital impression technique, a significant advantage is that the image capture process can be paused and continued multiple times to ensure the patient is comfortable during the procedure. A disadvantage at the present time is the size of the camera. This may prove difficult to capture second or third molars in smaller oral cavities (Figure 27-4). As technology advances, the size of the camera may decrease.

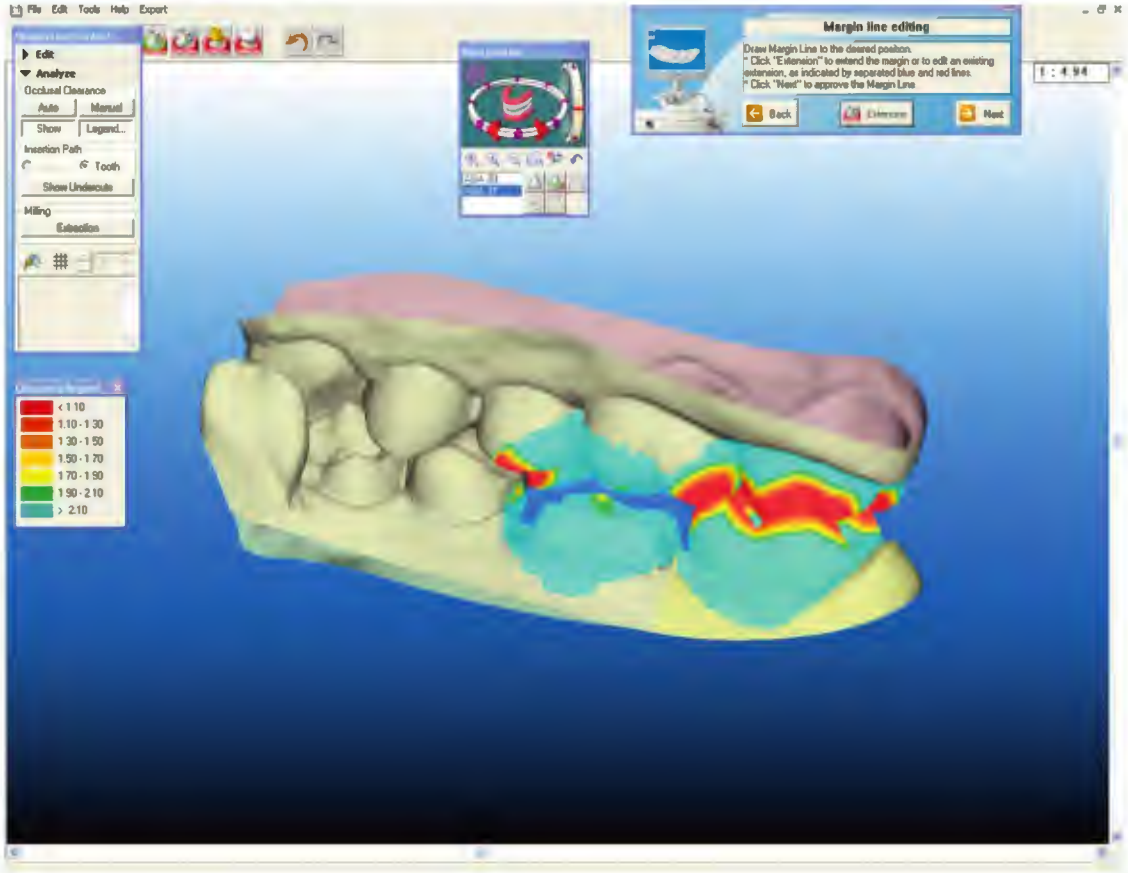


FIGURE 27-3. Real-time chairside feedback during which margins, occlusion, and contacts can be immediately verified.

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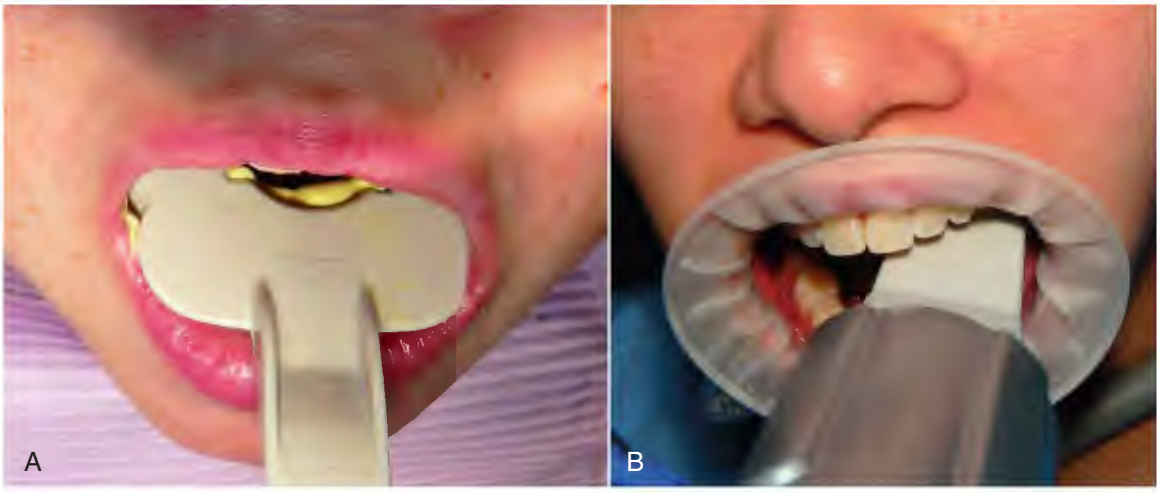


FIGURE 27-4. Intraoral access with conventional (**A**) and digital (**B**) impression techniques.

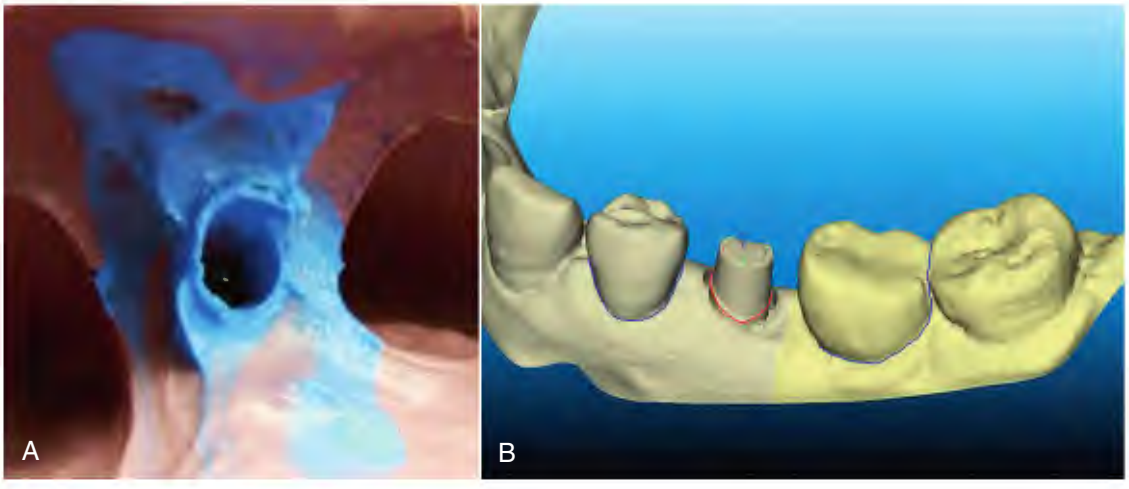


FIGURE 27-5. Comparing subgingival margins with conventional (**A**) and digital (**B**) impression techniques.

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Long-term Stability

The long-term stability of stone models created from PVS is excellent, which allows them to be stored for extended periods of time. However, this requires a significant amount of physical space for storage, which sometimes may prove to be a challenge. The virtual model created from the digital impression technique also has excellent long-term stability because images can be stored indefinitely on a hard drive, which requires very little physical storage space.

Cost

The initial cost of the digital scanning unit is high compared with stocking and storing PVS in the office. However, after this setup cost of the unit is taken care of, future digital impressions are made at a nominal fee—simply the cost of the disposables. The digital impression technique is considered to have an advantage over the conventional impression technique in remake situations. The cost of PVS is doubled when the entire impression needs to be remade. With the digital impression technique, the cost does not increase when additional images are taken at the same appointment.

Margins

When making an impression of a subgingival margin, the need for visualization of this margin is a challenge for both techniques (Figure 27-5). With the conventional impression technique, an impression coping and an implant analog can be used to create an implant body level stone model. This eliminates the need to capture any margins because the laboratory can select and prepare the implant abutment and margin to receive the final restoration. The digital impression technique has evolved to include implant scanning abutments, which allows the creation of a virtual implant level model, thereby again eliminating the need to capture any margins (Figure 27-6).

Other Challenges with Conventional Impressions

Some of the other challenges of conventional impressions include pulls and tears while extracting the impression, bubbles and voids within the impression, distortion of the impression, poor tray bond, time sensitivity, and many more. To overcome these problems, CAD/CAM technology and digital impression scanning devices have been introduced in dentistry, thereby eliminating the use of traditional office impression materials

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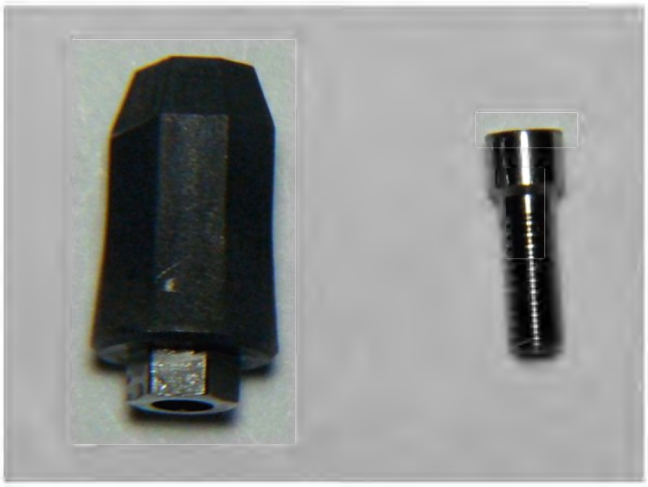


FIGURE 27-6. Implant scanning abutment.

and laboratory techniques.[2,8] Digital technology aids in ensuring a more accurate impression from the start, which results in a better-fitting restoration.

Differentiating Digital Impression Technologies

Since the introduction of scanning devices into the dental world, their manufacturers have broadly expanded the scope of indications for the use of their respective systems in the dental office. They have also integrated their hardware and software with most dental laboratories. Some of these devices include the CAD/CAM products CEREC (Sirona Dental Systems), E4D Dentist (D4D Technologies), Cadent iTero (Cadent Align Technology, Inc.), Lava Chairside Oral Scanner C.O.S. (3M ESPE), FastScan (IOS Technologies), Densys3D Solution (Densys), and (directScan, Hint-EL/Fraunhofer).[12]

The use of intraoral scanning acquisition devices in restorative dentistry has been ongoing for the past 25 years and is proprietary.[9] One of the critical components of the digital implant dentistry workflow involves the digital capture of the patient's dentition for planning, placement, and restoration. The intraoral scanning devices use a sophisticated optical surface scanning technology that works similar to a camera, but instead of merely capturing lights and colors, the sensors compute light reflection times from various surfaces through 3D processes to capture the object. The 3D software that uses specific alignment algorithms to allow for registration of the object then captures this information.

In dentistry today, there are several commercially available approaches for scanning and capturing detailed intraoral surfaces. Three of the common scanning principles used by intraoral dental scanners today are triangulation, active wave-front sampling, and parallel confocal laser scanning.[13]

Triangulation of Light Technology

Duret et al. and others introduced and described the use of an electronic digital impression system that incorporated CAD/CAM technology.[14-16] The first intraoral scanning system used in dentistry was based on the concept of triangulation of light.[15] There are three elements to this system, namely (1) a light source that (2) illuminates the object, which is positioned at an angle to (3) a detector. The triangulation technique uses a timed laser light that is directed at the tooth structure that is then reflected back to the camera, and the data are captured to register the image. The triangulation format allows one angled

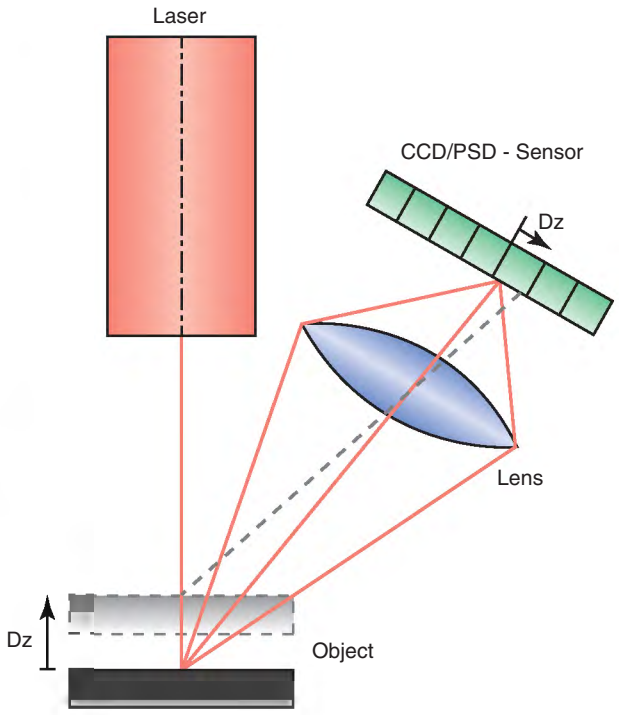


FIGURE 27-7. Triangulation of light technology.

cone of light to capture a single image at 15,000 microns. These dental scanning systems require that a reflective powder be applied to the teeth before scanning to ensure accurate capturing of the image (Figure 27-7).

The triangulation scanning technique was first introduced into dentistry in 1987 through CEREC by Sirona Dental Systems LLC.[13] The CEREC digital scanning system with its in-office ceramic block milling unit is capable of obtaining a direct intraoral digital impression based on this technology, where the intersection of light of three linear beams is used to locate a defined point in 3D space.[15-17] However, surfaces that do not disperse light evenly, such as enamel and amalgam or curved surfaces that are not continuous, affect the accuracy of the triangulation scan with this technology.[17] Therefore, the use of a reflective coating or opaque powder to create a uniform light dispersion has been advocated for use during the scanning process[18] (Figure 27-8).

Active Wave-Front Sampling Technology

The active wave-front sampling technique also requires a powder, but instead of using a laser light to capture the tooth data, these scanning systems use a lens with a rotating aperture. This allows the capturing of 3D data in a video sequence and models the data in real time (≈20 3D data sets per second) (Figure 27-9). The Lava C.O.S. intraoral scanner by 3M ESPE uses this technology.[13]

Parallel Confocal Imaging Technology

Cadent (Align Technology, Inc.) developed a free-standing digital scanning system that provides clinicians with an accurate alternative to conventional dental impression techniques without the requirement of an in-office restoration milling unit. The refined digital system that was first introduced in orthodontics to scan conventionally poured stone models for orthodontic applications was then applied to conventional prosthodontics.[19,20] Using the concept of parallel confocal

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imaging technology used in microscopy, Cadent's iTero scanning device projects 100,000 points of red parallel laser light in perfect focus at 300 focal depths of the tooth structure that converts the reflected light into digital data.[21,22] Only objects at a focal depth of 50 micrometers or less are capable of reflecting light through a small filtering device. The beams of red laser light act as optical probes when contacting the surfaces of an object and are able to record the anatomic surface details by detecting the confocal points (Figure 27-10).

The advantage of this technology is that it is able to capture details of different surface anatomy to within 15 micrometers without using a reflective surface powder in the oral cavity. This property allows for contact scanning techniques, which allows the clinician to place the handheld laser scanner directly on the object (tooth or abutment scanning device). This increases stability and decreases the need to rescan the patient. Various dental materials such as enamel, gold, amalgam, and resins are detected and recorded with equal accuracy. [9]

A Comparison of Some of the Intraoral Three-Dimensional Digital Scanners

The ideal digital impression would allow the ability to scan just the quadrant or the entire arch (Figure 27-11), allow for fabrication of all types of dental restorations, and even allow for subgingival preparations. Use of such advanced technology produces an accurate 3D image of the object being scanned in virtual real time. The clinician is able to view the 3D replica when the scanning procedure is complete.



FIGURE 27-8. Application of reflective powder to tooth surfaces.

The iTero intraoral laser scanner by Cadent Align Technology, Inc. consists of a mobile cart on wheels that can be moved to different operatories[23] (Figure 27-12). The handheld laser scanner (wand) releases a light stream of compressed air during the scanning procedure to prevent fogging of the lens that is attached to a proprietary data cable (Figure 27-13). The data cable is attached to a computer with a liquid crystal display (light-emitting diode [LED]) monitor that processes the electronic information. A wireless keyboard, mouse, foot pedal, and analytical instruments that are proprietary to the manufacturer control the entire digital scanning process.

The wand uses parallel confocal imaging to capture a 3D digital impression.[24,25] It emits a beam of laser light through a small hole and directs it toward the tooth surface. Only an object at the proper focal length will reflect light back through the filtering device.[10] The camera covers a 14 $mm^2 \times 18\ mm^2$ area at a scan depth of 13.5 mm.[26] No reflective medium is required for the laser light to be reflected from intraoral surfaces. It does not have to be held a fixed distance from the tooth and will scan when touching the teeth.[24] The foot pedal is used to activate the wand to capture successive images. After each scan, the option to accept or reject the scan is presented to the clinician. After being accepted, the scan is integrated into the digital model. The unit also provides visual and verbal prompts for active guidance during the digital impression process.[25]

The software prompts for a series of five scans (occlusal, facial, lingual, mesioproximal, and distoproximal views) per prepared tooth or abutment, with additional scans required for the adjacent teeth and opposing dentition. The usual series may range from 15 to 30 scanned images to record the preparation, opposing teeth, and the occlusal relationship.[10]

The Planmeca PlanScan Intraoral Scanner by E4D Technologies uses blue laser technology that delivers video rate imaging of teeth and soft tissues, models, or impressions to the monitor[24] (Figure 27-14). Heated mirrors in the scanner tip; continuously prevent fogging during intraoral scanning. To initiate the scanning process the scanner is positioned directly over the occlusal surface of the restoration site with the tip of the scanner pointing towards the distal in order to achieve the optimum focal distance.

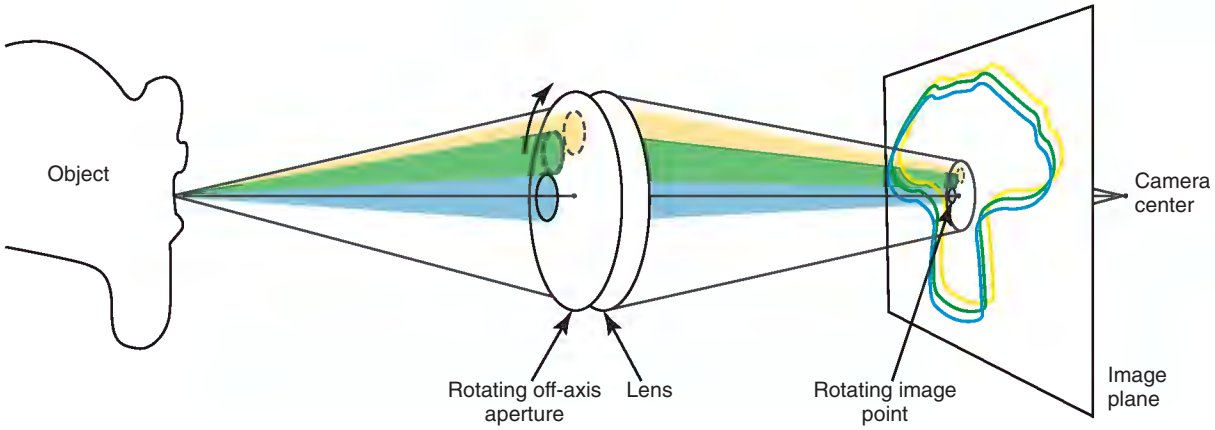


FIGURE 27-9. Active wave-front sampling.

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FIGURE 27-10. Parallel confocal imaging technology.



FIGURE 27-13. The iTero wand by Align Technology, Inc.



FIGURE 27-11. Full arches scanned using iTero intraoral scanner by Align Technology, Inc.



FIGURE 27-14. Planmeca PlanScan System: scanner, laptop, and milling unit. (Courtesy E4D Technologies.)



FIGURE 27-12. The iTero intraoral scanner by Align Technology, Inc.

For a true 3D capture, streaming video captures and records all of the exposed surfaces of the prepared and adjacent teeth in the quadrant. An ICE (I C Everything) feature of the software takes photographic images of the teeth and gingival tissue. As successive images are recorded, they are wrapped around the developing 3D model to create the ICE view. This provides the user with unrestricted images of the actual hard and soft tissue and aids with margin identification.[27] Planmeca's Romexis software stores implant, abutment, and crown models in the Planmeca Romexis library, which the dentist can then import and superimpose a soft-tissue scan and crown design with CBDT (cone-beam) data to allow the dentist easy planning and verification of implant placement.

CEREC AC by Sirona has a blue LED camera rather than the red laser light camera of prior CEREC systems (Figures 27-15 and 27-16) The shorter-wavelength blue light projected by the LED allows for greater precision of the resultant optical image[28] (Figure 27-17). The camera uses the active triangulation technique to record images. A pattern of blue light is projected onto the object and then read back at a slightly different angle. It uses a telecentric beam, which permits the capture of essential information from all of the prepared tooth's surfaces in a single view. The camera is positioned directly over the prepared tooth to initiate a scan. When the camera is stabilized within the 14-mm focal distance and held motionless by contact with adjacent teeth, the camera will automatically record an image.[29] This

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FIGURE 27-15. CEREC AC Bluecam. (Courtesy Ceramics Dental Laboratory, North Miami Beach, FL.)



FIGURE 27-16. The CEREC Bluecam's wand. (Courtesy Ceramics Dental Laboratory, North Miami Beach, FL.)

prevents the recording of inaccurate images because of camera movement. After the image is recorded, the camera is moved over adjacent teeth to record additional images. The software stitches the overlapping data from the successive images to calculate a single 3D model.

Sirona also offers the CEREC Connect portal through which the dentist can take a digital impression and transmit the data to a dental laboratory within Sirona's network. In turn, the laboratory can manufacture the dental restoration and return it to the dentist for insertion at a second patient visit. It also offers dental laboratories the inLab System, an array of CAD/CAM



FIGURE 27-17. The CEREC AC Bluecam shorter-wavelength blue light source. (Courtesy Ceramics Dental Laboratory, North Miami Beach, FL.)



FIGURE 27-18. Lava C.O.S.

equipment and software that enables the technician to fabricate restorations from data providing virtual or actual working models. Sirona introduced the inEos Blue digital scanner as part of the inLab family of products, enabling the laboratory to scan poured models and to either fabricate restorations in-house or upload the data files to Sirona's infiniDent central production facility.

The Lava C.O.S. intraoral scanner by 3M ESPE is 13.2 mm wide at the working end and contains 192 LED and 22 lens systems (Figure 27-18). The Lava C.O.S. intraoral scanner is

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based on the principle of active (optical) wave-front sampling.[30] Three sensors capture the clinical view from different perspectives and generate 3D surface areas in real time by means of proprietary image-processing algorithms.[30] This "3D-in-motion" technology records continuous 3D video images to create a volume model of the quadrant or arch in real time on the computer monitor.

The camera captures 20 3D data sets per second, or about 2400 3D data sets or 24 million data points per arch, to create the volume model.[26] Lava C.O.S. is the only intraoral video scanner as opposed to the still image mode of other systems. The camera is held from 5 to 15 mm from the surface of the teeth and soft tissues to activate scanning.[24] Movement of the camera outside this focal range stops the video recording until the camera is brought back within the range. This serves as a fail-safe mechanism to avoid recording poor data. The amount of the dentition to be recorded is determined by the dentist and can include a sextant to a full arch.[31]

Integrated Digital Imaging within the Office Workflow

Before initiating the prosthetic phase of treatment, the bone level around each of the implants is evaluated with a periapical radiograph (Figure 27-19, *A*). Primary implant stability is confirmed. Each individual dental implant is exposed, and a transmucosal healing collar is placed on the implant to allow for soft tissue healing to occur over a period of 2 to 3 weeks (Figure 27-19, *B*). Obtaining an accurate impression to isolate the position of the implant in the patient's mouth is critical to providing the precision needed for the dental restoration.

With the completion of the soft tissue healing period, traditionally, dental implant impression techniques use impression copings that are inserted into the implant at the time of impression. Traditional impression materials such as PVS or polyether are used to capture the representative teeth and mucosa in the impression tray. After the impression is taken, implant analogs



FIGURE 27-19. **A,** Checking the initial healing of the implant. **B,** The implant is exposed, and a transmucosal healing collar is inserted for healing of the soft tissue.

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FIGURE 27-19, cont'd. **C,** Implant scanner abutment. **D,** The implant scanning abutment is inserted, and a periapical radiograph is done to confirm the fit.

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are attached to the impression copings, and a stone model is created with the analogs representing the positioning of the implant in the model. Although this technique has been used in implant dentistry for several years, there are several layers of potential inaccuracies associated with the various steps involved.[13]

The digital impression technique replaces the traditional fixture-level impression coping with an implant scanning abutment (ISA) (Figures 27-19, *C* and *D*) that is specific to the implant manufacturer. The ISA transfers the intraoral 3D position of the implant within the virtual digital cast through a registration process of the specific shape geometry and anatomic surface facets. This allows for an accurate digital impression and provides information to the dental laboratory regarding implant platform diameter, position of the implant, and the desired emergence profile. In addition, this digital impression technique eliminates the use of the prosthetic laboratory analog that is used in combination with the traditional dental impression and resultant master cast[13] (Figure 27-20).

The clinical workflow starts with scanning the ISA and adjacent teeth to obtain the required surface anatomy (Figure 27-21). To ensure proper vertical dimension and occlusal relations, the opposing dentition is also scanned with the patient placed in maximal intercuspation (Figure 27-22). This eliminates the need to obtain the traditional bite registration for fixed prosthetic cases, reducing chair time and the cost of materials. After the arches are digitally scanned, the ISA is removed, and



FIGURE 27-20. Implant scanning abutment scanned digitally with adjacent teeth.

the maxillary and mandibular teeth are placed in maximum intercuspation to obtain a buccal bite registration. This step requires the removal of the ISA as the abutment might be too long vertically preventing accurate intercuspation of the teeth, thus interfering with a proper bite registration.

When obtaining the bite registration, it is extremely important that the patient is instructed to clench his or her teeth in the maximum intercuspation position (MIP). This allows the natural teeth to be slightly depressed into the periodontal ligament in the alveolus of the jaw and helps compensate for the

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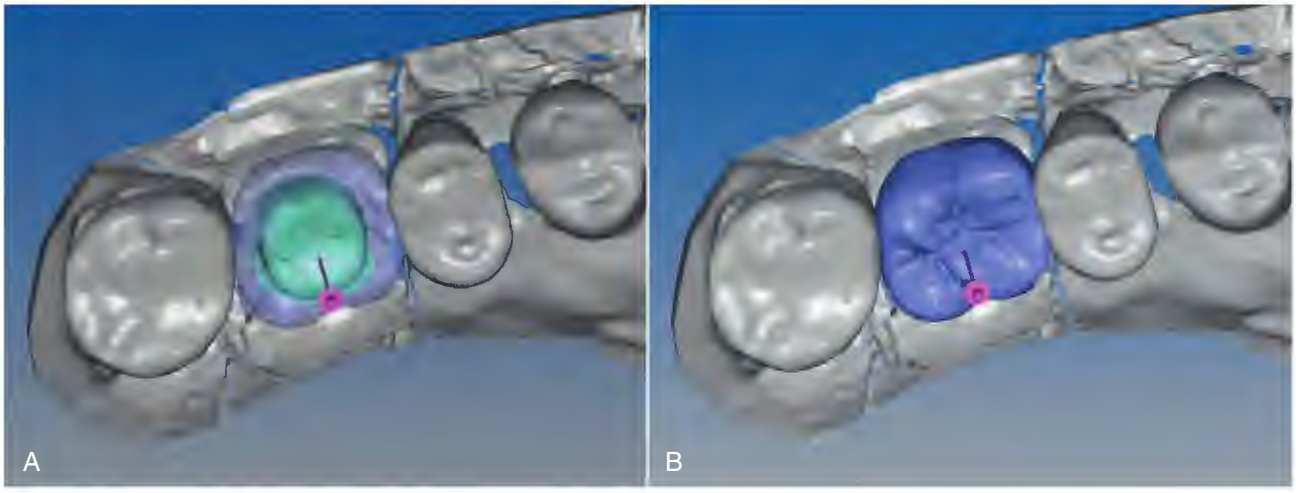


FIGURE 27-21. Functionally and esthetically driven software.

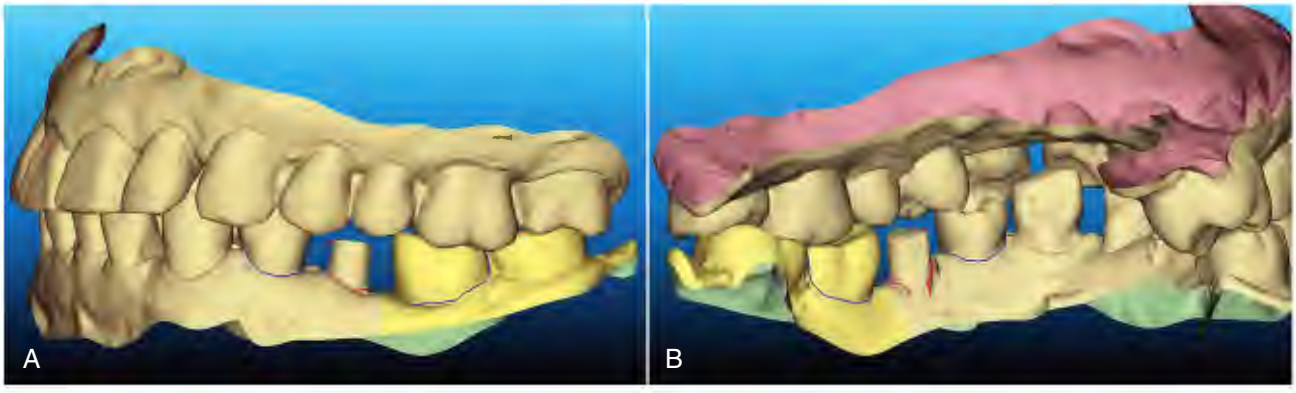


FIGURE 27-22. Implant scanning abutment scanned digitally with adjacent teeth.

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physiologic movement of teeth surrounding an implant crown. This techniques allow fabrication of the restoration that is in "infra-occlusion" or slightly out of occlusion with a light bite force to avoid a restoration that is "too high" during a heavy bite force that can result in undesirable premature occlusal contacts.

During the scanning procedure of the ISA, the surrounding soft tissues, adjacent teeth, and opposing dentition can be viewed with real-time images on the incorporated computer screen. With the aid of visual and audible prompts, the operator can make the necessary adjustments to obtain an accurate intraoral digital impression in virtual real time. The computer software automatically "stitches" together the multiple, overlapping pictures in a transparent process called real-time modeling to obtain the opposing arches in the MIP.

With each scan, the software captures 100,000 points of laser optical reference points to construct the 3D object being scanned.[13,14,21,22] After a satisfactory digital impression is obtained, the standard triangulation language (STL) file is electronically sent to a participating partner laboratory over the Internet using the proprietary computer software. An electronic laboratory prescription is completed by the dentist, which includes patient information and the type of restoration to be fabricated. The electronic data from the digital impression are produced in the form of an "open architecture" STL file of the implant scanning abutment, including the surrounding anatomic hard and soft tissues.[13]

By eliminating the process of conventional impressions, we are no longer concerned with the possibility of error because of air bubbles or voids, pulling or tearing of the impression material, tray movement, tray deflection, too little impression material, inadequate tray adhesive, or distortion of the impression material. In addition, centric occlusion has historically been registered through the use of a silicone or wax bite registrations. When performed digitally, there is no material placed between the maxillary and mandibular teeth. This dramatically reduces the risk of obtaining an inaccurate relationship.

In conclusion, digital dental impressions are proving to be a technological advancement that surpasses the accuracy and efficiency of former techniques for obtaining replicas of prepared teeth for the purpose of fabricating restorations. Adoption of this digital technology by dentists is rapidly eclipsing the use of elastomeric impression materials. The ultimate goals of dentists dedicated to quality prostheses are to make the treatment of their patients as accurate and efficient as possible. The companies that have developed systems to help dentists achieve these goals are constantly enhancing the precision and scope of indications of their products to improve the quality of the dentistry provided.[12]

Integrating the Dental Practice and the Laboratory

For the past several years, dental laboratories have been eagerly adopting digital impression systems that enable them to scan

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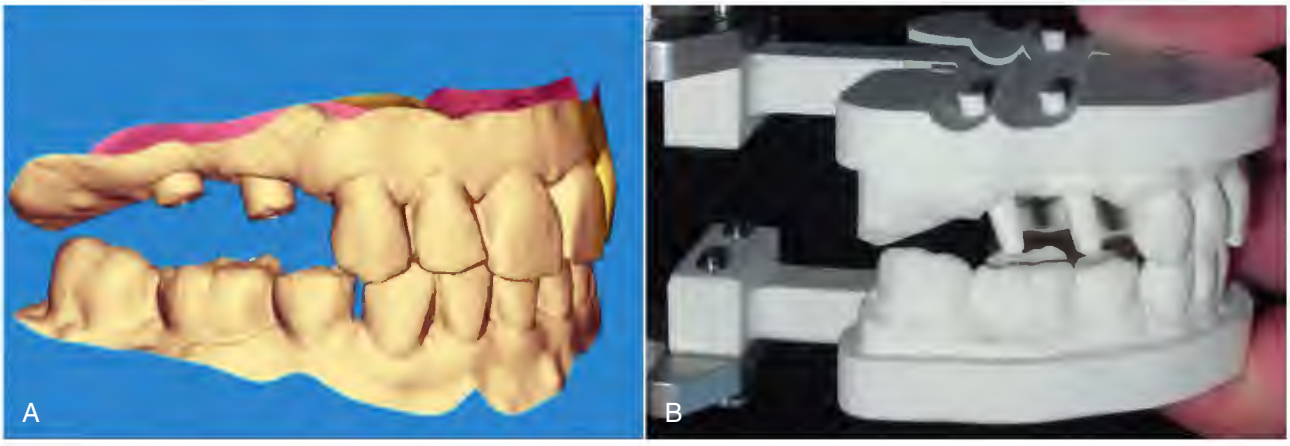


FIGURE 27-23. Converting the digital impression to a physical model.



FIGURE 27-24. Stereolithographic models on an iTero articulator.

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models or conventional elastomeric impressions. They have also been using digitized scans and CAD/CAM devices in the fabrication of models, copings, frameworks, and restorations, primarily in the name of greater accuracy, consistency, and efficiency. Over the past decade, dental laboratories have moved rapidly into digital forms of manufacturing. The basis for all-digital laboratory manufacturing processes is the creation of a digital file for each patient's unique dental anatomy.

The dental laboratory has two complementary applications for using this transmitted digital impression data. The laboratory technician can directly input the digital data into a compatible CAD/CAM program to design and mill substructures or full-contour restorations. Early adopters were limited to "closed architecture" systems in which the digital data could be used only with matched software and hardware from the manufacturer of the intraoral scanner.[32] Today, a more "open architecture" is evolving as manufacturers enter into partnerships with third-party software and hardware companies to use their digital scan data.

The laboratory technician can also use the digital impression data to process working models (Figure 27-23). The data are transmitted to a digital manufacturing center for postprocessing of the images and to create the models via a subtractive CAD/CAM milling process (iTero) or an additive resin printing process known as stereolithography (Lava C.O.S., CEREC)[33] (Figure 27-24). This results in improved accuracy of both the dental model and the final prosthesis.[6] Historically, the dental laboratory technician has performed most of these processes by hand.

The laboratory can upload the design of the restoration and abutment for processing while the stereolithographic models are being milled. These models and removable dies are fabricated for completion of the restoration and abutment. The restorative-driven software focuses on creating ideal designs of the abutment, framework, coping, and final porcelain veneer (Figure 27-25, *A*). This methodology allows for manufacturing of a complete coping to correctly support the porcelain veneer based on the ideal custom abutment shape from a single laser scan. Software parameters to fabricate the custom restoration and abutment include contours of the crown, emergence profile, interproximal and occlusal contacts, and material thickness to ensure strength of the restoration to resist occlusal forces.[14]

The implant abutment can be milled using CAD/CAM technology as titanium, zirconium, or a hybrid (metal connection with a zirconium post). The definitive restoration can be custom milled as an all-ceramic restoration or a PFM using traditional laboratory procedures. Milled CAD/CAM custom polyurethane resin models are also available to the restorative dentist for the purpose of checking the final fit of the restoration before delivering it to the patient. Such milled CAD/CAM resin models are more durable and resistant to deformation, shrinkage, expansion, chipping, and fracture compared with stone models.[13]

The result is a more accurate fitting restoration with little to no chairside adjustment (Figures 27-25, *B* and *C*). The final custom abutment shape is milled in the polyurethane model, eliminating the need to work directly on the final abutment in the laboratory. This advanced technology may help avoid the inaccuracies associated with using traditional hand-processed laboratory techniques, such as investing, casting, divesting, sandblasting, and polishing.[13] Furthermore, the level of communication between the dentist and the technician has dramatically increased.

Step-by-Step Process

After the digital impression and bite registration, the procedure moves to the computerized world for scanning and fabrication.

Step 1. File creation. A file is created within the software for each individual case. The operator inputs the patient's name,

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case number, dentist's name, date and tooth numbers(s), and type of restoration desired (full crown, veneer, inlay or onlay, or framework coping). Additional preferences can be set either globally for all cases from an individual clinician or specifically based on the individual case. These options include contact tightness preferred, occlusal contact intensity, and the virtual die space that defines the internal fit of the final restoration to the die or preparation. After all of this information is input, the computer can begin its search among the tooth database libraries to acquire the correct tooth form (Figure 27-26).

Step 2. Scanning. Using the CEREC 3D optical scanning device, the working model with the die(s) trimmed is scanned and digitally captured and transferred into the computer's virtual laboratory. The computer now has all the information it needs to work with the working model, the preparation, and the occlusion parameters (from the antagonistic image).

Step 3. Virtual model. The 3D virtual model is then presented on the screen and can be rotated and viewed from any perspective (Figure 27-27).

Step 4. Design. The first step in design of the restoration is to virtually section the model and remove the die. The parameters and borders of the final restoration are defined using the antagonist information, the adjacent teeth and contact areas, and finally the gingival margins of the preparation. The desired contact areas are marked electronically on the adjacent teeth, and the preparation margins are identified and outlined greatly assisted by the computer.

Step 5. Database selection. The computer will now present a database menu, which will allow the operatory to select the relative age of the tooth's desired design by examining the surrounding dentition. From this information and the parameters defined, the computer will now propose a restoration and restoration position over the preparation and within the arch (Figure 27-28).

Step 6. Virtual placement. The computer has placed the restoration in the most appropriate (based on all input) position, but the operator's experience and knowledge of form and function is needed to manually position and contour the restoration to the dentally preferred location. Simply with a few mouse clicks, the position and rotation of the crown can be altered as desired, and the software's Cusp Settling application will automatically readjust each individual cusp tip; triangular ridge; and the restoration's contours, contacts, and marginal ridges based on the preferences and antagonistic information according to the newly desired position and rotation. The virtual restoration responds and adapts all parameters immediately as they relate to the new position (Figures 27-29 and 27-30).

Step 7. Occlusion confirmation. An automated function of the software is that it is designed to propose fossa-point contacts

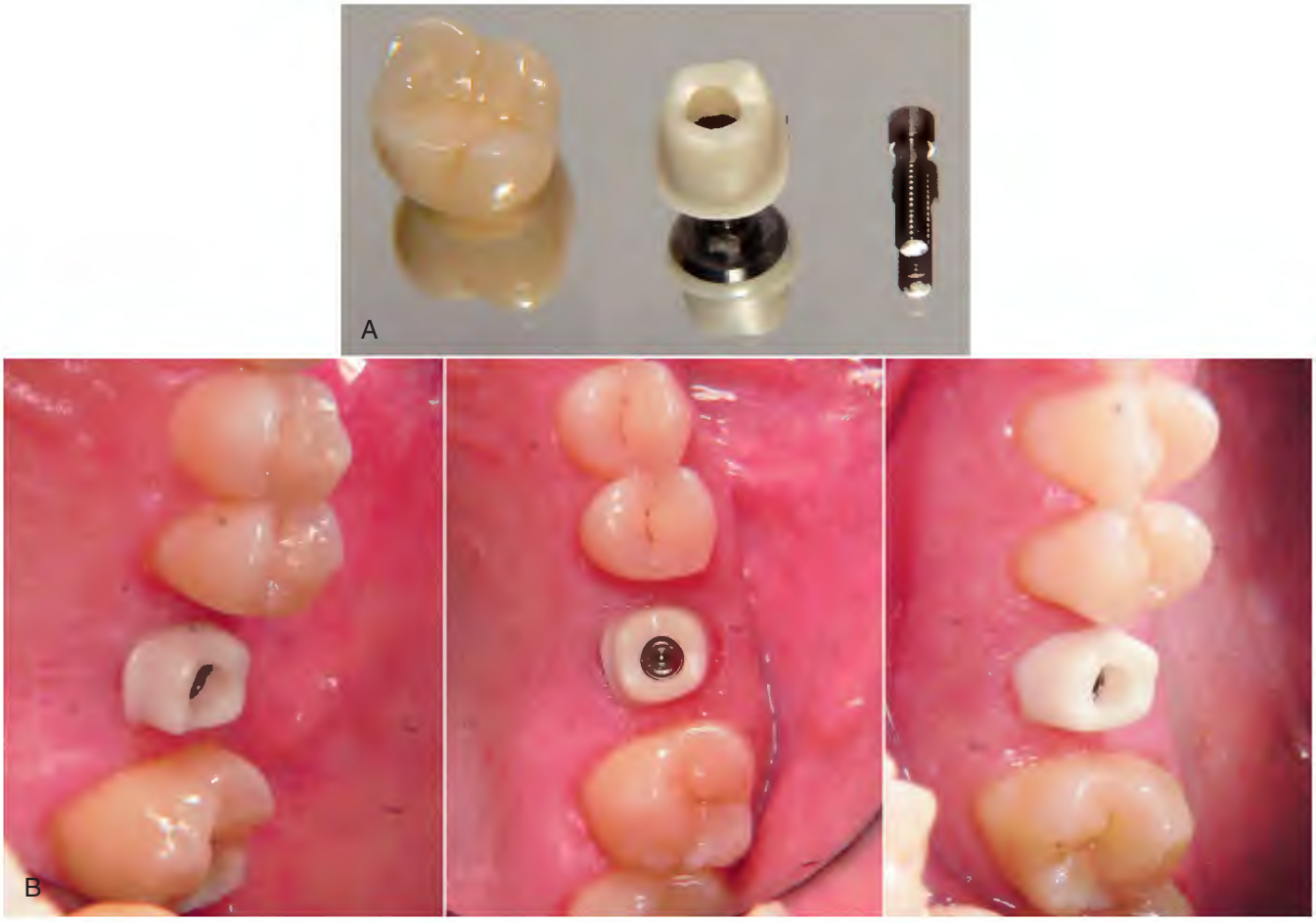


FIGURE 27-25. **A,** Custom abutment and restoration created using restoratively driven software. **B,** Custom abutment inserted.

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FIGURE 27-25, cont'd. **C,** Implant crown inserted and periapical radiograph to evaluate fit.

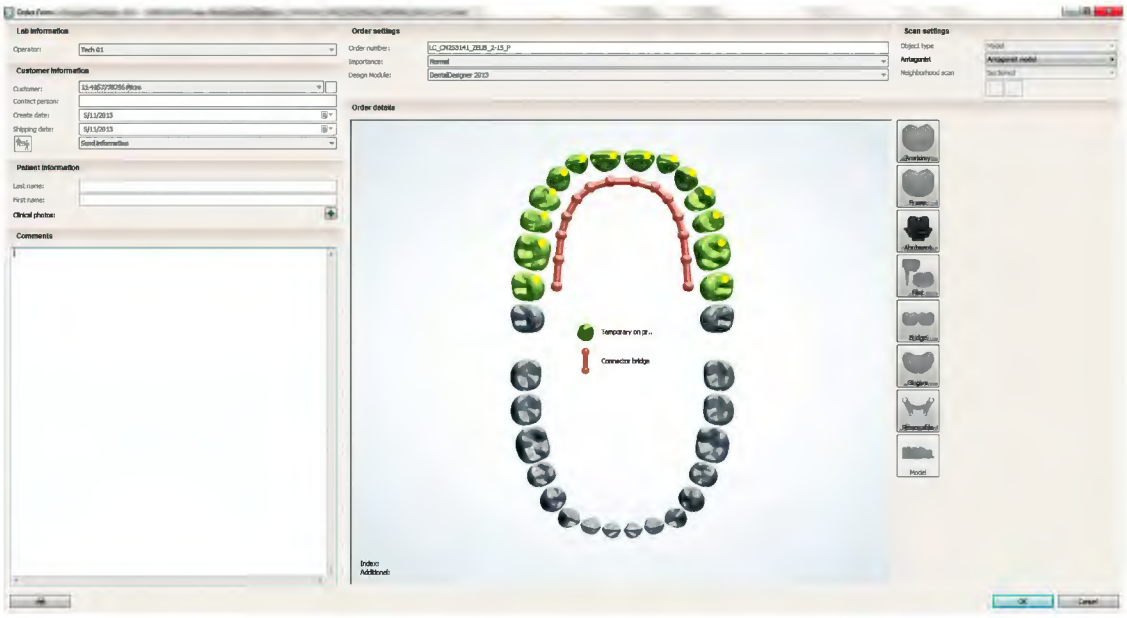


FIGURE 27-26. Creation of digital file.

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FIGURE 27-27. Optical scan of working model.

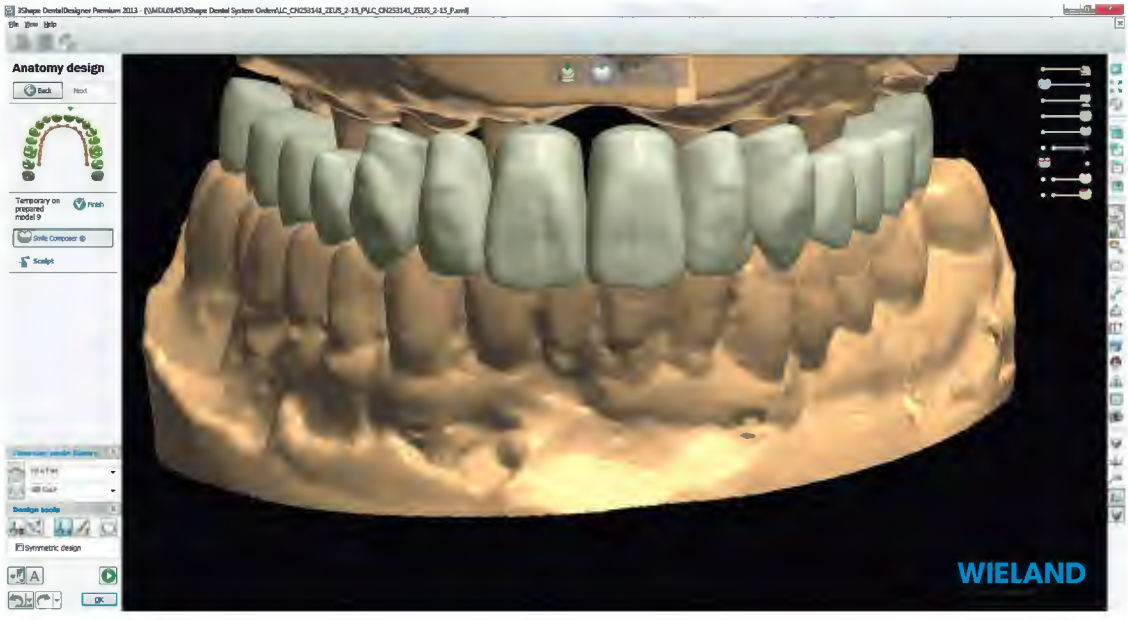


FIGURE 27-28. Computer proposal of restoration position.

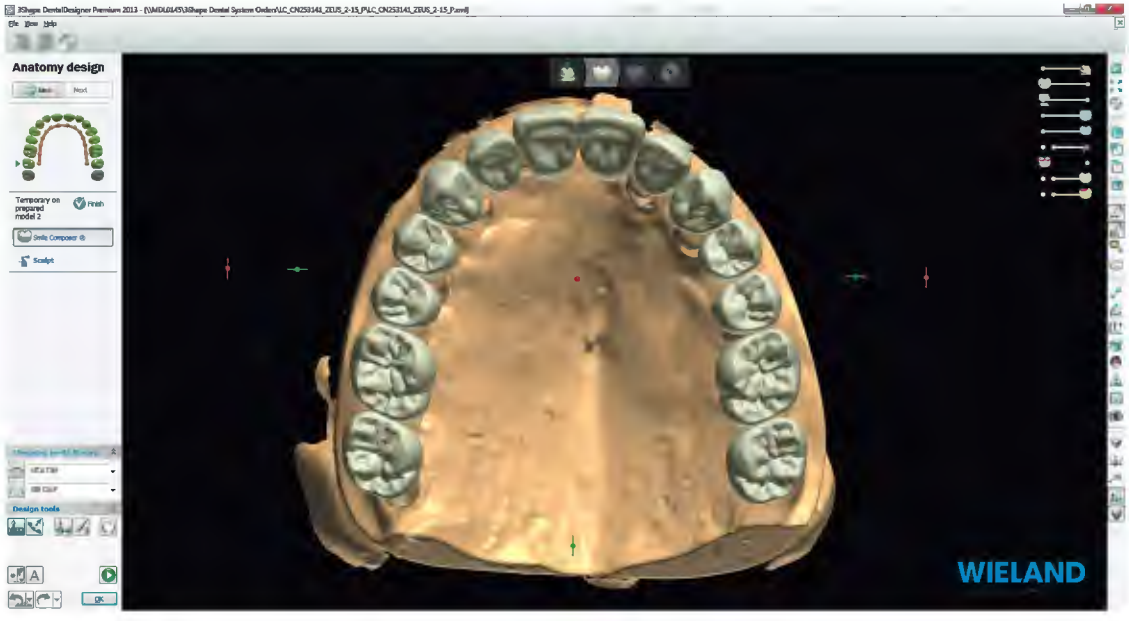


FIGURE 27-29. Occlusal view of initial proposal.

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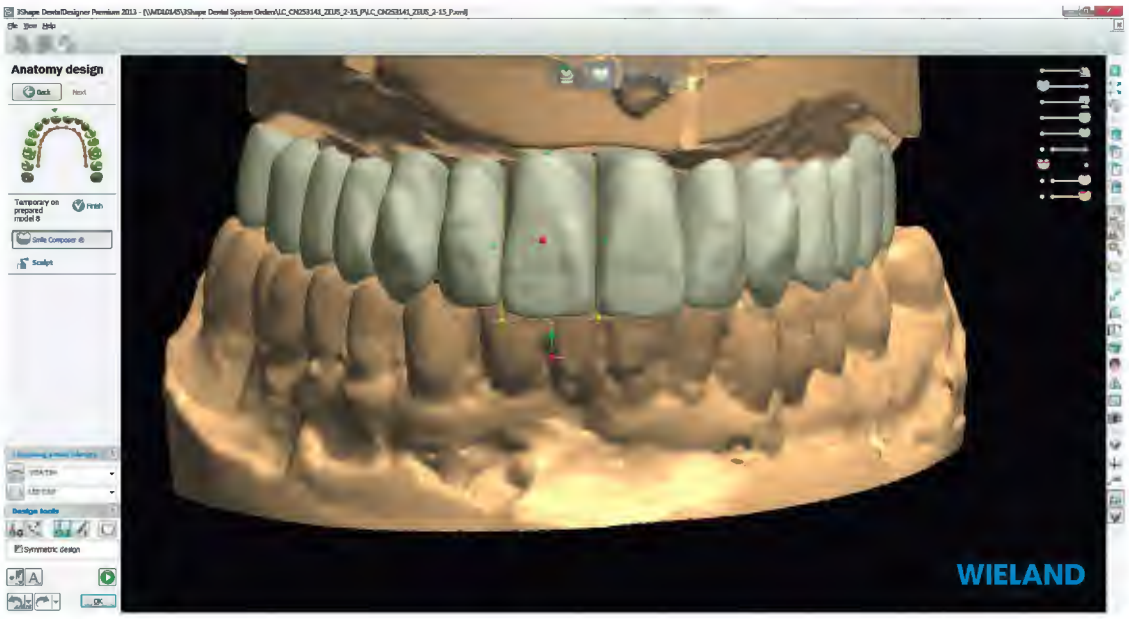


FIGURE 27-30. Facial view of full-arch digital design after modifications with digital "waxing tools."

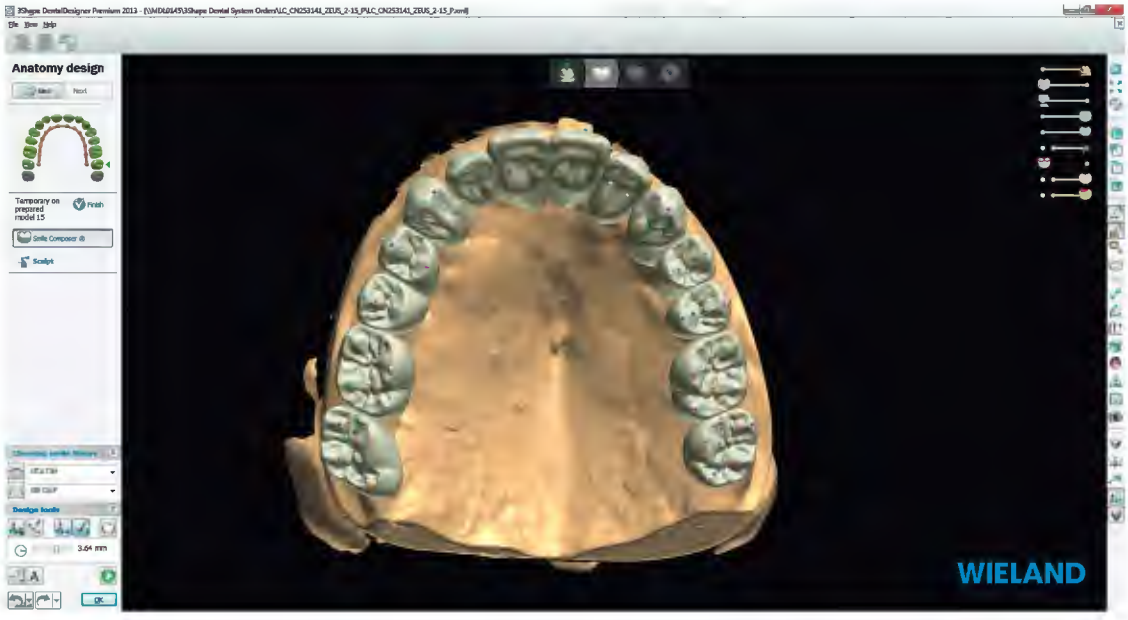


FIGURE 27-31. Occlusal view of full arch digital design after modifications with digital "waxing tools."

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on the appropriate triangular ridges. Using the virtual grinding tool, this can be easily modified to provide a Dawson-type "mortar–pestle" arrangement of occlusal–fossa contacts with broad, flat holding areas for the opposing cusp tips (Figure 27-31). The position and intensity of each contact point is graphically demonstrated and color mapped immediately on the screen and can be adjusted easily pending operator and clinical preference.

Step 8. Anatomical customization. Customized aspects and artistic creativity are also possible through an array of virtual carving and waxing tools. These can be used to manipulate occlusal anatomy, contours, and occlusal preferences mimicking the actual laboratory methods and armamentarium. Each step is immediately updated on the screen so the operator can see the effect of any changes (Figures 27-32 to 27-36).

Step 9. Milling. After the final virtual restoration has been designed, it is simply a matter of loading a chamber with the predetermined shade and size of ceramic or composite block and pressing an on-screen button, and in approximately 15 minutes, an exact replica of the design is reproduced (Figures 27-37 and 27-38).

Step 10. Finishing and polishing. The milled restoration can then be customized conventionally using staining and glazing techniques appropriate for the ceramic selected (Figures 27-39 to 27-41).

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FIGURE 27-32. Translucent facial view showing implant placement.

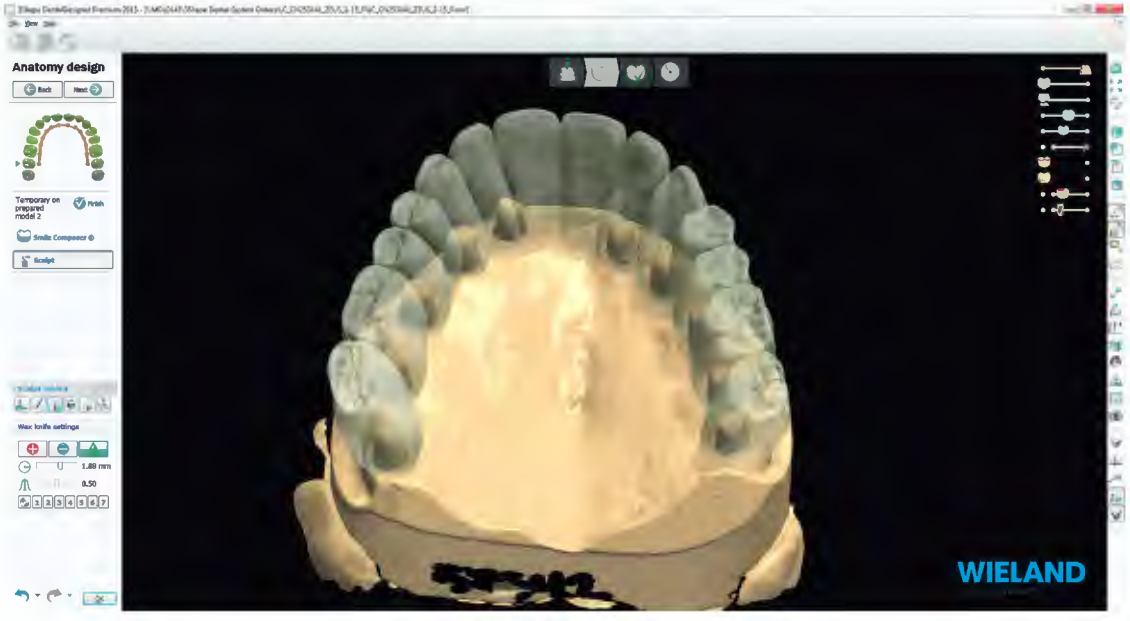


FIGURE 27-33. Translucent occlusal view showing implant placement.

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The Future of CAD/CAM Dentistry

Where traditional approaches to dentistry required the fabrication of an impression and the subsequent use of a diagnostic wax-up to communicate the desired contours and tooth form to the technician, modern technologies will allow the clinician to forward a digitally captured impression and a modifiable digital diagnostic wax-up that can then be used to improve immediate communication with both the patient and the laboratory. Shade transfer is another aspect of dental treatment that currently remains based on traditional tab systems that convey a degree of accuracy but remains limited by user interpretation. As technologies continue to advance, the use of automated shade capture devices will eventually be able to be applied in conjunction with CAD/CAM formats to further improve the reliability and thoroughness of data transfer for results that were previously unachievable.

Advancements within digital dentistry are now developing rapidly, drawing on the existing capabilities of modern systems and seeking to improve the dental professional's ability to provide optimal care within a fraction of time. The development of new CAD/CAM systems and software allowed for the custom positioning and design for implant abutments. After the abutments have been placed, the restorations continue their digital journey to completion. As the related software and fabrication processes continue to evolve, new generations of technologies will enable increased diagnostic capabilities that will allow the user to deliver comprehensive dentistry with increased predictability while taking into account critical functional concerns such as occlusion and anatomical nuances.

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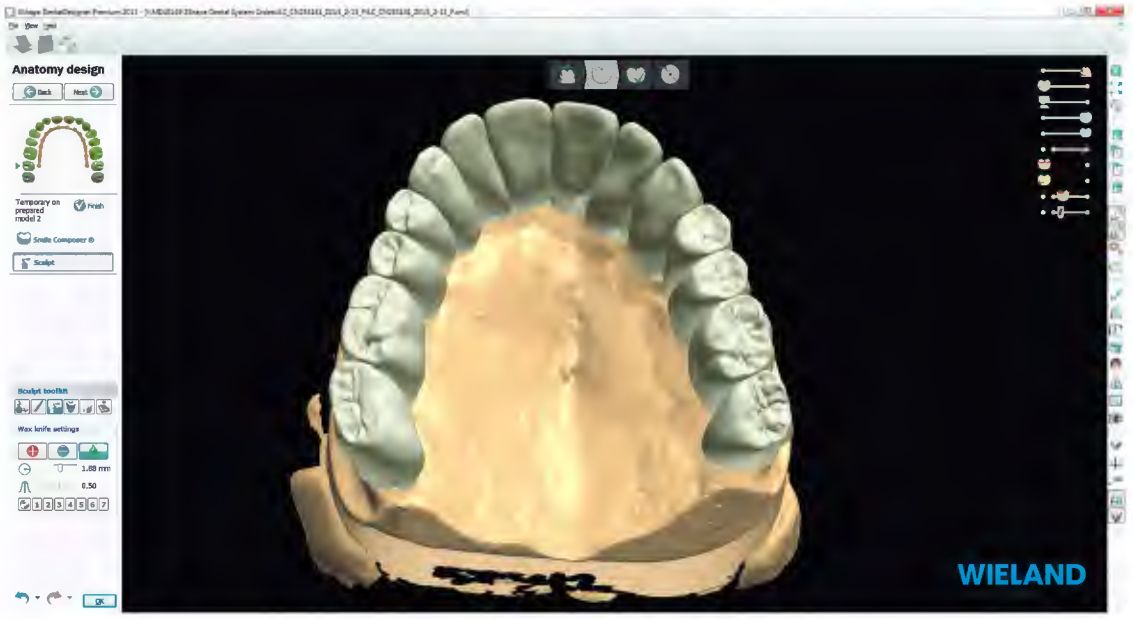


FIGURE 27-34. Final occlusal digital design for a full-arch, full-contour zirconia restoration.

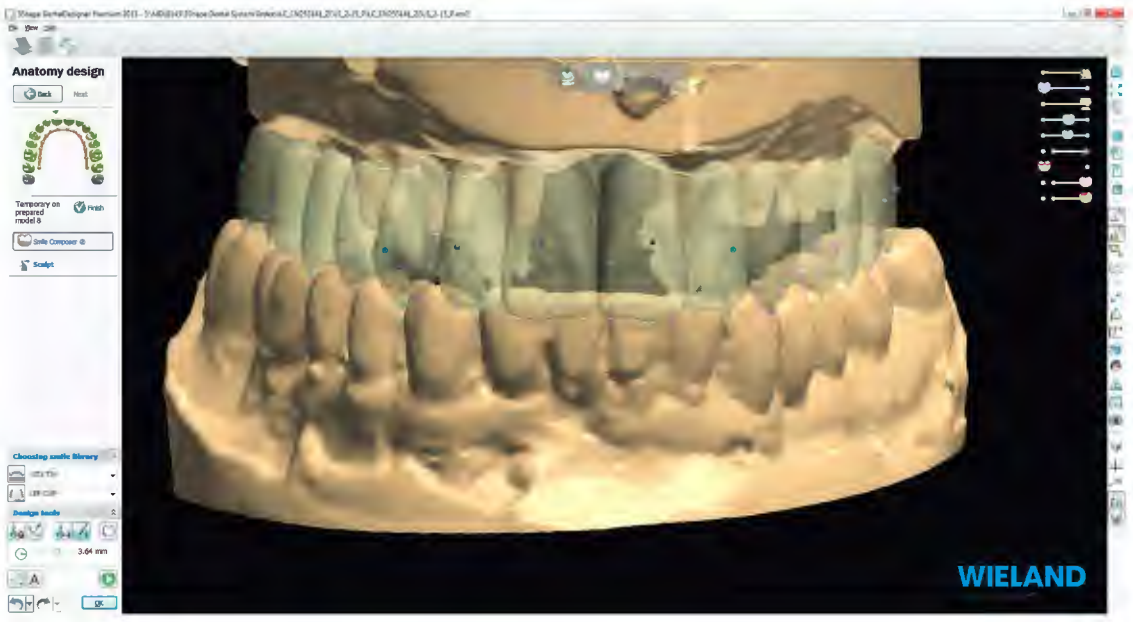


FIGURE 27-35. Final facial digital design for a full-arch, full-contour zirconia restoration.

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Conclusion

Technological advancements have always consisted of an initial design that is improved upon in several iterations until an ideal format is reached. In the past, traditional communication methods resulted in insufficient data transfer and increased patient dissatisfaction caused by the need to remake an ill-fitting or undesirable restoration. While CAD/CAM technologies evolved, dental professionals continued to use tried-and-true methods for data transfer, incorporating digital dentistry to fill in some of the blanks that were caused by familiar methods. As the field of digital dentistry further expands, CAD/CAM systems will be increasingly applied for treatment planning procedures, implemented from the very beginning of treatment throughout the entire restorative process. By incorporating advanced systems in the diagnostic phase, dental professionals will continue to reduce the margin for error available using traditional methods and further enable the dental professional to replicate natural esthetics while focusing on proper function and occlusal harmony using CAD/CAM technology.

The most exciting factor surrounding these technologies is not, however, only in the potential applications of the technology that are being hypothesized by dental professionals. The excitement truly lies in the fact that these "hypothetical" applications are currently being developed today, and some are even in the final stages of development.

These advancements are not, therefore, something that will "eventually" emerge in the market—they are realities that will be released within a relatively short time period to further revolutionize the quality of dental care that is being delivered in modern practice.

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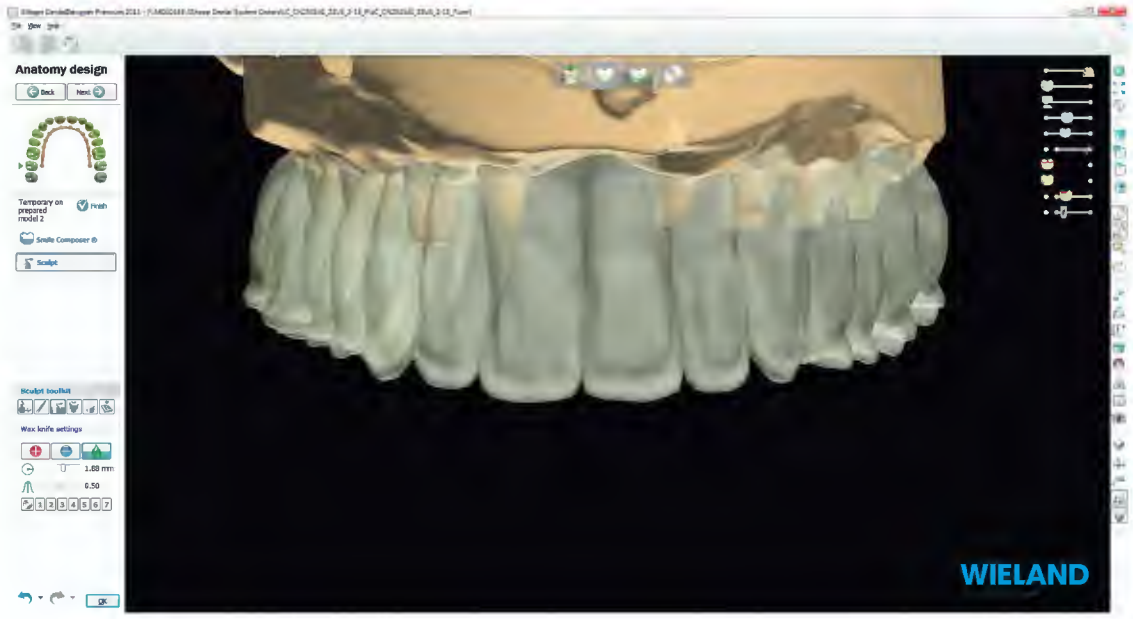


FIGURE 27-36. Translucent reduction view.

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FIGURE 27-37. Milled final restoration still within the milling machine.



FIGURE 27-38. Milled restoration still connected to disk.



FIGURE 27-39. Milled zirconia restoration in milled "green stage." It is shown with presintering shading colors added.



FIGURE 27-40. Milled zirconia restoration after sintering showing internal shading colors and ready for final minimal ceramic application.

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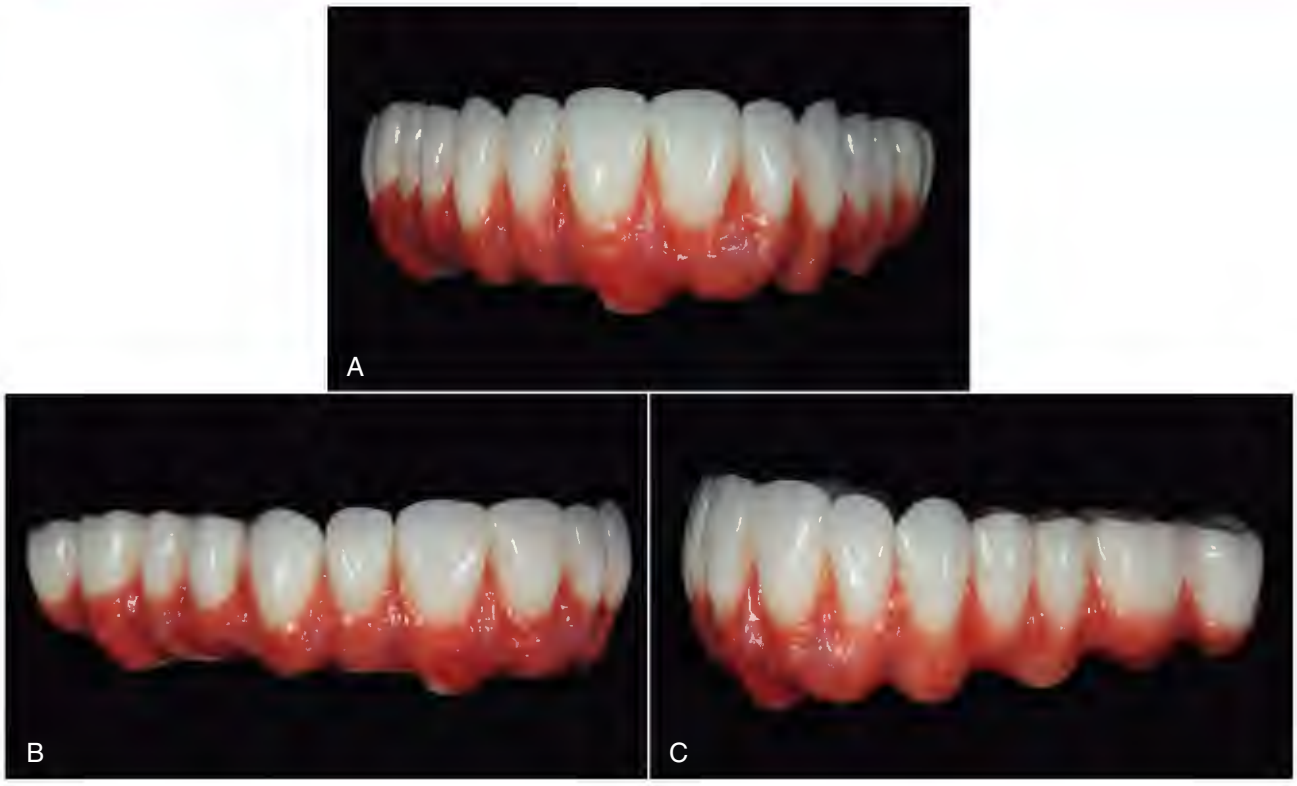


FIGURE 27-41. **A** to **C,** Final implant-supported full-arch, full-zirconia restoration. Shown is the final restoration with the addition of tooth- and tissue-shaded ceramics.

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The dental profession currently regards CAD/CAM technology as just machines that fabricate full-contour ceramic restorations or frameworks. Digital dentistry and the digital dental team represent a totally new way to diagnose, treatment plan, and create functional esthetic restorations for our patients in a more productive and efficient manner. CAD/CAM dentistry will only further enhance the dentist–assistant–technician relationship as we move together into this new era of patient care.

Automation has been slow in coming to dentistry, and although new equipment has been introduced to make our jobs easier, we still create complex dental prosthetics using techniques that are thousands of years old. And even though the "lost wax" technique is still a tried-and-true method of fabrication, there will come a day in the near future when all frameworks and full anatomical crowns will be designed on computers. Only then will we truly realize the wonder and awe of dental CAD/CAM technology that were initially introduced so long ago.

Summary

The successful incorporation of computerization and new technology into the dental laboratory will continue to provide more efficient methods of communication and fabrication while at the same time retaining the individual creativity and artistry of the skilled dental technician. The utilization of new technology will be enhanced by a close cooperation and working relationship of the dentist–technician team.

The philosophy, technique, and procedures that have been outlined in this book are fundamental principles of restorative dentistry. New technologies in dentistry will only be successful if they are combined with a complete understanding of basic comprehensive dentistry. Although new technology and computerization can make procedures more efficient, less labor-intensive, and more consistent, they will not replace education, practical experience, and clinical and technical judgment.

Acknowledgment

All technical work was performed by Jack Marrano, CDT, Micro Dental DTI, 5601 Arnold Road, Dublin, CA 94568.

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CHAPTER **28**

Principles for Abutment and Prosthetic Screws and Screw-Retained Components and Prostheses

Carl E. Misch

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The screw is a simple machine that follows the mechanics of a spiral inclined plane and therefore is highly efficient. It has been used for several centuries in most civilizations. A screw design is the most commonly used implant body to initially fixate an implant into bone and load the bone after hard tissue healing. A screw almost always is also used to connect the abutment components into the implant body. In addition, a screw may be used to fixate the prosthesis into the abutment or directly into the implant body (Figure 28-1).

Abutment and prosthetic screw loosening is one of the most common complications for implant prosthetics. Hence, dentists should have an understanding of implant screw mechanics rather than solely depending on an implant manufacturer to fulfill the needs of the profession. This chapter addresses the primary aspects of screw mechanics for implant components and presents methods to fabricate and handle complications of screw-retained abutments or prostheses.

Screw Retention

Abutment Screws

The primary use of screws in implant restorations is to fasten prosthetic components together. In almost all implant systems, a screw is used to fixate the abutment component (i.e., abutment for cement retention, abutment for screw retention and abutment for attachment) to the implant body (Figure 28-2, *A*). Many years ago, cement retention was frequently used for this purpose but now is not typical for the following reasons:

1. Hydrostatic pressures during cementation often stop the components from completely seating, which leads to a cement margin at the bone crest.
2. The excess cement is at the level of the bone, several millimeters below the tissue margin, and is almost impossible to remove completely without surgically reflecting the tissue.

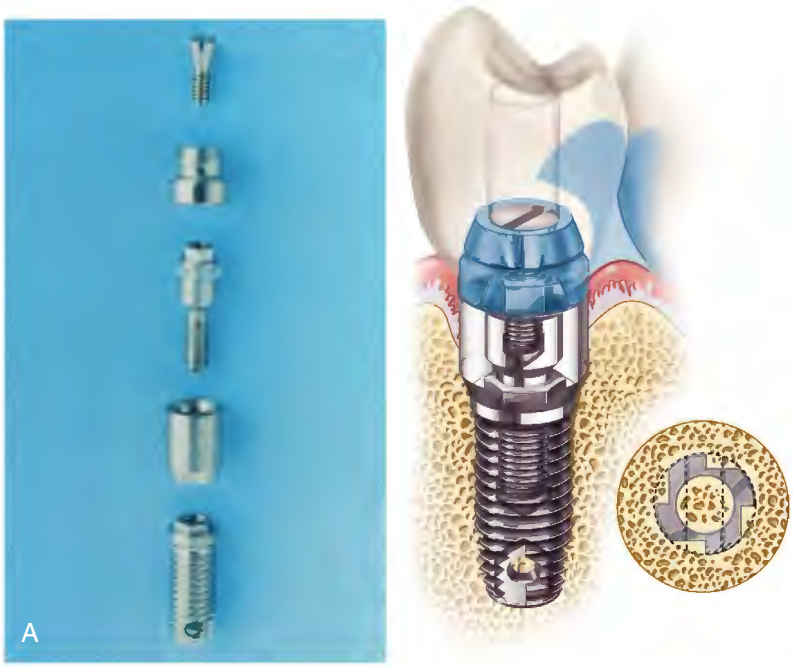


FIGURE 28-1. **A,** In 1985, the Nobelpharma implant was a series of screws to act as a foundation for a prosthesis. **B,** The implant body was screwed into the bone. The abutment screw fixated an abutment for screw retention. The coping screw retained the prosthesis.

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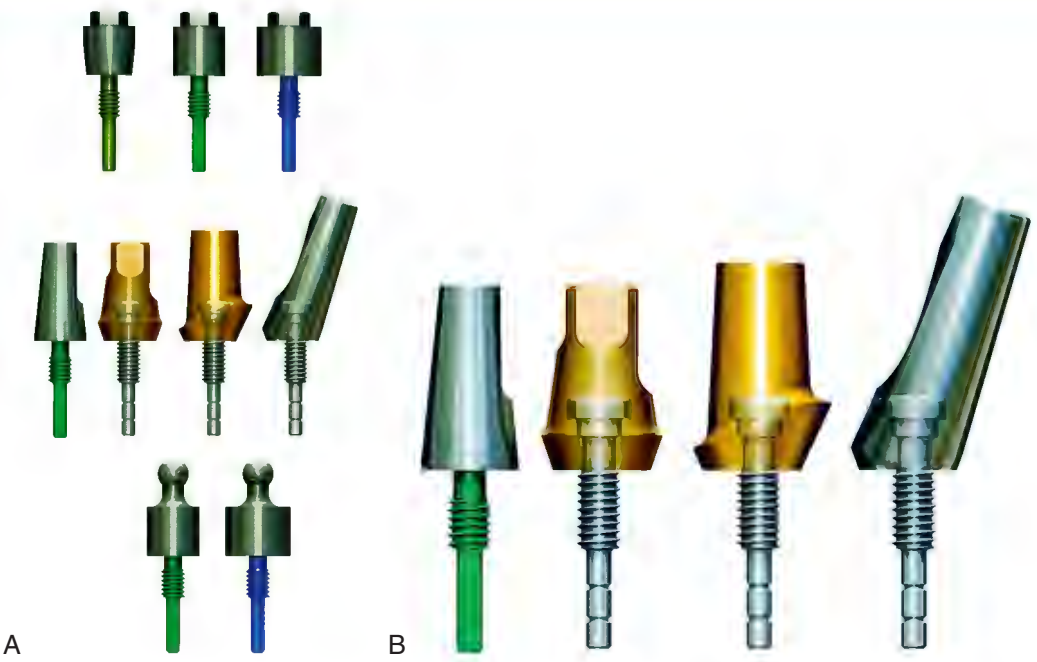


FIGURE 28-2. **A,** The abutment most always is screwed into the implant body. The abutments for screw retention *(top)*, the abutment for cement retention *(middle)*, and the abutments for attachments *(bottom)* come in various sizes and designs. **B,** The abutment for cement retention is screwed into the implant body.

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3. The abutment post is only 2 to 3 mm in diameter, too small for predictable cementation. In addition, cementing metal-to-metal components is not as predictable as cementing to tooth structure.
4. Whenever an abutment is cemented into an implant body, a composite resin cement is indicated because it has the greatest compressive and tensile strength. However, composite resin is even harder to remove than any other cement, and residual cement may contribute to crestal bone loss. In addition, many resin cements are not radiopaque, and the presence of residual cement is difficult to determine.
5. The small-diameter abutment post is at increased risk of fracture, especially when it is not seated completely into the implant body.
6. If an abutment fatigue fractures long term, it must be cut out of the implant body. This procedure is difficult and often overheats the implants, leading to bone loss or implant failure. The process may also perforate the thin outer wall of the implant, which usually causes failure (Box 28-1). Therefore, a cemented post rarely is indicated unless all other methods of screw retention have failed, in which case a cemented post then is used as a salvage device.

Several advantages justify the use of a screw-retained abutment component. The abutment screw is the easiest, safest, and most efficient method to fixate prosthetic components to an implant body. The abutment screw provides retention even for small dimensions. The abutment screw is easily retrievable, so transfer impressions may be made. Impression transfer copings may be used to transfer the implant body position to the laboratory. These components must be uncoupled after the transfer is made. In addition, the restoring dentist may decide to exchange one abutment for a slightly different design, angle, or height, so easy insertion and removal is of benefit. Therefore, the readily retrievable aspect of a screw is a significant advantage.

There is also no risk of residual cement at the interface (Box 28-2).

BOX 28-1 Disadvantages of Cemented Abutment Posts

1. Hydrostatic pressure causes incomplete seating
2. Excess cement at bone crest is difficult to remove
3. Residual cement causes periimplantitis
4. Small abutment post diameter
   a. Less retention
   b. Risk of breakage
5. Metal-to-metal properties of luting agents
6. Difficult component replacement (unretrievable)

BOX 28-2 Advantages of Screw-Retained Abutments

1. Easy
2. Efficient and predictable
3. Retrievable for transfer components and so on
4. No cement in the soft tissue periimplant area
5. Retention even for small dimensions

Screw Loosening of Abutment and Prosthetic Screws

Screw retention of the abutment also presents some potential problems. The abutment-to-implant body connection approximates the level of bone and is several millimeters below the margin of the tissue. It may not be completely hermetically sealed and may contribute to bacterial infection, especially when the abutment screw becomes loose.

Chronic screw loosening can be costly and time consuming.[1-24] Reports indicate that as many as 6% to 20% of maxillary prosthetic screws loosen at least once during the first year of

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function.[4,25] The coping screw is usually the weakest link in the prosthetic chain. Any discrepancy in occlusion, casting fit, or force may result in vibration during function and screw loosening or breakage where the force is greatest or the metal dimension is weakest. This complication protects the implant body from more severe complications. However, after they occur in a splinted restoration, the other implant abutments are at greater risk of overload and complications than the offending implant because a cantilever and magnification of the load have been created. The amount of increased force varies but may be extreme. For example, moment forces can multiply stress on the crest of the bone-to-implant interface in direct relation to the distance to the next retained abutment. As a result, a 0-moment force can increase to a 250–lb mm moment load with a 25 lb force, although the next abutment is only 10 mm away.

Many conditions that cause prosthetic screw loosening also affect a cement-retained restoration, but the cement seal is often not the weakest link. As a result, unlike the screw-retained restoration, the overload results in complications limited to the region of the higher forces. In addition, the stresses are not magnified by moment of loads created from a partially retained restoration. Increased biomechanical stress during prosthesis fixation can lead to a myriad of complications (i.e., marginal bone loss, implant failure, screw loosening).

The access hole through the occlusal material results in an increased risk of porcelain fracture compared with cement-retained restorations. In a split-mouth study by Nissan et al. of bilateral edentulous sites, ceramic fracture occurred in 38% of screw-retained restorations compared to 4% for cement-retained prostheses.[13] The mean loading period for these restorations was 5 years.

The screw-retained prosthesis is not loaded in the long axis, so marginal crestal bone regions have higher stress.[2] The occlusal access holes are less esthetic than a cemented prosthesis. Access in the back of the mouth may be limited for the fixation screwdrivers. Progressive bone loading cannot be effectively accomplished because the splinted restorations are not passive.[17] The additional cost of analogs and impression transfer components is required for fabrication of the prosthesis (Box 28-3). Most of these disadvantages are addressed in Chapter 26.

After the final abutment is selected and positioned, the restoring dentist does not want the abutment to become loose. Yet abutment screw loosening for fixed prostheses is one of the more common complications, especially for a single-tooth implant. The abutment for cement retention is screwed into the implant body (Figure 28-2, *B*) Abutment screw loosening is less likely in multiple splinted restorations but also has frequently been reported. Initially in the 1980s, abutment screw loosening was reported to be as high as 65% of the time within a 3-year period.[9,14] When the screw is loose, the cemented restoration is different to remove to gain access to the abutment screw. As a consequence, many dentists recommended a screw-retained prosthesis. Since that time, manufacturers have addressed the issue using metal screw mechanics.

BOX 28-3 Disadvantages of Screw-Retained Prostheses

1. Risk of prosthetic screw loosening
2. Fracture risk of prosthetic screws
3. Device not sealed (bacterial growth)
4. Nonpassive castings
5. Lack of axial occlusal loads
6. Less esthetic restorations
7. Increased risk of porcelain fracture
8. Access difficult
9. Lack of progressive loading
10. Increased cost

Metal Screw Mechanics

The increased risk of prosthetic or abutment screw loosening may be decreased by understanding metal screw mechanics.

The goal of a simple machine is to reduce the effort needed to work. Five systems increase an applied force: (1) screw, (2) incline plane, (3) lever, (4) wheel, and (5) pulley. Of these, the lever and screw are the most important to a restoring dentist. A cantilever is able to magnify a force in relation to the length of the lever (i.e., $M_f = F \times$ cantilever length, where M_f is moment force and F is force). A screw is even more efficient as a force magnifier. A 20–N-cm force on a screw is able to move two railroad cars on a flat plane. A *screw joint* is the term used to describe the connection.

Several factors related to screw design and fabrication can increase or decrease the risk of abutment or prosthetic screw loosening in a metal-to-metal screw system. These primarily are related to preload. In addition, factors that affect abutment screws also include component fit, hex height (or depth), and platform diameter (Box 28-4).

Preload

Preload of an abutment or prosthetic screw is the initial load created by the application of a torque and causes elongation of the screw. Preload places the screw in tension and leads to an overclamping force between the parts of the implant system.[26] The aim of tightening a screw using preload stress is to maximize the fatigue life of the screw yet provide satisfactory resistance to loosening. The preload is affected by seven factors: (1) torque magnitude, (2) screw head design, (3) thread design and number, (4) composition of metal, (5) component fit, (6) surface condition, and (7) diameter of the screw (Box 28-5).

Torque Magnitude

The amount of force applied to tighten a screw joint is related to the success of the components staying connected. Torque rotational forces on a screw may be measured in newton-centimeters (N-cm). Too small a torque leads to low clamping forces, which increase the risk of loosening. The clamping forces on a metal-to-metal screw component are one of the more important considerations for long-term screw fixation. The joint strength is improved more by increasing clamp forces than any other condition related directly to the screw. The clamp force is directly proportional to the force used to tighten the screw. The magnitude of the preload is related directly to the clamping force.

BOX 28-4 Screw Parameters Affecting Screw Loosening

1. Preload
2. Component fit
3. Platform dimension
4. Hex height

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BOX 28-5 Screw Preload Parameters Affecting Screw Loosening and Fracture

1. Torque magnitude
2. Screw head design
3. Thread design and number
4. Metal composition
5. Surface condition
6. Screw diameter

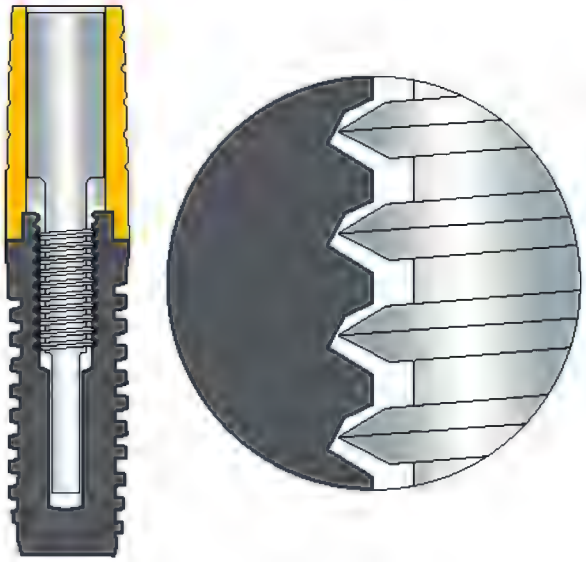


FIGURE 28-3. The abutment screw male (gray) engages the female receptor site (blue), and as it rotates in position, the male component is stretched (strain) in relation to the preload force.

The torque applied to a screw component affects both the compressive forces in the threads and the compressive force applied to the head of the screw on the recipient component. The torque applied to the screw also results in tensile forces within the male component of the screw. The compressive and tensile forces from the torque forces are magnified because they are applied to the inclined plane of the screw components (Figure 28-3). The tensile forces attempt to lengthen (strain) the screw when enough torque is applied. The strain (change in length divided by original length) of the screw also is related directly to the amount of torque force. The higher the force, the greater the strain.[27] Too great a torque force causes plastic or permanent deformation or a permanent change in the material, at which point the screw is no longer retrievable and additional force causes fracture of the screw. In other words, too large a torque results in fracture of the screw or stripping of the thread components. The suggested amount of the torque for a preload should be 75% of the value to reach permanent deformation of the screw to provide a safety valve for the screw joint.[28]

The amount of preload applied to a screw joint should be consistent and great enough to cause deformation (strain) within the screw thread. In the original screw retention system of Nobelpharma from 1980 to 1990, only finger forces on a handheld screwdriver were used to tighten screws. A hand screwdriver cannot produce a consistent torque value.[29,30] In a study by Misch with 136 dentists, the average torque placed on a screw joint with a hand screwdriver was 11 N-cm and ranged from 5 to 21 N-cm. As a consequence, abutment and screw loosening during that era was observed in almost 50% of the restorations.

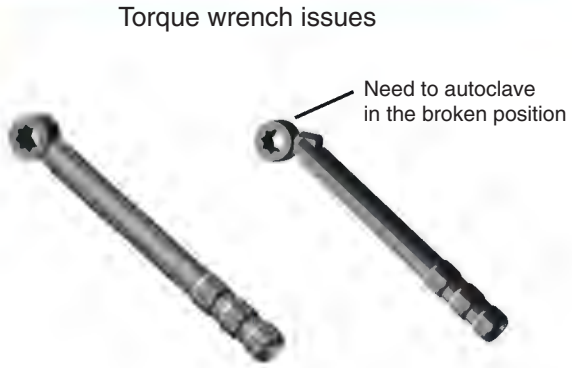


FIGURE 28-4. A torque wrench often is used to place a consistent preload on a screw, which decreases the risk of loosening. The torque wrench should be autoclaved in the open position to decrease corrosion of the mating components, which increases the torque and decreases the accuracy of the wrench.

In the early 1990s, a torque wrench was used to provide these clamping forces. A torque wrench uses the advantages of a lever to apply the force. The length of the lever of a torque wrench can increase the torque magnitude to more than 100 N-cm of clamping force to the screw, well beyond the elastic limit of the material. Hence, the wrench has a safety valve that limits the torque value to a consistent limit. A torque wrench with high torque stretches the abutment screw. This concept reduced abutment screw loosening to less than 16% during the first year of loading.[31]

A torque wrench is required to obtain a consistent value of torque. However, several reports have shown that torque wrenches are not completely accurate and components may corrode after autoclaving many times, which may increase the torque applied to the system.[29,32,33] Therefore, autoclaving hand torque wrenches in the open position and the doctor testing the torque wrench before use are suggested to make sure the pieces are not frozen in place (Figure 28-4). Periodically, the torque wrench should be recalibrated by the implant company or manufacturer.[33]

A 30-degree angle, V-shaped screw thread design most often is used for the metal-to-metal connection of an implant system and is called a *fixture thread design*.[34] This 30-degree incline places shear loads on the metal components and permits the metal to be stretched during preload to prevent screw loosening. The amount of torque suggested by most implant manufacturers on abutment screws ranges from 20 to 35 N-cm. However, a wide divergence in optimum torque values applied to screw components has been reported in the literature, ranging from 12.4 to 83.8 N-cm depending on the material and screw design.[35,36]

It should be noted that because the torque value used during preload is less than the permanent deformation of the screw material, the stretched length of the screw rebounds slightly and reduces the clamping force. As a consequence, it is suggested that the screw is torqued to 75% of its permanent deformation (i.e., 30 N-cm) and then loosened and torqued again. After 10 minutes, the screw is again tightened (it should not be loosened after the second time). This delayed torque method reduces the amount of relapse in the strain of the screw.[37]

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As the screw components work against each other, the wear (settling) slowly lessens the clamp force of the screw to hold together the components. As a consequence, it may be advantageous to periodically tighten a screw after each several-year period, especially in a patient with greater than usual external forces (i.e., parafunction).

The dentist must take care when placing torque to the screws because torque forces are also transmitted to the bone–implant body interface (Figure 28-5). Bone is 65% weaker to shear forces, and torque places shear forces on the bone. The amount of torque to break the interface of an osseointegrated implant depends on implant design, surface condition, and bone density but may be less than 20 N-cm in soft bone types.[38] Therefore, the use of a counter-torque procedure is advocated, especially in soft bone.

A simple counter-torque method is to use a modified hemostat to hold the abutment while the torque wrench tightens the screw (Figure 28-6). Because the abutment engages the antirotational component of the implant body and the abutment cannot rotate with the hemostat in position, the rotational forces applied to the abutment screw do not transmit to the implant–bone interface.[38]

To use this counter-torque technique the abutment must engage the hex or antirotational design of the implant. To ensure that the abutment seats completely on the implant body and fully engages the hexagon or antirotational feature of the implant body, a radiograph is often necessary before using the torque wrench when the implant platform is placed below the soft tissue. The counter-torque technique to reduce shear loads to the crestal bone is only effective when the components do not have rotational misfit.

Coping or prosthetic screws that do not engage an antirotational feature on the abutment cannot use a counter-torque technique to prevent torque applied to the implant system (Figure 28-7). This issue is less of a factor when the torque applied to the prosthetic screw is less than the abutment screw (i.e., 10–20 N-cm) and the implants are splinted together. When possible, individual implant crowns with prosthetic frameworks should engage the abutment hex. As a result, the torque applied to the prosthetic screws can be resisted by a counter-torque technique.

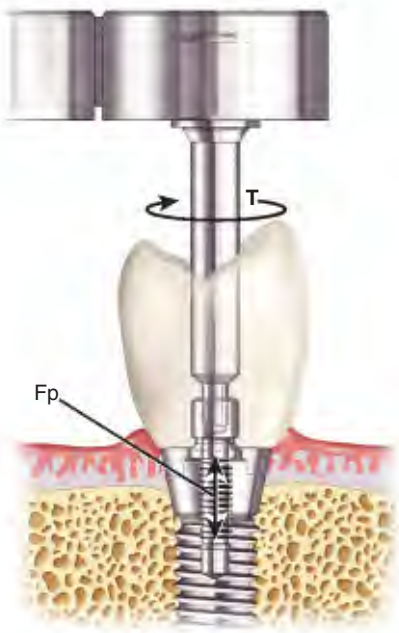


FIGURE 28-5. The torque (T) applied to an abutment screw (which strains the screw (Fp) is also applied to the implant–bone interface.

Screw Head Design

In an effort to minimize clinical complications, the features of the screw have been enhanced to maximize preload and minimize the loss of input torque to friction. The head of the screw is wider than the outer thread diameter and for an implant abutment or prosthetic screw may be tapered or flat.

In screw fixation outside of dentistry, a 30- to 45-degree tapered head often is used to help align the individual components that have a misfit during fixation.[39] The tapered head acts as an incline plane to align the misfit pieces as the screw is tightened into position. The prosthetic screw was also initially used by Nobelpharma implants in the mid-1980s (see Figure 28-1, *A*). However, the tapered head prosthetic screw design reduces the clamping effect and reduces the tensile force in the threads of the screw. Most of the force within the tapered screw



FIGURE 28-6. A counter-torque technique (which stops the abutment from rotating) is used when possible to resist the rotational force applied to the screw being applied to the implant–bone interface.



FIGURE 28-7. A counter-torque technique cannot be applied to prosthetic screws if they do not engage an antirotational feature on the component. However, because the implants are splinted together when the component is used, the risk of overload to the implant–bone interface is reduced.

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head is distributed to the head rather than to the fixation screw component. When 20 N-cm of torque force is applied to a tapered head screw, 15 N-cm is distributed to the tapered head incline, and 5 N-cm is applied to the screw threads.

Coping or prosthetic screws designed with tapered (rather than flat) heads should be limited in implant prosthetics[28] (Figure 28-8). The tapered screw head distorts and aligns nonpassive frameworks and gives a nonpassive casting the appearance of proper fit. However, the superstructure is not deformed permanently and therefore leads to continued stresses in the system. Even a 10–N-cm torque force applied to an inclined plane of a screw can distort a superstructure and result in significant stress at the crestal bone region.

A flat-head screw is preferred for prosthetic screws. When 20 N-cm of torque force is applied to a flat-head screw, 10 N-cm of clamping force is applied to the screw head, and 10 N-cm is distributed to the screw threads. The increase in torque to the threads increases the strain in the components and decreases the risk of loosening. A flat-head screw also distributes forces more evenly within the threads and the head of the screw and is less likely to distort a nonpassive casting. As a result, the dentist can more easily identify the nonpassive casting[40,41] (Figure 28-9).

Thread Design and Number

The thread design is also a primary factor influencing the risk of screw loosening. As previously mentioned, the most common abutment screw design used by implant manufacturers is a fixture that is a V-shaped 30-degree angle[39] (Figure 28-10). The fixture design allows the preload torque applied to the screw to stretch the male component down the 30-degree angle of the female component of the screw to help fixate the metal components. However, this screw design places almost all of the strain in the first few threads (Figure 28-11, *A*). As a consequence, when a 30-degree V-shaped thread is used, the number of threads does not need to be more than two times the diameter of the screw.[34] As a result, most manufacturers only have a few threads on their abutment or prosthetic screw designs. Because the prosthetic screw has less diameter than an abutment screw, it has fewer threads. The most common abutment screw design is a flat head with five threads and four threads for a prosthetic screw.[42]

The space industry also uses screws to fixate metal components together. When the space shuttle escapes and enters the earth's atmosphere, violent shaking of the components occurs. These uneven loading forces can result in screw loosening. For these reasons a different screw design was created by the space industry to distribute the pretorque loads on the screw to each male and female thread component of the screw (Spiralock; Detroit Tool Industries, Madison Heights, MI) (Figure 28-11, *B*). As a result, the sketching of the screw is more harmonious within each screw thread, and more threads are beneficial and may be added to the system. Additional threads on the screw further increase its resistance to loosening.[41,43] This modified Spiralock thread shape was used on the space shuttle to maintain the screw joint integrity.

The Spiralock thread shape has been used exclusively by an implant manufacturer (BioHorizons Dental Systems, Birmingham, AL). The Spiralock implant abutment and prosthetic screws each have eight to 10 threads (Figure 28-12). In a 5-year prospective study, no abutment screw loosening was reported.[44] In a multicenter 10-year report for posterior single-tooth replacement, abutment screw loosening occurred in fewer than 1% of the prostheses.[45] Elimination of screw loosening is not a consequence of one feature. However, use of improved engineering principles apparently can dramatically decrease the risk of screw loosening.



FIGURE 28-8. A tapered screw head is not indicated for fixation of implant frameworks because the tapered head reduces the torque within the threads.

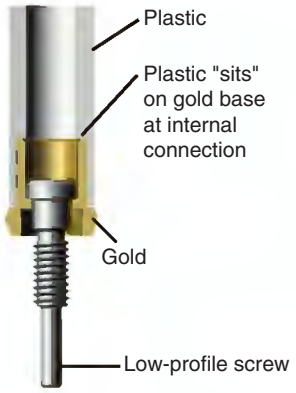


FIGURE 28-9. The clamping force applied to a flat-headed screw secures components with higher preloads within the threads. Plastic components, which are cast, do not fit against the flat-head screw as accurately as a machined component. An improved design uses a machined metal coping and a plastic sleeve combination.

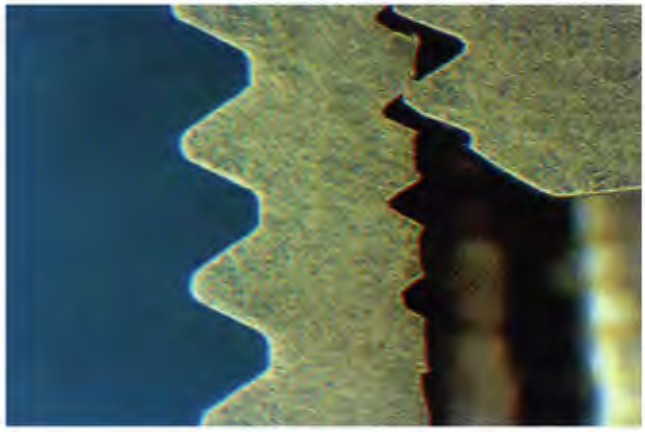


FIGURE 28-10. A 30-degree V-shaped thread is called a fixture. This design is used most often to secure metal components because the male component of the screw is stretched down the female receptor at a 30-degree angle when torque is applied to the screw head. The Nobel Biocare, 3i, Paragon, and LifeCore implant bodies also use this same thread design for the implant body.

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FIGURE 28-11. **A,** A 30-degree thread design *(left)* has almost all of the preload torque applied to the first few threads. Hence, the number of threads is not critical. **B,** The SpiraLock thread design *(right)* distributes the stresses to each thread in the system, so the increase in the thread number is a benefit to reduce loosening.



FIGURE 28-12. The number of threads on an abutment or coping screw varies depending on the manufacturer. The SpiraLock thread of BioHorizons has 10 threads *(bottom)*. The 30-degree fixture abutment screw of Zimmer has six threads *(top)*.

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Metal Composition

The composition of the material is another factor that modifies the performance of the screw. The composition of the metal may influence the amount of strain in the screw from preload and the point of fracture and therefore directly affects the amount of preload that can be safely used. Screw material and yield strength vary greatly when all other factors are similar (12.4 N for a gold screw to 83.8 N for a titanium alloy screw fixation).[35,26,] A prosthesis screw may exhibit a torsional ductile fracture at 16.5 N-cm versus 40 N-cm, depending on the material from which it is fabricated.[34]

The plastic deformation or permanent distortion of the screw is the end point of the elastic modulus. Titanium alloy has four times the bending fracture resistance of grade 1 titanium. Therefore, abutment screws made of grade 1 titanium deform and fracture more easily than the alloy. Titanium alloy is 2.4 times stronger than grade 4 titanium. As such, a higher torque magnitude can be used on the titanium alloy abutment screw and female component (found within the implant body), less on grade 4 titanium, less on grade 1 titanium, and the least on gold screws.

The elongation of metal is related to the modulus of elasticity, which depends on the type of material, its width, its design, and the amount of stress applied. The material of which the screw is made (e.g., titanium alloy, titanium, or gold) has a specific modulus of elasticity. A prosthetic gold screw exhibits greater elongation than a screw made of titanium alloy (but a lower yield strength).

Although the strengths of different titanium grades are dramatically different, the modulus of elasticity is similar for grade 1 to 4 titanium. Hence, the strain of the abutment screw is similar with each grade of titanium, but the safety load relative to fracture is different. Titanium alloy (grade 5) has a slightly higher modulus of elasticity. Although not clinically relevant to metal–bone osseointegration, the titanium alloy screw should use a slightly higher preload value. This is not a consequence relative to permanent deformation or fracture because it is more than twice as strong as the other grades of titanium.

The metal is also important to consider for the screwdriver used in the torque wrench. Stripping of the screw head prevents the clinician from tightening or removing the screw. Some manufacturers make the torque wrench driver titanium alloy, and the screw is made of gold or titanium. The concept is that the torque wrench will not deform the hexagon and will not strip, so the device lasts longer. However, this is not ideal. It is easier to replace the torque wrench driver than the abutment or prosthetic screw. Hence, the torque wrench should be made of titanium and the screw of titanium alloy.

From a clinical standpoint, the receptor site for the torque wrench is also a feature of the screw head to consider. The screw head has a rotation feature, usually a straight slot or a hexagon design. The more sides to the rotation feature, the more often the head will strip. Hence, a slot or triangular feature will strip less than a hexagon.

Surface Condition

The surface condition of the screw is a controversial issue in screw mechanics. One school of thought thinks that a rougher surface condition enhances the resistance (friction) in the screw joint and minimizes the risk of loosening. However, those who advocate use of friction-reducing coatings claim that the gain in preload strain is an effective way to enhance fixation. Tests on rough and smooth screws indicate that there may not be any statistical difference at the dimensions of an abutment or prosthetic screw.[39,46]

Screw Diameter

The diameter of the screw may affect the amount of preload applied to the system before deformation. The greater the diameter, the higher the preload that may be applied and the greater the clamping force on the screw joint.[39] Most abutment screws of different implant manufacturers are of similar size. However, the coping and prosthetic screws of many companies are smaller in diameter (and may be a different material). The strength of the material is related to the radius times the fourth power. In other words, a screw half the diameter is 16 times weaker. As a result, abutment screws loosen less often because they can take a higher preload compared with coping and prosthetic screws. Some companies offer similar diameters for abutment and prosthetic screws. As a result, a similar clamping force may be used for either component.

Abutment Screw Connection

The factors of external forces and conditions that affect preload apply to both abutment and prosthetic screws. In addition,

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some features found in abutment screw connections can increase or decrease screw-related complications.

Component Fit

Not all implant manufacturers have the same range of component misfit. In the science of machining metal components, there is a range of dimensions manufactured. In other words, a 4-mm-diameter implant is really a range between 3.99 mm and 4.01 mm. Likewise, the abutment and prosthetic coping connection also has a range. As a result, if a smaller implant body hex dimension is mated with a larger abutment connection, the components may not ideally fit together. Most implant companies allow a misfit range, which results in the abutment or coping being able to rotate ±10 degrees on the implant body. Misfit of abutment components between the abutment and implant body may have a misfit of 10 degrees in a rotational dimension, and horizontal discrepancies have been reported up to 99 microns.[47-50] These ranges are different with each implant system. The machining tolerance of a few systems may be as small as 5 microns and less than 1 degree in rotation. The more accurate the component fit, the less force applied to the abutment or prosthetic screw (Figure 28-13).

The incidence of screw loosening is also a function of the accuracy of fit of the flat-to-flat connection of the implant and abutment or prosthetic component. Implant abutment connections or prosthetic connections with an unstable mating interface place undue stress on the screw that connects the components.[47-50] Mechanical testing has demonstrated a direct correlation between the tolerance of the flat-to-flat dimension of the external hexagon and the stability of the abutment or prosthetic screw. Binon suggested that a mean flat-to-flat range of less than 0.005 mm exist on the hexagon, and a flat-to-flat range of less than 0.05 mm for the entire sample would result in a more stable screw joint.[48] A plastic castable pattern may have a vertical misfit as high as 66 microns.[47,50]

When the abutment head taper is reduced to less than 5 degrees (Morse taper), an increase in the frictional fit occurs. Several implant abutment designs use only the Morse taper, without threads, to fixate components together (Figure 28-14). The Morse taper has been called "cold welding" in advertising. However, no metal composition has changed, and limited strain is present in the connection, so this attachment is primarily a frictional fit.

Morse tapers in engineering are designed to make components easily retrievable, not to keep them fixated together.[39] Any tensile or shear force will separate the individual pieces. Hence, a cantilever or angled force to the crown will transmit tensile and shear loads to the abutment and cause the Morse taper to loosen. The most common device that uses a Morse taper in dentistry is a dental lathe. As a result, the polishing wheels are more easily removed and replaced. Rather than threading a pumice wheel into position, only to unthread and thread a polishing wheel, a Morse taper permits the dentist to quickly remove and replace the components.

The same manufacturing conditions apply to impression transfer copings and analogs. Many manufacturers have a wider machining range (+ or – variance) for the prosthetic components to reduce the cost of manufacturing (Figure 28-15). Hence, when transfers and analogs are used in impressions and then to fabricate the prosthesis in the laboratory and the implants are splinted together, the casting may not passively seat.

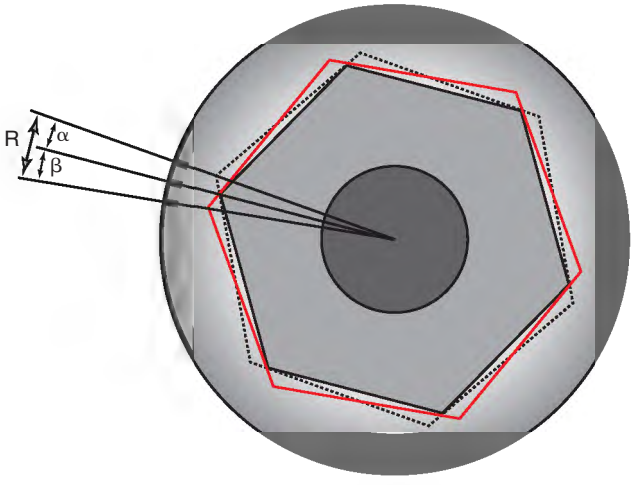


FIGURE 28-13. The rotational fit of the abutment-to-implant body is variable from one manufacturer to another. The greater the rotational misfit (*red line* and *dotted line*), the more force is applied to the abutment screw.



FIGURE 28-14. The abutment *(gray)* may be retained by the implant *(black)* with a functional fit called a Morse taper.

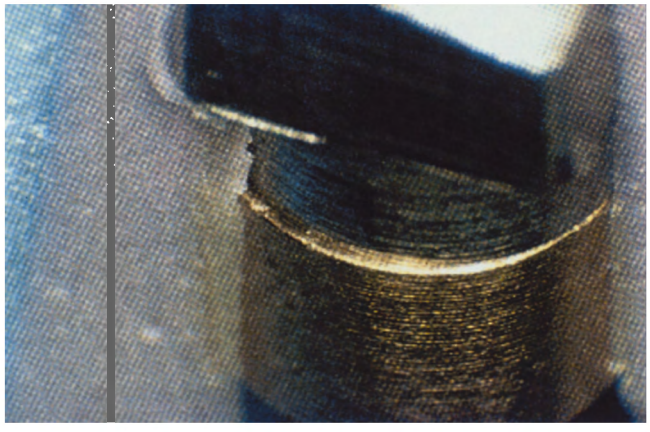


FIGURE 28-15. The direct impression transfer copings should be manufactured to fit the implant abutment screw or crest module precisely. A precise fit is required to reduce the risk of a nonpassive casting.

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Settling is a term used to describe the effect of parts wearing and fitting closer together. Minor irregularities on or within a casting that incorporates the top of an abutment for screw can cause slight elevation of the casting or the screw head. Over time, micromovement wears down the irregularities, and the parts fit closer together. However, this settling relaxes the preload force on the prosthetic screw and is more likely to cause screw loosening.

When a castable component is used, sandblasting alters the surface and therefore component fit. Chemically devastating the castings with a commercial acid has been advocated to decrease marring and damaging the coping. Polishing the abutments and coping margins with hardened stainless steel polishing caps to protect the coping abutment interface also is recommended.[51]

Plastic burnout prosthetic copings cost less, but they exhibit much greater laboratory variance and poor fit because of irregularities and settling of the superstructure. Besides cost, another advantage of a plastic burnout pattern for a coping is that one type of metal is used for the coping and superstructure, lessening the risk of metal corrosion or separation between the coping and superstructure.

To reduce settling, a machined coping may be used to fit the implant abutment more accurately. Some manufacturers suggest a titanium coping to reduce the risk of misfit. However, oxides form on the titanium machined coping surface and impair metal adherence when the prosthesis or abutment metal work is cast to the coping. Mechanical retentive features on the coping improve this metal-to-metal attachment.[52]

Laboratory studies demonstrate that an alloy-cylinder compatibility exists when noble metal alloys are used rather than titanium for a superior metal-to-metal connections. A machine coping connection is still present, so it is superior to the plastic components used to cast one metal.[53] The risk of oxides forming between the coping and metal of the prosthesis is also reduced (see Figure 28-9).

Antirotational Features

As a general rule, most implant bodies have an antirotational feature for the abutment connection. The most common designs are an external hexagon, an internal hexagon, a Morse taper, and a Morse taper with threads.

Many manufacturers have stated that the internal connections are more esthetic for the implant crown. This is not true. The internal and external antirotational features have the same esthetic consequence. All external hexagon implant bodies have an abutment that has a matching internal hex. When the two components are connected together, they form a connecting line between them. The crown margin is placed above the connecting line of the abutment to implant body. All internal hexagon implant bodies have an abutment that has a matching external hexagon. When the two components are fixated together, they form a connecting line between them. Hence, after the abutment component is connected, there is no esthetic difference for the crown that is attached to the abutment (Figure 28-16).

Factors that affect the abutment screw connection and screw loosening include the height (or depth) of the hexagon and the platform diameter.[47-49,54] Boggan et al. studied the influence of design factors on the mechanical strength and quality of fit of the implant abutment interface.[54] Whereas failure mode for static test samples was bending or deformation of the abutment screw, fracture of the abutment screw was the common failure mode for the fatigue test samples. The static failure load was



FIGURE 28-16. An internal hex implant *(left)* has an abutment with an external hex connection. An external hex implant *(right)* has an abutment with an internal hex connection. When the abutments (gold) are attached to the implant, the abutment-to-implant margin is similar related to esthetics.

TABLE 28-1
Failure Loads of Various Implant Types

Implant Type	Static Failure Load (N)
1.0-mm external hexagon, 4 mm	966
1.0-mm external hexagon, 5 mm	1955
0.7-mm external hexagon	756
0.6-mm internal octagon	587
1.7-mm internal hexagon	814

greater for the external hex implants of 1 mm in height compared with implants with an internal hexagon of 1.7 mm. The larger-diameter implant had the greatest static load before failure (Table 28-1).

A mechanical analysis of the abutment–implant interface was conducted to further clarify the importance of hexagon height (or depth) and platform diameter. The load on the abutment screw was shown to be a function of the hexagon height (or depth) and the platform diameter according to the following equation:

$$Fs = \frac{(P[H] - R2\,[h])2}{D}$$

where *Fs* is the load on abutment screw, *P* is the lateral load on the abutment, *H* is the abutment height, *R2* is the reaction load of the implant hexagon on the abutment, *h* is the external hexagon height (or depth) of the implant, and *D* is the platform diameter of the implant.

Use of this equation demonstrates that as the hexagon height (or depth) increases, the load on the abutment screw decreases. Likewise, as the diameter of the implant platform increases, the force on the abutment screw decreases. Reduction of the lateral load (P) on the abutment screw is important so as not to load the screw beyond the yield strength of the material or to reduce

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the number of cycles to fracture (because fatigue is related to both force and cycles).

Height (or Depth) of the Hexagon

The height (or depth) of the antirotational hexagon is directly related to the force applied to the abutment screw with any lateral load[54] (Figure 28-17). Because the crown is connected to the abutment and the abutment rests on the implant platform, a lateral force on the crown creates a tipping force on the abutment. This tipping force is resisted by the hexagon height or depth, the platform, and the abutment screw. When the arc of rotation is above the hexagon height, all of the force is applied to the abutment screw. For the hexagon height to be above the arc of tipping forces, the hexagon height must be at least 1 mm for a 4-mm-diameter implant. Yet many implant manufacturers using a hexagon height have only a 0.7-mm hexagon, so almost all of the force is directed to the abutment screw and increases the occurrence of screw loosening and fracture.

The 0.7-mm hex dimension was the original design for the Nobelpharma titanium screw implant.[55] In the research of Brånemark , the implant body was placed 1 mm below the bone crest, and a 1-mm-tall cover screw was placed over the external hex.[56,57] This resulted in the implant and cover screw positioned level with the bone. When the implant was not countersunk, the external hex feature was above the bone and made it more difficult to obtain and maintain soft tissue closure. The external hex was only used to thread the implant into the bone. The cover screw and abutment did not engage the hex of the implant crest module. Hence, the height of the hex was not a prosthetic antirotation feature. The lower the hex height, the less countersunk the implant was in the bone.

When the internal hexagon implants were introduced, the internal connection did not alter the overall height of the implant platform position in the bone. The antirotation feature did not affect soft tissue closure. Hence, the hex dimension could be greater, and this additional height reduced the force on the abutment screw. In the static failure study of Boggan et al., the 1.7-mm internal hexagon had a greater load before failure than the 0.7-mm external hexagon.[54] However, it was less than the 1.0-mm external hexagon implants (see Table 28-1).

Platform Diameter

The platform diameter allows the abutment to seat on the implant crest module adjacent to the antirotational hexagon (external or internal). The tipping forces applied to the abutment form an arc with a radius from the outside abutment margin opposite to the force to the dimension of the hexagon on the same side of the force. The platform width resists the arc of rotation on the side opposite the tipping force. The narrower platform has a short fulcrum point and platform width and makes it more vulnerable to tipping forces. The wider the platform diameter, the more the resistance to the tipping forces. Therefore, the larger the platform diameter, the less force applied to the abutment screw.

In the Boggan et al. study, the force on the abutment screw was decreased by 12 units when the 0.7-mm hex height was increased to 1.0 mm. When the force on the screw was evaluated for a 4-mm-diameter implant compared with a 5-mm-diameter implant (with the same hex height), a decrease in force of 40 units was observed[54] (Figure 28-18). In other words, the diameter of the implant (and corresponding platform dimension) was more important to reduce the risk of screw loosening than the height (or depth) of the antirotational hexagon. In a clinical report by Cho et al., abutment screw loosening was observed during a 3- to 7-year period in 14.5% of 4-mm-diameter implants. When a 5-mm-diameter implant supported the prosthesis, the screw loosening was reduced to 5.8%.[58]

Larger-diameter implants with a wider platform should be used to decrease the force applied to the abutment screw whenever external force factors are greater than usual. Hence, a wider implant in the canine or maxillary central incisor single-tooth restoration is suggested for bruxing patients.

The parameters that affect the incidence of abutment and prosthetic screw loosening are variable from one patient to another because the external force factors are different. The doctors should consider factors such as preload, implant position, implant number, and implant diameter to reduce this complication. Other factors are related to the specific implant product selected to support and retain the prosthesis. These

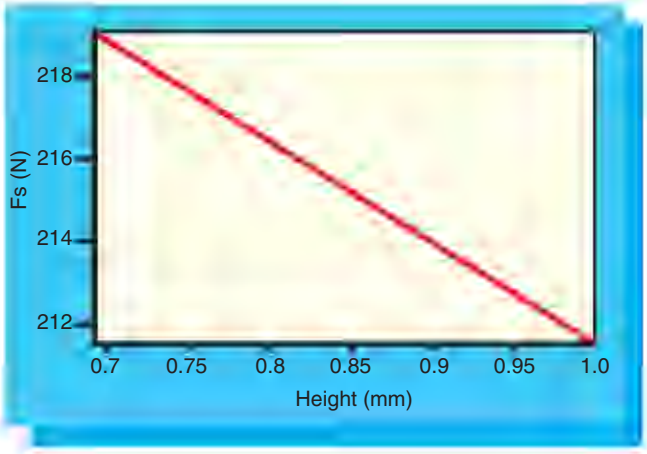


FIGURE 28-17. The higher (or deeper) the antirotational hexagon component (x component on the graph), the less the force applied to the abutment screw (Fs) on the y-axis. A 0.7-mm hexagon height is standard in the industry and was used first by Nobel Biocare. A 1-mm hexagon height has less risk of screw loosening because the force on the screw is decreased.

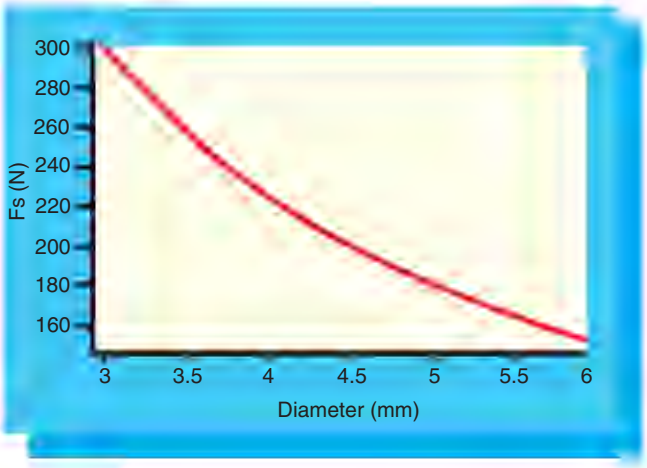


FIGURE 28-18. To reduce forces on the abutment screw, the platform diameter of the implant is more important than the hexagon height. The larger the diameter (*x*-axis), the less the force applied to the screw (*y*-axis).

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FIGURE 28-19. One option to retighten a loose abutment screw is to cut off the cemented crown, tighten the screw, and redo the crown.



FIGURE 28-21. A cemented crown on a screw-retained abutment is difficult to remove when the abutment screw becomes loose. In posterior crowns, an access hole to the abutment screw is prepared in the occlusal surface.



FIGURE 28-20. An orthodontic wire may be wrapped around the tooth below the interproximal contacts. The crown remover may then be attached to the wire instead of a subgingival margin.

include screw head design, thread design, metal composition, component fit, and screw diameter.

Method to Retighten Abutment Screws

A common complication of a threaded two-piece abutment is the loosening of the abutment screw from the implant body under a cement-retained crown, which remains luted to the abutment. Removing a cemented crown from a mobile abutment is often difficult. The impact force applied to the mobile crown is dissipated because of the loose abutment screw. In addition, when the crown margin is subgingival, it is difficult to engage with a crown remover.

One option to tighten the abutment screw is to cut the crown off, tighten the abutment screw, and redo the crown (Figure 28-19). If the dentist cannot engage the subgingival margin with a crown and bridge remover, an orthodontic wire may be wrapped around the tooth below the interproximal contacts (Figure 28-20). A crown and bridge remover may then use the wire to apply the impact force to the cement seal.

To solve this problem in the posterior regions of the mouth, the dentist may be able to drill an access hole through the occlusal aspect of the crown to gain access to the abutment screw (Figure 28-21). This procedure, however, may also damage the porcelain or the incisal edge of the crown and may mandate replacement of the crown.[59]

Screw-Retained Prostheses

Protection of the Prosthesis

A predictable surgical protocol for endosteal rigid fixation was developed and reported by Brånemark and Adell et al. more than 30 years ago.[55,56] However, on occasion, an implant may fail during the initial healing process from traumatic surgery, compromised healing, poor case selection, or unknown reasons. Patients understand that medicine is not an exact science and that their bodies may respond with individual variation to a standardized procedure. As a result, patients are more inclined to accept the implant surgical failure. To the contrary, after the implant is uncovered and the patient is told that it is successful, any short-term complications that lead to its loss or compromise of the implant often become unacceptable to the patient.

The patient rarely can evaluate the causes of implant surgical failure but on the contrary can assess several aspects of the prosthetic result, such as esthetics, occlusion, function, speech, and maintenance. The additional time, appointments, laboratory steps, and associated cost of inventive prosthetics required on poorly placed implants are not fully appreciated. Patients may believe that bone loss or implant loss resulted because the screws were too tight or too loose, the casting did not fit adequately, or the occlusion was incorrect rather than understand the original cause of poor bone quality or poorly angled implant bodies from the surgical phase. All of these factors complicate patient management for restoring dentists.[60]

The time required to remove a failed implant after initial healing and place an additional implant is often minimal and often may be accomplished at the second-stage surgical appointment. The time required to fabricate the prosthesis is usually five or more prosthetic appointments. An implant failure after final prosthesis delivery also may result in five additional prosthetic appointments and additional laboratory fees. In addition, an implant failure after loading may cause significant bone and soft tissue loss. As a result, replacing the implant may require bone and soft tissue grafting and additional time required

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before reimplantation. The patient may blame the restoring dentist for the associated bone loss after implant failure.

The restoring dentist usually educates the patient about the limitations of the restoration of a malpositioned tooth. Orthodontic treatment or extraction often is suggested with natural teeth rather than a compromised final prosthetic result. Yet, still too often, dentists consider implants successful with the sole criterion of rigidity. They often overlook an underengineered implant foundation with too few implants, improper implant placement in mesiodistal and buccolingual directions, an excessive sulcus depth, insufficient load-bearing surface area of the implant body, poor angulation, poor bone quality, unacceptable soft tissue contour and quantity, and the relationship of these to esthetic requirements and their influence on complications. Long-term acceptable criteria should be established, and the limiting factors should be identified before the prosthetic reconstruction to minimize the occurrence of complications related to the restoration, maintenance, or patient management.

The retention system of the prosthesis should be designed before surgery. In a screw-retained fixed prosthesis, anterior implants are to be placed more lingual than for a cement-retained restoration because the access hole to the prosthetic screw is placed in the cingulum. The correction of facially placed implants for screw-retained restorations may be more difficult and may lead to unmanageable esthetic compromises.

A cement-retained restoration should ideally have 8 mm or more of crown height space (CHS). This dimension permits at least 1 mm for occlusal material on the crown, 5 mm of abutment height for retention and resistance form (with a subgingival margin), a 1-mm subgingival margin, and 2 mm for a junctional epithelial attachment above the bone. If inadequate space is present, an osteoplasty of the bone is indicated before implant insertion. In other words, the restoring dentist should identify the type and contour of the restoration, including the type of retention system (i.e., cement or screw retained), early in the treatment plan and convey this information to the implant surgeon before implant placement. The surgical phase should aim at providing the best possible foundation to protect the long-term performance of the prosthesis.[61]

Advantages of Screw-Retained Prostheses

There are several advantages to a screw-retained prosthesis compared with a cement-retained restoration. These include ease and retrievability, low-profile retention, reduced moment forces with overdentures, reduced risk of residual cement, and splinting nonparallel abutments (Box 28-6). The retrievable benefits have been previously presented.

BOX 28-6 Advantages of Screw-Retained Prostheses

1. Ease of retrievability
2. Low-profile retention
   a. Limited crown height space
   b. Low-profile bar for overdentures
   c. Crown contour requirement
3. Reduced moment loads (overdentures)
4. No residual cement
5. Splinting nonparallel abutments

Low-Profile Retention

The primary advantage of a screw-retained superstructure is the lower profile retention of the abutment system. Cemented prostheses require a vertical component of 5 mm or more to provide retention and resistance form. A crown height reduction of 2 mm may decrease the retention as much as 40% when the implant abutment is only 4 mm in diameter.[62] The screw-retained system is more resistant to removal forces than the cement abutment when the abutment height is less than 5 mm. The prosthesis should be screw retained if the crown height does not allow sufficient abutment height and surface for cementation.

The CHS is measured from the crest of the ridge to the occlusal plane and is shorter in the posterior regions of the mouth because the space is closer to the hinge of the temporomandibular joint. The opposing landmarks in the posterior regions (i.e., maxillary sinus and mandibular neurovascular canal) limit the bone height for implant insertion and often contraindicate osteoplasty to improve the crown height. A minimum 8 mm of CHS is needed for a cemented prosthesis. Therefore, if the CHS is less than 8 mm, a screw-retained restoration should be considered. However, in such conditions, the space required to insert a screwdriver may be a limitation not appreciated until the prosthetic appointment.

Osteoplasty before implant placement can increase the abutment height to improve the retention of the cemented fixed prosthesis. However, the dentist must consider the decrease in implant body height. In addition, a gingivoplasty after osteoplasty almost always is indicated to decrease sulcular depth and improve oral hygiene conditions. The dentist also may consider placement of additional implants and abutments or a customized abutment to increase cement retention.

The low-profile abutment may also offer significant advantages for removable prostheses (RP-4 or RP-5). The lower height of the superstructure permits easier placement of denture teeth. The greater volume of acrylic also increases the strength of the acrylic portion of the restoration.

The more lingual position of implants in the mandible may interfere with the tongue. In these instances, a low-profile screw-retained restoration may be fabricated that does not compromise the lingual contour of the crown or overdenture. An abutment with reduced height may be required when the implant is positioned too lingual or palatal in the maxilla (Figure 28-22). A 5-mm or more high abutment may interfere with a tongue position or occlusion with the opposing arch. Therefore, clinical situations of short abutments are indicated for the use of a screw retention system.

Reduced Moments of Force

A screw-retained superstructure bar for a RP-5 overdenture (implant and soft tissue support) may be subjected to less moment forces during prosthesis movement. The moment force to the implant is reduced with a low-profile abutment when stress breakers on the superstructure separate the removable prosthesis from the implant support (Figure 28-23). These elements decrease the effect of lateral loads on the implant body and prosthetic screws.

Risk of Residual Cement in the Sulcus

Another advantage of screw-retained crowns is the absence of residual cement in the gingival crevice, which may cause irritation to the surrounding tissues and lead to increased plaque

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FIGURE 28-22. The implant position in this anterior mandible was lingual to the crown contour necessary to restore the patient. A low-profile abutment permits room for the tongue during speech and swallowing.



FIGURE 28-23. A low-profile bar has less moment forces applied against the implant–bar system when a soft tissue–borne, implant-retained overdenture is fabricated.



FIGURE 28-24. **A,** This maxillary restoration has implants placed more than 30 degrees from parallel. **B,** The implants may be splinted together to restore the edentulous arch with a fixed prosthesis.

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retention and inflammation, similar to an excess cement condition with crowns on natural teeth.[61]

When possible, the crown margin of a cement-retained prosthesis should be above the tissue so that cement excess can be readily removed. Subgingival margins increase the incidence of incomplete cement removal on teeth or implant abutments. The cement may remain embedded deeper into the sulcus of the implant abutment because of the less tenacious junctional epithelial tissue and the lack of connective tissue attachment compared with a natural tooth.

Nonparallel Implants

When implant bodies are unparallel by more than 30 degrees, an abutment for cement retention cannot be adequately prepared for a path of insertion. A low-profile screw abutment may engage the implant bodies at significant angles. For example, a pterygoid or zygomatic implant may be placed at 45 degrees from anterior implants, yet these implants may be splinted together with a screw-retained restoration (Figure 28-24). It should be noted that to splint nonparallel implants together with a screw-retained restoration, the antirotation feature of the implant body usually cannot be engaged. In addition, most often the abutment for screw has an external hex, so a wider platform dimension is available.

Therefore, greater low-profile retention, reduced moment force in RP-5 overdentures, greater space for denture teeth or occlusal materials, and absence of cement residues are advantages for screw-retained superstructures. Most of these conditions are more characteristic of implant-supported overdentures than fixed restorations.

An interesting note is that in the mid-1980s and 1990s, practitioners who challenged the concept of implant-supported, cement-retained restorations were regarded as a minority. Over the past decades, the profession has reassessed its position, and today most fixed prostheses on implants (≈90%) are restored with cement-retained restorations rather than screw-retained prostheses.[62,63]

Complications of Screw-Retained Prostheses

External Force Factors

External forces that act on a screw joint greatly increase the risk of screw loosening. These forces may be called joint-separating forces when related to screw loosening but are the same forces previously presented as risk conditions for implant failure, crestal bone loss, and component fracture. When screws are tightened and put on a desk with no separating forces, they will remain tight forever. When the external joint-separating forces

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are greater than the force holding the screws together (called clamping forces), the screws will become loose. Therefore, the external forces from parafunction, crown height, masticatory dynamics, position in the dental arch, and opposing dentition are the factors that can increase dramatically the stress to the implant and the screw joint. In addition, conditions that magnify these factors are considered, including cantilevers, angled load, and poor occlusal designs (Box 28-7).

External forces applied to the joint system are important to account for to decrease the incidence of screw loosening. For example, a study by Boggan et al. demonstrated that the force on the screw was related directly to the crown height.[54] The crown height is a vertical cantilever and magnifies the force on the abutment screw. Hence, a single-tooth implant in a patient with past periodontal bone loss and greater crown height is at greater risk of abutment screw loosening.

Fatigue is related to the amount of the force and the number of cycles (Figure 28-25). There is a force magnitude so great that one cycle can break the material (e.g., a hammer hitting a piece of glass). There is an external force that is so low that an infinite number of cycles does not fracture the material (e.g., tapping on a piece of glass with your finger). The endurance limit of a material is the amount of force required to fracture the object when enough cycles are applied (e.g., bending a wire—the first bend does not fracture the wire, but repeated bending over time will fracture the wire). The greater the force, the fewer cycles before fracture. Hence, it is the combination and relationship of both the amount of force and the number of cycles that causes the complication.

BOX 28-7 External Forces That Increase Screw Loosening

1. Parafunction
2. Crown height space
3. Masticatory musculature dynamics
4. Arch position (anterior, middle, posterior)
5. Opposing arch
6. Cantilevers
7. Angled loads
8. Poor occlusal designs
9. Lack of key implant positions
   a. Canine
   b. First molar
10. Inadequate implant number
    a. No three adjacent pontics
11. Nonpassive prostheses

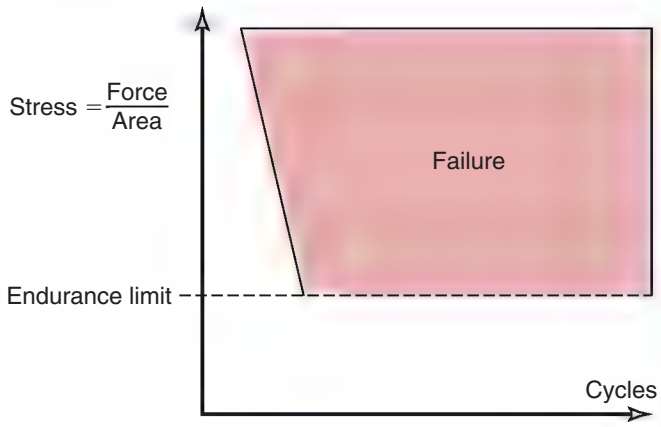


FIGURE 28-25. A fatigue curve is related to fracture or screw loosening. The incidence of complications increases as the force increases or the cycles increase (when above the endurance limit).

Of all the external forces, the primary factor is parafunction. A horizontal bruxing patient is loading the implant crown with an angled force repeatedly and increases the magnitude of force, cycles to fatigue failure, and the angle of the force that places shear on the interface. Abutment screw loosening can be expected in a patient with a severe bruxing habit. A parafunction patient increases the amount of force to the system and, as important, increases the number of cycles to the system. Hence, fractures of porcelain and cement seals and screw loosening or fracture are inevitable. When the adjacent natural teeth are mobile to lateral or angled forces, the rigid implant and implant crown may be overloaded. A heavy bite force occlusal adjustment, which allows the adjacent teeth to move before implant crown contact, is required to reduce the risk of overload.

Partially unretained restorations are more common with screw-retained superstructures than with cement-retained prostheses. The screw loosening is most likely to occur during the first year and may occur 8% to 20% of the time.[25] Screw loosening of abutment or prosthetic screws occurs more often on individual implant crowns than when implant crowns are splinted together. For example, in a report for single molar replacement, abutment screw loosening rate was 40% during a 3-year period. When two implants were splinted together, the screw loosening was reduced to 8%.[24] Screw loosening is more common with fixed prostheses in partially edentulous patients and is far less common with implant-retained overdentures fabricated with stress relievers on the superstructure.[64,65]

Conditions that lead to excessive occlusal loading increase the risk of abutment and prosthetic screw loosening. Any of these external forces applied to a cantilever will further magnify the joint-separating forces. For example, cantilevers on prostheses lead to uneven occlusal loads. Uneven occlusal loads cause repeated cycles of compression and then tension and shear of implant components. Screws are especially vulnerable to tensile and shear forces. Both of these are dramatically increased with cantilever forces or angled loads. Because the screw is an inclined plane, the continued vibration causes it to unthread. The greater the range of external forces, the fewer the number of cycles before screw loosening.

Occlusal loads can have a cumulative effect on the preload, and the screw material may go into plastic deformation, therefore exceeding the yield strength of the material.[66] When the force exceeds the yield strength, plastic deformation occurs, and the screw begins to deform. This material deformation causes the screw to loosen and leads to potential failure of the device.

Screw loosening is also affected by the amount of the force and the number of cycles and is similar to fatigue. External methods to limit screw loosening include factors that reduce the biomechanical stress. These include key implant locations, sufficient number of implants, passive frameworks, and adequate occlusal schemes[37] (see Box 28-7).

Passive Screw-Retained Prostheses

Common causes of screw-retained implant prostheses' short-term implant failure or complications often stem from nonpassive superstructures or partially retained restorations.[54-58] These conditions magnify forces on the part of the implant system that is still retained and lead to bone loss, implant mobility,

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component fracture, or the need to repair the prosthesis.[67] These complications have a greater incidence with screw-retained restorations compared with cement-retained restorations because cement-retained restorations are more passive and have less strain on the implant system.[68] Although a cement-retained restoration is often preferred, screw-retained restorations are indicated when low-profile retention is necessary on a short abutment or when the implant bodies are more than 30 degrees from each other and splinting is required to restore the patient.

Screw loosening and partially unretained restorations are common complications of nonpassive castings. The more passive fit on the implant abutment for screw retention and the more controlled the occlusal forces, the more secure the fixation device. The repeated compressive and tensile forces from nonpassive castings under occlusal loads cause vibration and loosening of the screw components. Hence, accuracy in design and fabrication of the metal superstructure are determining factors for the reduction of forces at the implant abutment and implant-to-bone interface.

Passive screw-retained restorations are more difficult to fabricate than passive cement-retained restorations. When the screw is threaded into position, the superstructure may distort, the implant may move within the bone, or the abutment screw may distort. The distortion of the superstructure and implant system may reach a level such that a 500-micron original gap may not be detectable.[69] As a result, the casting may appear to fit the implant abutment for screw retention. However, the superstructure, bone, and components do not bend beyond their elastic limit, and compression, tensile, and shear forces are placed on the bone-to-implant interface.[70,71] The bone must remodel to eliminate these forces.[72] If the forces are beyond physiologic or ultimate strength limits, resorption of the bone-to-implant interface occurs. As a result, greater crestal bone loss has been associated with nonpassive castings. Creep (a constant force applied over time on a material) or fatigue also can contribute to fracture of the components over time because of a constant load or cyclic load frequency.

Truly passive screw-retained prostheses are virtually impossible to fabricate.[9,65,73] Almost no tolerance for error is possible in the fabrication of the prosthesis because a direct metal-to-metal connection exists, and many variables are not in the control of the doctor. Originally, the term *passive fit* was used in implant dentistry to describe a prosthesis fit compatible with the ability of the body to adapt adequately and remodel to the stimulus. Passive fit was described by Brånemark to be ideally in the 10-micron range.[57] The definition has evolved to describe a clinically acceptable fit in which stress and strain conditions are within the physiologic range and in which the implant remains undisturbed when the prosthesis is screwed into place.

Ideally, the screws in the final position place compressive, tensile, and shear forces that are limited to the coping, implant abutment and screw, and hold the prosthesis securely in place (Figure 28-26). Because no space exists between the coping and implant abutment, the casting must fit passively and accurately before the screw is inserted with a considerable torque force. Elastic deformation of impression materials (dimensional shrinkage), stone expansion, analog variance, wax distortion, investment expansion, metal shrinkage, acrylic or porcelain shrinkage, soldering inaccuracies, and the manufacturer variance of a number of implant components interrelate in the fabrication of completely passive superstructures, yet they are not controlled directly by the dentist[73] (Box 28-8). The restoring dentist can attempt only to minimize the errors in the fabrication process. This forms the basis for the discussions in this chapter.



FIGURE 28-26. When a screw-retained restoration *(yellow)* is fixated in place, compressive, tensile, and shear forces are present with the screw components *(blue)*.

BOX 28-8 Factors Influencing the Fabrication of a Passive Splinted Casting Prosthesis

1. Custom tray material
2. Impression material (dimensional variation)
3. Stone expansion
4. Wax distortion
5. Investment expansion
6. Metal shrinkage
7. Acrylic or porcelain shrinkage
8. Manufacturer variance or tolerance
9. Component variance
10. Analog variance
11. Technique

Passive Castings

Ideally, when a prosthesis is retained by prosthetic (coping) screws, the restoration passively sits on top of the abutments, and the prosthetic screws fixate the two components together. The screws place a compressive, tensile, and shear force on the abutments, but no force is transmitted to the implant bodies. If the casting of the prosthesis does not sit passively on the abutments for screws, the force of the prosthetic screws are then transmitted to the implant bodies (Figure 28-27).

A screw is a combination of inclined planes and wedges and is one of the most efficient machine designs. A torque force of 20 N-cm applied on a screw can move two railroad cars. This same force applied to a nonpassive casting tends to distort the superstructure, underlying bone, and implant components (Figure 28-28). Because the force is constant, it can introduce biomechanical creep into the system, which can fatigue materials and bone. An implant does not predictably move within bone, yet retained stresses from nonpassive castings must be accommodated through a bone remodeling process.

When the screw-retained prosthesis is attached to the abutment for screw retention of the implant, no space exists between the crown and abutment. Instead, a metal-to-metal system with zero tolerance for error is created. Nonpassive screw-retained restorations may create permanent strain conditions on the

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FIGURE 28-27. When the prosthesis is not passive *(yellow)*, the compressive tensile and shear forces are directly applied to the implant system (i.e., abutment, implant body, abutment screw, marginal bone, implant–bone interface).

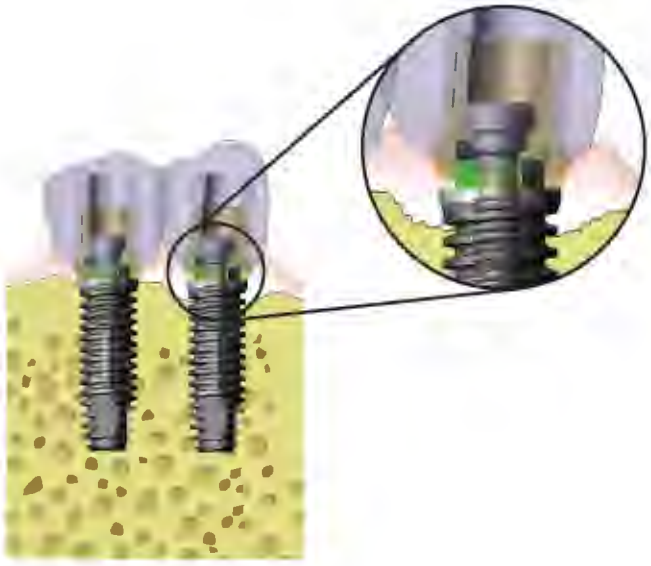


FIGURE 28-28. Nonpassive or improperly seated screw-retained restorations may be distorted when seated into position when the prosthetic screw is threaded. The distortion of the superstructure causes stresses that are concentrated at the crestal bone level and may cause bone loss.

implant system that can be many times greater than those of cemented prostheses. The microstrain applied to the bone may fall beyond the overload zone and into the pathologic zone in which bone remodeling occurs with crestal bone loss or even implant failure.

Nonpassive castings are a primary cause of unretained restorations, crestal bone loss, implant component fracture, and implant mobility.[67] A truly passive screw-retained dental restoration is virtually impossible to fabricate on multiple splinted implants.[74] Too many variables are out of the dentist's control when attempting to fabricate a prosthesis with zero tolerance for error, and laboratory procedures may lack the precision needed for such an exact result.

All impression materials shrink while setting.[75] For example, whereas polysulfide materials shrink 0.22%, addition silicone (polyvinyl siloxane) shrinks 0.06% at 24 hours.[76,77] Shrinkage may be clinically relevant because implant analogs used in the impression for a screw-retained restoration do not compensate for the dimensional change of the impression material, and the dimensions between and around them are affected by the shrinkage of the material (Figure 28-29).

Dental stone expands 0.01% to 0.1% and does not correlate to the dimensional changes of impression materials.[78-80] In addition, the wax patterns distort while setting or spruing, and the investment material expands[79] (Figure 28-30). The metal castings shrink when cooled, and the shrinkage does not permit an accurate metal-to-metal connection.[81-83] The metal superstructures are often thicker and larger in implant prostheses than in traditional prostheses because the implant abutment is of reduced diameter and bone loss volume often is replaced by the final prosthesis. Dimensional changes during metal work fabrication are correlated directly with the size of the casting.[84,85]

The marginal fit and tolerance between the implant analog and implant abutment are often different from actual implant and abutment components.[86] Implant components are not all fabricated to exact dimensions, and each transfer of an implant component has a slightly different size, which leads to misfit and is magnified by the number of different pieces used during the fabrication steps.

Full-arch restorations more often are not passive despite an acceptable metal try-in because the volume of porcelain or acrylic shrinkage may have caused material distortion. Porcelain and acrylic shrinkage also is related directly to material volume and may distort the superstructure even though the superstructure was initially passive.[79]

As a result of all of these variables, implant prosthesis distortions ranging from 291 to 357 microns may be observed during the fabrication of the restoration.[84] Passive final restorations are highly unlikely when more than two implants are splinted together and support a prosthesis with screw retention as the method of fixation. If a casting has a 50-micron misfit, the casting and implant may have to move 200 microns before the system is completely passive (Figure 28-31). This is a considerable risk relative to crestal bone loss, loose prosthetic screws, and implant failure.

In a study by Strong and Misch, a screw-retained bar was fabricated on five Nobelpharma implants placed in a simulated anterior mandible made of polymethylmethacrylate with a hardness factor of D1 bone density.[73] Three different impression materials and two different dental stones were used (with both direct and indirect impression procedures). The castings were cast with precious metal. After 100 castings were fabricated, the most passive bar (retained with 10 N-cm) moved every implant from 3 to 8 microns (Figure 28-32). This provides a visual report that screw-retained restorations immediately load implants enough to distort the bone–implant interface, which makes the casting appear as clinically passive.

The "clamping down" while tightening the prosthetic screws of an inaccurate structure may lead to screw loosening and fracture.[87,88] After prosthesis delivery, an abutment for screw retention or prosthesis screw may loosen between appointments.[89] This usually indicates that the casting is not seated passively, yet the cause often is overlooked. Instead, the screws are tightened again (often with more torque), and the bone must remodel to release the strain in the implant system. This strain may lead to crestal bone loss and even implant failure.

Passive castings represent a considerable advantage for cemented prostheses.[88,90] Stone dies are often used for cemented prostheses, and the expansion of the stone makes the casting more passive. In addition, die spacers on the stone dies help

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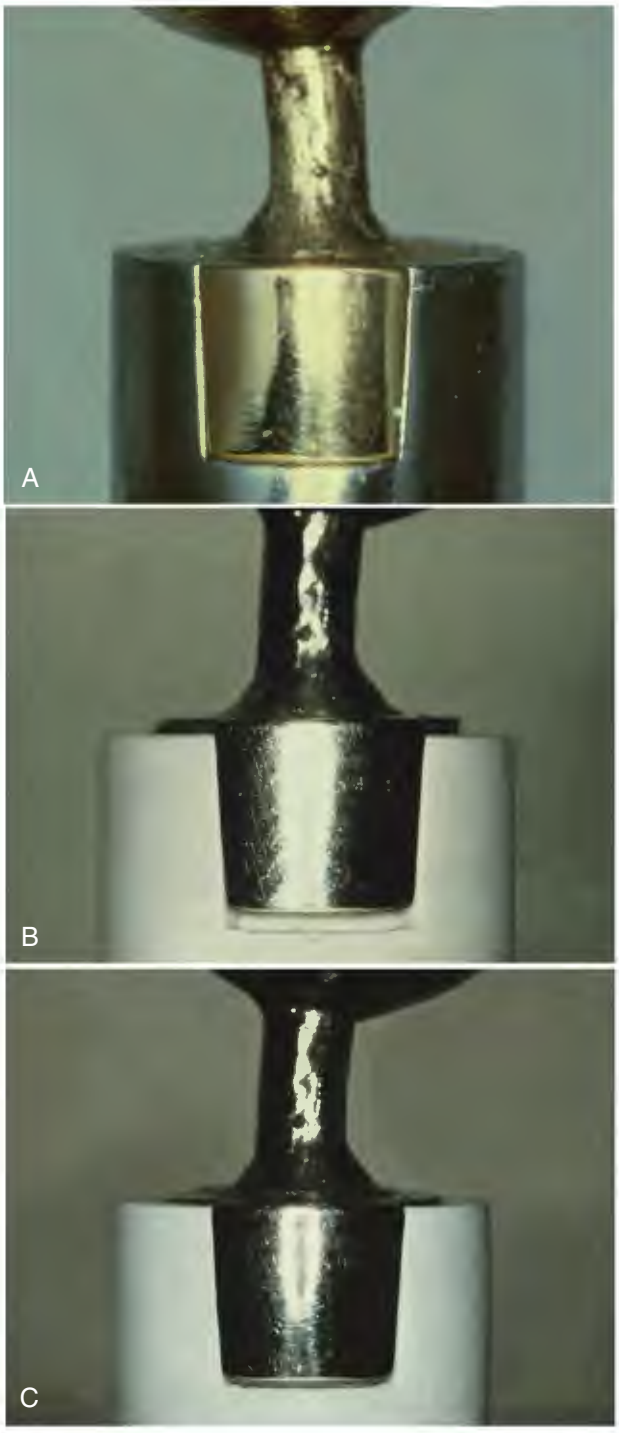


FIGURE 28-29. **A,** A male and female component were fabricated to fit together precisely. The axial walls are tapered slightly so that one may evaluate the accuracy of fit. An impression was made of the female component with different impression materials, which were poured 24 hours later. **B,** When polysulfide was used to make the impression of the female component, the male insert did not fit precisely. The shrinkage of 0.22% for the material is primarily responsible for this lack of fit. **C,** When the impression of the female component was made with additional silicone (polyvinyl siloxane), the male fit precisely into place with no visual discrepancy.



FIGURE 28-30. Wax patterns of a substructure may distort as the wax cools during fabrication or during spruing.

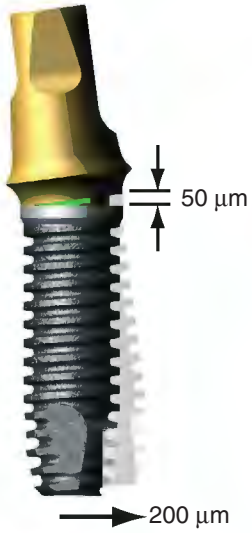


FIGURE 28-31. A 50-micron misfit may require the implant to move 200 microns at the apex before the system is completely passive.



FIGURE 28-32. In a study by Strong and Misch, 100 screw-retained bars were made using various techniques, impression materials, investment materials, dental stones, and metals.[22] The five implants were retained in a D1 bone simulant. With a 10–N-cm force on the prosthetic screws, every implant moved 3 to 8 microns with the most passive casting.

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create approximately a 40-micron cement space that compensates for some of the dimensional variation of laboratory materials and permits the fabrication of a more passive casting with cement-retained restorations. This cement space even may extend to the margin of the restoration because cement fills the space, and decay is not a consequence with implants.

Impression Procedural Steps

Multiple impression techniques have been proposed for the production of a master cast replica that is as accurate as possible, although none has proved absolutely precise. Regardless of the technique advocated, the principles described in the following paragraphs can be applied.[91-99]

Impression Materials

The four categories of elastic impression materials are polysulfide, condensation silicone, addition silicone (polyvinyl siloxane), and polyether. To date, no impression material is completely accurate.[100-105] The amount of permanent deformation and dimensional changes of impression materials are critical factors in the generation of passive castings.

Dimensional Changes

The dimensional change of the impression material from 2 minutes after it leaves the mouth to 24 hours later is an important property. The amount of change can be used as a yardstick to evaluate other properties of the material. All elastic impression materials shrink after they are removed from the mouth. The rate of shrinkage is not uniform. In general, about half of the shrinkage occurs during the first hour after removal from the mouth. Therefore, the greatest accuracy occurs if impressions are poured soon after they are made. Polyethers absorb water, which increases dimensional change, and thus should not be stored in this medium. In addition, most impression materials continue to change after the 24-hour period. The exception to this rule is addition silicones, which are stable and may not change for many days.[106,107]

The greatest dimensional change occurs with condensation silicones (Table 28-2), which exhibit more than a 0.5% dimensional change. This change is clinically relevant. Superstructures fabricated from these models will be less precise. Therefore, use of condensation silicone should be avoided. Polysulfide has about half the amount of shrinkage as the condensation silicones (0.2%). This also may be clinically relevant. Polysulfide continues to shrink dramatically after 24 hours. Therefore, pouring of the impression as early as possible is strongly advised.

In a study comparing tray and impression material performance over time, addition silicone impression materials exhibited the longest stability, with up to 720 hours.[105] Although varied results have been published, the vast majority of studies appear to conclude that the least amount of dimensional change occurs with addition silicones (0.06%) and polyethers (0.1%).[108-112] Therefore, use of these materials to make the final impression for a screw-retained restoration is strongly suggested.

Permanent Deformation

Permanent deformation is measured by the manufacturer with a 10% compression of an impression for 30 seconds after setting is complete.[108] Permanent deformation of impression materials in implant dentistry may be a concern when the impression distorts from the undercut region of the indirect impression transfer coping during the removal of the impression from the mouth. Sixty percent of the deformation found in the material may occur when an elastomeric impression is removed from structures having 1-mm undercuts in height and depth.[113] The material distorts out of the undercut but may not return to its original position next to the transfer pin.

As a consequence of permanent deformation, the receptor hole for the impression coping may be permanently larger than the original dimension. Permanent deformation has been measured as almost 3% for polysulfide impression materials and 0.07% for addition silicone[96-116] (see Table 28-2). Distortion of the impression was a consistent result in a study of indirect and direct impression transfer copings as a result of transfer manipulations.[97]

The indirect impression transfer copings remain in the mouth when the impression is removed and are replaced into the impression before pouring the working or master cast (Figure 28-33). The greater the permanent deformation, the less retentive the impression pin and the more variable its position in the distorted receptor site.[117] As stone is vibrated around the indirect transfer, the attached abutment analog may move, and the final position is not accurate relative to the intraoral abutment position.

Another source of impression transfer error may occur when the impression is made. An air bubble inadvertently may be present on the top of the transfer coping; as a result, the transfer

TABLE 28-2
Setting Properties of Elastic Impression Materials

	Permanent Deformation (%)	Dimensional Change at 24 Hours (%)
Polysulfide	3.0	0.22
Silicone		
Condensation	0.4	0.58
Addition	0.07	0.06
Polyether	1.1	0.10



FIGURE 28-33. Indirect impression transfers are inserted intraorally, and a closed-tray impression is made. These transfers then are removed, connected to an implant analog, and reinserted into the elastic impression material.

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may be reinserted into this void beyond its initial position. Some manufacturers have incorporated a screw hole or slot in the top of the transfer coping, which should be blocked out before making the impression. Otherwise, the positive replica in the impression may prevent the indirect transfer from seating completely in the impression before the pouring of the master model.

The effect of permanent deformation or inaccurate placement of the indirect transfer coping in the impression may be eliminated by using a direct impression transfer coping for the final impression (Figure 28-34). The direct impression transfer is not removed from the final impression before the master cast is fabricated but is designed to be held rigidly while the stone is poured into the impression. Therefore, the use of a direct impression transfer coping eliminates two sources of error and is strongly encouraged for screw-retained prostheses.[91-93,98,118] A common technique is to connect the direct impression transfers with acrylic before making the impression. However, the practice of joining transfer copings with resin has not been proved as a definite advantage.[97] In fact, the shrinkage of resin may cause the implants or components to move closer together before the final impression process.

Custom Impression Tray

A custom tray provides the advantage of a uniform thickness of impression material. As a result, the use of a custom impression tray minimizes error in interabutment distance and cross-arch distortion compared with stock impression trays.[119-121] In a study by Gordon et al., the cross-arch measurement change of metal die positions was 0.6% for a stock tray compared with 0.1% for a custom tray[119] (Figure 28-35). This is clinically significant for a full-arch screw-retained prosthesis.

The technique for a full-arch edentulous patient with implants captures both the soft tissues and implant positions. A working cast is first fabricated from a preliminary impression made with a closed tray and indirect impression transfer copings at the stage II implant recovery, suture removal, or first prosthetic appointment. When addition silicone is used for the preliminary impression rather than irreversible hydrocolloid, the dental laboratory may pour the impression at a later date. The laboratory attaches implant abutment analogs to the indirect transfer copings and reinserts the components into the impression before pouring the cast. A working cast is poured with dental stone.

The indirect impression transfers in the cast are replaced with direct impression transfers (Figure 28-36). Wax or clay is placed around the direct impression transfers to create approximately a 3-mm space and 1-mm space with a soft tissue stop in edentulous regions. The 3-mm space permits the transfer to be positioned in the mouth at any rotational position before making the final impression.

Cold- or light-cured acrylic may be used to fabricate the open custom tray. The tray is placed over the regions of the wax spacers and permits the long fixation screws to protrude through the top of the tray (Figure 28-37). The open custom impression tray fabricated of cold-cured acrylic must be made 24 hours or more before the final impression. During this time, the tray distorts and changes dimensionally because of monomer evaporation.

If the custom tray cannot be fabricated more than 24 hours before the final impression, two options are available. The tray

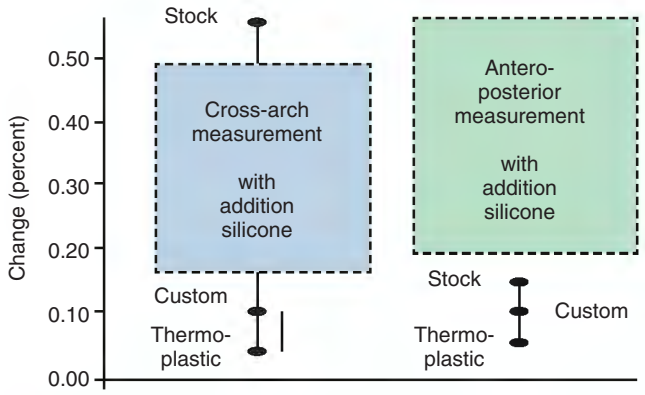


FIGURE 28-35. In a study by Gordon et al.,[124] the cross-arch measurement changes for metal die positions or anteroposterior positions were greatest for a stock tray.



FIGURE 28-34. Direct impression transfers have two components, including a long fixation screw. An open-tray impression is made and the fixation screws are unthreaded before the impression is removed from the mouth.



FIGURE 28-36. A custom tray is made from the indirect transfer impression. The indirect impression transfers (see Figure 28-33) are replaced with direct impression transfers in the cast before fabrication of the custom open tray.

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FIGURE 28-37. The custom open tray is fabricated so that the long fixation screw of the direct impression transfers goes through the occlusal surface of the tray.



FIGURE 28-38. The body of the direct impression transfer remains in the open-tray impression, and this minimizes positioning errors when the cast is poured.

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may be inserted into boiling water for more than 15 minutes to remove the excess monomer to eliminate the distortion. An alternate procedure is to use light-cured acrylic materials to fabricate the impression tray, and it can then be used immediately afterward for the impression without the problem of additional distortion.[122]

The two-piece direct impression transfer pin should be screwed firmly into the abutment for screw (or implant body) in the patient's mouth to ensure complete seating without placing too much shear force on the implant–bone interface. The open tray is inserted and evaluated for overextension and so on before the impression is made. An adhesive is then used in the custom impression tray for retention of the elastic material and to control the direction of polymerization shrinkage. A rigid addition silicone, or polyether, is the impression material of choice for the final direct transfer impression.

To increase the working time of addition silicone impression material, it may be stored in the refrigerator. The working time may be increased by two times if the temperature is 20°C rather than 37°C. Addition silicone is more temperature sensitive than any other impression material. After the impression material is set, the transfer abutment screw is unthreaded from the abutment screw retention. The impression is removed and incorporates the direct impression copings (Figure 28-38).

Analog Variance

The abutment for screw retention usually is fabricated in titanium or titanium alloy. The transfer coping and the implant abutment laboratory analog often are made of titanium, stainless steel, aluminum, or brass. As previously stated, manufacturers often do not machine transfer copings and implant analogs with the same plus or minus variance as the actual abutment for screw retention. As a result, the analogs may not be an accurate representation of the abutment for screw retention in the mouth[42,47,49] (see Figure 28-15). Threads inserted into brass or aluminum analogs also can distort, and the transfer pin may not be seated completely. The dentist must take care to ensure that the implant abutment analog is flush and properly seated with the direct impression transfer coping before the stone is poured. A 20-micron variance in the final position of the transfer coping has been reported.[93]

If the final prosthesis is to be connected to the abutment, the analog used should represent the abutment for screw retention, not the implant body. Some implant manufacturers suggest that impression transfers should always be of the implant body. An implant body analog is transferred to the master model, and the abutment for screw is selected and placed in the cast by the laboratory. The advantage of this approach is that the laboratory selects the abutment, so there is a reduction of inventory for abutments for screw retention by the dentist. Because these abutments may range from 3 to 6 mm in height, this may represent a significant overhead cost. However, this procedure may introduce another factor of error because the two transfers are made in the dental laboratory.

On occasion, in case of limited CHS, the restoration may be designed to directly connect to the implant body. An implant body impression is then indicated under these conditions. No abutment for screw retention is used in the implant prosthetic system. Instead, the prosthesis is connected to the implant body. It should be noted that when this is the desired effect, the implant body should have an external hexagon as the antirotational component. The prosthesis does not engage the hexagon, but the platform dimension is greater on the external hex and more easily permits direct fixation.

Stone Expansion

The master cast for a screw-retained restoration presents different requirements compared with a cement-retained restoration. A space is desired in a cemented prosthesis between the abutment for cement retention and the prosthesis. The space is occupied by cement and permits complete seating of the prosthesis when cement is placed into the coping. The space is about 40 microns but may be larger, especially in regions above margins. Therefore, stone expansion is of benefit for a cement-retained restoration. In addition, a die spacer is added to the surface of the die before fabricating the coping.

The cement-retained restoration is usually fabricated on dies composed of the actual die stone. This requires a hard material able to resist abrasion and fracture. As a general rule, the harder the dental stone, the greater its setting expansion. Die stones are harder than dental stone and are less likely to break or be altered during the laboratory process. Gypsum die

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material (American Dental Association [ADA] product classification IV) expansion usually ranges from 0.01% to 0.1%, depending on the manufacturer.[123] The addition of hardeners such as colloidal silica and cyanoacrylate further increases the setting expansion (e.g., Die-Keen [Heraeus-Kulzer, Hanau, Germany] is 0.2%).[124-127]

In the master cast for a screw-retained restoration, metal analog components represent the abutment for screw retention. As a result, surface hardness of the die stone is not critical, but the expansion percentage is because it may alter the interabutment distance[128,129] (Figure 28-39). Because all impression materials shrink, the dental stone should expand to compensate for the dimensional change.[130] Because addition silicone or polyether shrinkage is 0.1% to 0.06%, the expansion of the die stone should be in a similar range. The expansion of dental stone (ADA product classification III) varies by product but as a general rule exhibits less expansion than die stone (ADA product classification IV).[123]

Epoxy resins have properties comparable to those of gypsum with the added benefit of increased compressive strength, abrasion resistance, and detail reproduction. However, epoxy resins shrink, rather than expand, at a range of 0.2% and should not be used for screw-retained master casts.[131] The doctor and laboratory should be aware of the properties of the impression material and stone and should attempt to use products that tend to compensate for each other.[132]

The dental laboratory should follow manufacturer-suggested guidelines for the weight of material and amount of distilled water to use in mixing the dental stone. Decreasing the amount of water causes an increase in expansion.[133] A vacuum mix provides a more consistent, denser master cast. Polyether or addition silicone is suggested for the impression, which then is poured in ADA classification III dental stone, which expands a similar amount as the impression material shrinks.

Acrylic Shrinkage

Processed methylmethacrylate shrinks about 7% in volume and as much as 18% when cold cured, especially with excess monomer, and some studies suggest that the shrinkage may continue up to 180 days.[123,133,134] The actual change in final dimension is related to the amount of material cured at one time. Therefore, the salt-and-pepper "sprinkle on" technique often is indicated for baseplates so that smaller volumes cure each time, minimizing dimensional changes.[135]

In the laboratory, the direct impression copings are connected to the abutment analogs after pouring the cast and before making the baseplate (Figure 28-40). The baseplate is then fabricated so the connection between the transfer coping and abutment is visible. In this way, the baseplate may be used for the wax-rim and as a verification jig to confirm the impression was accurate (Figure 28-41). The acrylic connecting these metal analog units cannot change the abutment position in the stone (unlike in the bone) because they are incorporated into stone even though some acrylic shrinkage occurs around them. As a result, baseplates and verification jigs may be fabricated from acrylic fabricated on stone casts.

The acrylic shrinkage concern regarding the baseplate and wax-rim as a verification jig is also a concern when the final impression is made. The use of intraoral autopolymerizing acrylic to join implants before direct impressions is a popular technique, yet this may move the abutment from its original position during acrylic setting. Acrylic resin patterns tested on implant master casts around gold cylinders yielded shrinkage results in all dimensions.[136] Light-cured material shrinkage is in the range of 4%, and although less than for cold-cured acrylic resin, it is still appreciable. Clinical experience demonstrates



FIGURE 28-40. The direct impression transfers are reattached to the abutment analogs after the dental cast is set.



FIGURE 28-39. The direct impression transfer coping impression is poured with a dental stone or die stone that has an expansion similar to the impression material shrinkage.



FIGURE 28-41. A baseplate and wax-rim or verification jig are fabricated on the final cast using the direct impression transfers.

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that patients often are able to feel the shrinkage pressure effect on natural teeth during the intraoral setting of an acrylic provisional restoration and with acrylic splinting of the transfer copings. A study performed to evaluate the specific implant movement during this procedure concluded that a greater deviation occurred with the splinted technique than with the unsplinted technique.[137] Therefore, routine clinical practice is not to connect the impression transfers in the mouth before impression making.

Acrylic (or porcelain) shrinkage is also important to consider when the final fixed prosthesis is fabricated of acrylic resin and metal. Acrylic gains strength with bulk, and considerable amounts of resin may be used in the implant prosthesis. The processing of the denture resin may distort the metal substructure. As a result, even though the casting was passive at the metal try-in appointment, the final restoration may not be passive.

Long spans or narrow metal superstructures are at greater risk of distortion from acrylic shrinkage because the flexibility of the metal is related to the cube of the distance or to the thickness of the metal. For example, a 10-mm span of metal may flex 6 microns, but a 20-mm span will flex 97 microns when all other conditions are similar. Prostheses with metal occlusals may exhibit less shrinkage when porcelain or acrylic is added to the final restoration because less bulk of acrylic material is introduced and a greater metal volume is present to resist the acrylic or porcelain shrinkage.

Wax Distortion

The lost wax technique is the preferred technique for cast restorations.[123] ADA wax specifications allow for a maximum of 1% flow at 30°C to 90% maximum at 45°C.[138] In addition, linear expansion may reach 0.7% with an increase in temperature of 20°C, and shrinkage of 0.35% may occur when cooling from 37° to 25°C.[139] The casting shrinkage is inversely proportional to the flow of the wax pattern. After the wax pattern is fabricated by the technician, several additional conditions may lead to wax distortion. As the wax is heated and cools, residual strain may build up within the material. When the wax pattern is removed from the abutment for screw and sprued before casting, the strain may be released and distort the pattern (see Figure 28-30). Handling of the wax patterns also may distort their accuracy, especially in full-arch restorations. Screw-retained castings may be more accurate and passive when fabricated in smaller sections to reduce this distortion.

The precision of fit of the final casting is affected not only by the softening temperature of the wax but also by the investment properties. An investment material with thermal or hygroscopic expansion is indispensable to compensate for the shrinkage related to superstructure fabrication.[140,141] The expansion of the investment material is highly technique sensitive.

The size, shape, temperature, and manufacturer type of the casting ring and the position of material within the ring affect the final dimensions of the metal casting.[123] As a result, the final casting may be larger or smaller than the original wax pattern (which also may distort). A study by Carr and Brantley on full-arch implant framework accuracy showed that investment material, liquid concentration, completeness of mold fill, and investment mold shape are critical factors in the accuracy of the casting.[53] A larger casting ring is suggested for castings of thick patterns (e.g., large implant metal frameworks) or wax with high strength, high softening temperature, and low-flow percentage[141] (Figure 28-42).



FIGURE 28-42. The casting ring size and investment expansion may be another source of dimensional change and result in a nonpassive casting.

Metal Casting Shrinkage

The problems associated with metal shrinkage during the casting process have been a concern for many years in traditional cement-retained fixed prosthetics.[142] The range of precious metal shrinkage varies depending on manufacturer and technique but approximates 1.5%; shrinkage of semiprecious alloys may be twice that amount.[143,144] In a study by Misch, 50 paired castings of precious and nonprecious metal were made for five implant-supported screw-retained prostheses. Not one of the nonprecious castings was passive on the models. Therefore, precious metals should be used for screw-retained prostheses. Type IV dental alloys with high-yield strength (needed to resist occlusal forces), high-fusing alloys (e.g., high palladium alloys), or low-fusing high gold alloys typically are used.[144-146]

Precious metal is also preferred for the superstructure casting because metal corrosion in direct contact with titanium is reduced, accuracy of the casting is improved, and separation and soldering (if required) are less technique sensitive. *High nobility* means resistance to tarnish and corrosion. During superstructure casting, separation of the castings and soldering periodically are required to obtain a more passive casting.[147] Advantages of casting the superstructure in one piece are less laboratory time and maintenance of work-hardening properties.[95] However, regardless of the other variables, values of all one-piece castings in vitro exceeded by 10 times the requirement for passive fit (mean error of 0.130 mm) and led Carr and Brantley to the conclusion that one-piece castings are not satisfactory.[53] Decreased bone strains have been measured when superstructures have been soldered or laser welded.[124-127,148-150] Casting a few units together and laser soldering usually provide a more passive casting than casting a large section in one piece[118] (Figure 28-43).

A one-piece casting may be indicated if the span of the substructure is short and thermal expansion for the investment is used because fewer soldering steps produce fewer errors. However, large castings in volume or distance for screw-retained restorations should be fabricated in sections because of the highly variable dimensional changes during fabrication and casting.[148-151]

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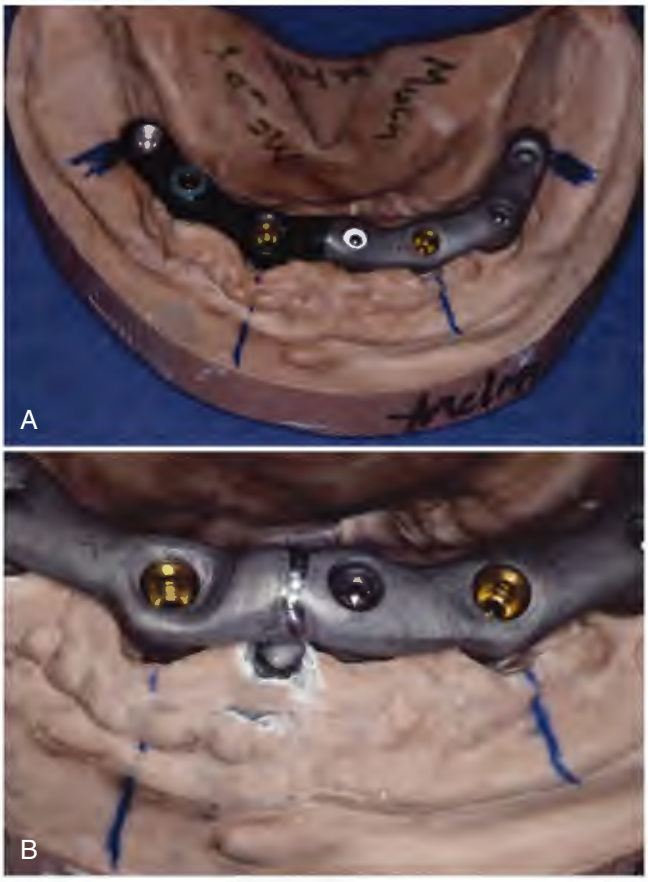


FIGURE 28-43. **A,** Metal shrinkage may lead to a nonpassive casting. When the bar is fabricated in two or more sections, the volume of metal is reduced, and the amount of shrinkage is minimized. **B,** When the casting is made in sections, it then may be laser soldered together. The two-step cross-section results in a stronger union than when the sections are split in one dimension.



FIGURE 28-44. When a casting rocks, it is not passive. Rocking side to side means that the most distal abutments are not passive. Forward and back rocking indicates that the center abutment is not passive.



FIGURE 28-45. A nonpassive casting is separated with a thin disk. The dimension of the cut should be thinner than a playing card (0.005–0.008 inch).

Porcelain Shrinkage

Porcelain shrinkage of approximately 20% occurs during the firing process and may distort the metal superstructure. This shrinkage is related to material volume, so it is more likely when the prosthesis has a large CHS and the metal work is thin or when several pontics are present in the prosthesis. The stress distribution during shrinkage in overcontoured porcelain-fused-to-gold crowns on implant abutments of smaller diameter is increased and even more likely to cause metal distortion.[149] Therefore, a full wax-up with 2-mm reduction is indicated so the porcelain thickness is not more than 2 mm thick.

Porcelain fracture is the second most common complication with crowns on natural teeth and occurs more often with large bridgework and implant prostheses.[152] Therefore, metal occlusals on screw-retained restorations result in decreased material shrinkage and decreased metal distortion when porcelain is added, so they have a decreased risk of nonpassive castings. In addition, porcelain fracture risk is reduced. As a result, in nonesthetic regions, the use of metal occlusals is encouraged for screw-retained restorations.

Soldering

Metal castings usually appear clinically passive. The casting is clinically acceptable if the marginal fit is within a horizontal or vertical range of opening of less than 75 microns, similar to a crown on natural tooth. When splinted implant abutments are used, the casting is positioned on the implants, and the dentist attempts to rock the casting.[151] Rocking side to side indicates that one of the most distal abutments is not passive. Forward and back rocking indicates that the center abutment is not passive (Figure 28-44). According to Dedmon, discrepancy or acceptable castings on screw-retained prostheses by experienced doctors may exhibit a range of opening from 32 to 250 microns in the horizontal plane and 43 to 196 microns in the vertical dimension.[153]

When the casting is not passive, the superstructure is separated around the offending abutment(s) (Figure 28-45). After being separated, each component is tested for a passive fit.[154-156] The distance of casting separation is 0.005 to 0.008 inch (0.13–0.20 mm), or the thickness of two sheets of paper.[157-159] Too small a separation will cause dimensional change when the casting is heated and expands, and too large an opening may provide a weaker joint and casting distortion warp because of shrinkage of the solder during solidification.[160]

After the nonpassive casting is separated the ideal distance, the casting may be screwed into position with long fixation screws, such as those used for direct impression transfer copings (Figure 28-46). An impression tray then is modified to allow

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FIGURE 28-46. Long screws from the impression transfers are used to secure the sectioned bar.



FIGURE 28-48. The fixation screws are unthreaded, and the impression picks up the bar. The laboratory adds analogs to the bar and pours a model for soldering.



FIGURE 28-47. An impression tray is modified to an open tray, and the impression is made of the bar while it is fixated in position.

the fixation screws to exit the top. An addition silicone may be injected around the superstructure to index and surround the pieces and the impression tray (Figure 28-47). After the material has set, the long screws and the seated impression tray are removed with the incorporated casting and are sent to the dental laboratory (Figure 28-48). This technique picks up the bar within the impression and permits transfer to the laboratory without risk of superstructure separation during transport. The laboratory inserts the abutment for screw retention analogs into the castings and pours a base to prepare the superstructure for soldering. The superstructure is soldered, polished, and checked for passive placement.

The soldering of two sections end with a more passive casting compared with a full-arch one-piece casting. Although better in a comparison study by Mendes et al., even the soldering procedure for full-arch castings result in a nonpassive casting which results in abutment deformation when screwed into place.[161]

Screw Fixation

The order in which the retaining screws are fixated may affect the accuracy of prosthesis fit and range of passivity. When the prosthetic screws are fully torqued into position in order from one end of the prosthesis to the other, the prosthesis misfit is greatest.[162] In this example, the first prosthetic screw to abutment is most passive. The next connection is less passive. The last abutment and prosthetic screw is the worst condition in the splinted units. All of the inaccuracies are compounded in the last connection.

Instead, the abutment in the center of the restoration is first slightly attached with finger pressure. The casting is then rocked mesially and distally and then facially and lingually. A rocking movement of the casting indicates a nonpassive casting. When stable, the adjacent abutments are engaged with prosthetic screws. Then the next two adjacent screws are attached. After it is complete, the process begins again in the center. The screws are torqued to a firm finger pressure in the same order. Finally, the torque wrench is used on the screws in the same order.

Digital Dentistry

Digital dentistry has dramatically improved the ability to have passive screw-retained restorations. The intraoral impressions may be computer scanned in the mouth, which eliminates the problems of impression material shrinkage. The scanned impression may use a virtual model. This eliminates the effects of laboratory transfer error and stone expansion. If the impression transfer is made in the traditional open-tray technique, the traditional implant models may be computer scanned, which eliminates fabrication errors. The framework may be digitally machined, which eliminates wax distortion and metal shrinkage concerns. As a consequence, the future advancements of digital dentistry are most advantageous for screw-retained implant prostheses.

Complications

The most common complications of screws used in implant dentistry are abutment and prosthetic screw loosening. The cause is often related to nonpassive castings. Both of these entities have been addressed in detail in this chapter. In addition, screw fracture may occur. Fracture of implant components is an intermediate to long-term complication. A review of medical device reports for dental implants and related components revealed that component fracture continues to present problems for dental implant systems. Fractures occur in implants,

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prosthetic screws, and abutments for all six leading dental manufacturers and represent 1% to 3% of the devices.[23]

Screw Fracture

The most common causes of screw fracture are a partially unretained restoration or fatigue related to the amount of force or the number of cycles. Prosthetic screw fracture occurs approximately 4% of the time and abutment screw fracture 2% of the time. The difference is related to the diameter of the component.

There are five options to remove a fractured screw, and the method proceeds in a particular order. The first method most always is successful and takes only a few minutes. A very small, round bur is used in a slow-speed handpiece, preferably below 50 rpm. The round bur is placed at the seam of the fractured screw and abutment (implant). As the bur spins clockwise, the friction on the screw makes it turn counterclockwise, and the screw unthreads (Figure 28-49).

If this technique is not successful, the screw complex may have gone through plastic deformation and distorted the components before fracture. Attempts to unthread the component with an ultrasonic or Cavitron device rarely are effective once this occurs.

The second method to remove a fractured screw works only for gold prosthetic screws. An inverted cone drill and slow-speed handpiece is used to drill in the center of the screw. The handpiece is stopped immediately after it penetrates the screw 1 to 2 mm. The bur sticks in the gold screw. The bur is unattached from the handpiece, and the bur and fractured screw are unthreaded. Commercial devices are available that follow this same scheme.

The third method (and usually the second attempted) is to make a slot 1 mm deep through the center of the screw with a high-speed handpiece and a very narrow fissure bur. A small screwdriver is then used to unthread the screw (Figure 28-50).

The fourth method to remove a fractured screw is used when the prosthetic screw fractures in an abutment for screw retention. The abutment is removed and replaced with a new abutment and prosthetic screw of the same design and size. This approach costs a little more but is very effective.

The last option to retrieve an abutment screw is to grind out the fractured abutment with a high-speed handpiece and fissure bur. This process has the most risk. The heat generated during this process is high enough to cause bone necrosis and implant failure. The process is performed with copious amounts of water and no anesthesia. The patient is instructed to notify the dentist when the generated heat is noticeable, which is often less than 5 to 10 seconds after the initial drilling. The process continues in these short intervals until the abutment is removed.

Be careful using this technique. The bur may inadvertently perforate the side of the implant body. There is no method to repair the implant body if this occurs. The patient should be informed that implant failure may result as a consequence of this technique.

After the abutment screw is ground out from the implant body, a new abutment screw is tried in. Most of the time it will



FIGURE 28-49. **A,** A fractured abutment screw in a bruxing patient. **B,** A very small round bur is used in a slow handpiece. **C,** The bur is positioned in the seam of the screw and implant and as it rotates clockwise, friction unthreads the screw.

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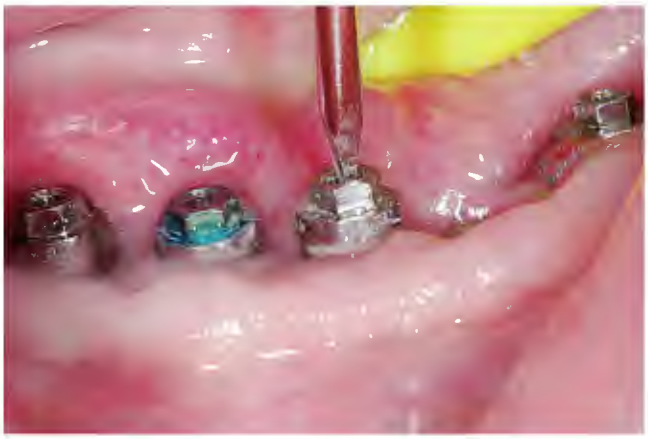


FIGURE 28-50. A slot is made in the screw with a high-speed handpiece and narrow fissure bar. A screwdriver is then used to unthread the screw.

not thread into position but is press fit (similar to a custom endodontic post). The new abutment screw is then cemented into the implant body with a resin cement.

Be aware that residual cement is a complication that may lead to periimplantitis. The resin cement is often not radiopaque and is difficult to observe on a radiograph. The abutment–implant connection is often subgingival and more than 2 mm below the tissue. Anesthesia is often required to confirm no residual cement is present.

Summary

Screw loosening is a common complication in implant dentistry and may affect the abutment screw or the prosthesis screw. Screw mechanics may be used to dramatically reduce this incidence. Many of these factors are controlled by the product selected, and different manufacturers have different complication rates. Many of these conditions are related to external force factors and are more influenced by the treatment plan. Other conditions that cause this are most in control of the restoring dentist. Each of these entities has been addressed in this chapter.

A screw-retained prosthesis attaches to the implant abutment with significant compressive forces (10–30 N-cm torque). The coping screw should not place tension, compression, or shear forces on the superstructure. To accomplish the goal of a passive superstructure, all aspects of prosthesis reconstruction are scrutinized in an attempt to compensate for errors and variations during the process. Fabrication variables most important to the dentist include impression material shrinkage, permanent deformation, custom versus stock impression trays, variance among manufacturers in analog parts, stone and investment expansion, metal shrinkage, acrylic and porcelain shrinkage, soldering, and torque force amount applied to the coping screw. The step-by-step clinical protocol for screw-retained prostheses is presented to produce the most passive castings as is technically possible and therefore minimize crestal bone loss and screw loosening.

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CHAPTER 29

Mandibular and Maxillary Implant Overdenture Design and Fabrication

Carl E. Misch

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The average total edentulous rate around the world is 20% of the adult population by age 65 years, although there is wide disparity from the countries with the highest and lowest rates.[1] For example, from the 65- to 74-year age group, the total edentulous rate in Kenya and Nigeria was 4%, but the Netherlands and Iceland have rates of 65.4% and 71.5%, respectively. The edentulous rate in Canada was 47% at 65 to age 69 years and 58% from ages 70 to 98 years (with Quebec at 67% for those older than age 65 years compared with Ontario with a 41% rate).

A 1999 to 2002 survey found that total edentulism in the United States of both arches was present in almost 20 million people.[2] As expected, older persons are more likely to be missing all of their teeth. Total edentulism has been noted in 5% of employed adults ages 40 to 44 years, gradually increasing to 26% at age 65 years and almost 44% in seniors older than age 75 years[3] (Figure 29-1). Gender was not found to be associated with tooth retention or tooth loss after adjustments were made for age.

The maxillary arch may be completely edentulous, opposing at least some teeth in the mandible. This condition occurs 35 times more often than the reverse situation. At age 45 years, 11% of the population has maxillary total edentulism opposing at least some teeth, which increases to 15% by 55 years of age and then remains relatively constant.[2,3] Therefore, an additional 12 million individuals in the United States have total edentulism in the maxillary arch, representing 7% of the adult population overall.

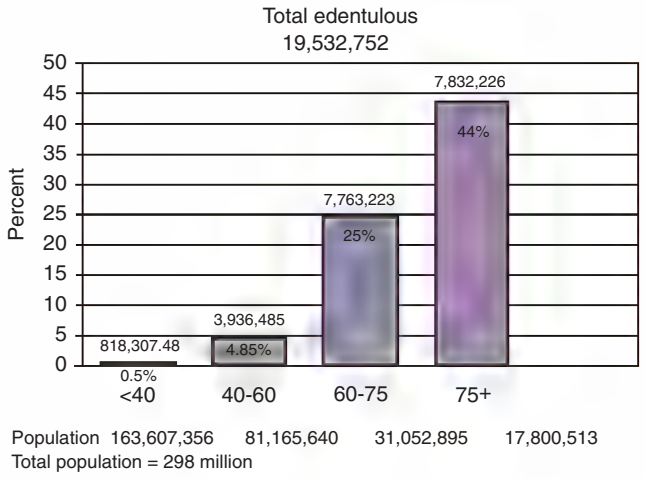


FIGURE 29-1. Almost 20 million Americans are completely edentulous. After the age of 60 years, more than one third of the population has no teeth.

The percentages of one or two arch total edentulism translate into more than 30 million people or about 17% of the entire U.S. adult population.[4] To put these numbers in perspective, 30 million people represent approximately the entire U.S. African American population, the U. S. Hispanic population, the whole population of Canada, or the total population in the United States older than 65 years of age.

Although the edentulism rate is decreasing every decade, the elderly population is rising so rapidly that the adult population in need of one or two complete dentures will actually *increase* from 33.6 million adults in 1991 to 37.9 million adults in 2020. The total numbers of edentulous arches were estimated at 56.5 million in 2000, 59.3 million in 2010, and 61 million in 2020.[5] Complete edentulism, therefore, remains a significant concern, and affected patients often require implant dentistry to solve several related problems. If four implants were used to help support each complete edentulous arch, a total of 226 million implants would be required. Yet only 10 million implants in the United States were inserted in 2010 for all patient treatment.

The vast majority of completely edentulous patients are treated with complete dentures. Despite these numbers, almost 70% of dentists spend less than 1% to 5% of their treatment time on edentulous patients, leaving a great unfulfilled need for implant dentistry. However, the dental profession and the public are more aware of the problems associated with a complete mandibular denture than any other dental prosthesis.

The placement of implants enhances the support, retention, and stability of an overdenture. As a result, edentulous patients are very willing to accept a treatment plan for a mandibular implant overdenture (IOD). There is greater flexibility in implant position or prosthesis fabrication with a mandibular IOD. As a result, it is also an ideal treatment modality to begin an early learning curve in implant surgery and prosthetics. Therefore, one of the most beneficial treatments rendered to patients is also one of the best introductions for a dentist into the discipline of implant dentistry.

An increased awareness from the profession and patients has now rendered the mandibular IOD the treatment of choice for edentulous patients regardless of most clinical situations, bone densities, and patients' desires to restore an ever-growing number of patients.[6–43] As a consequence, mandibular overdentures have become the minimum standard of care for most completely edentulous mandibles.[38]

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Anatomical Consequences of Edentulism

There are many negative consequences for completely edentulous patients. They include continued bone loss of the jaws; soft tissue consequences that support the prostheses; facial esthetic consequences of bone loss; decreased masticatory performance, resulting in diet-related health issues; and psychological aspects of a total tooth loss (Box 29-1). Some of these issues are addressed in Chapter 1. Other related issues to overdentures are reviewed in this chapter.

Bone Loss

Wolff's law (1892) states that bone remodels in relationship to the forces applied.[44] Every time the function of bone is modified, a definite change occurs in the internal architecture and external configuration.[45] In dentistry, the consequences of complete edentulism and remaining bone volume were noted by J. Misch in 1922, where he described the skeletal structure of a 90-year-old woman without teeth for several decades[46] (Figure 29-2).

Bone needs stimulation to maintain its form and density. Roberts et al. report that a 4% strain to the skeletal system maintains bone and helps balance the resorption and formation phenomena.[47] Teeth transmit compressive and tensile forces to the surrounding bone. These forces have been measured as a piezoelectric effect in the imperfect crystals of durahydroxyapatite that comprise the inorganic portion of bone.[48] When a tooth is lost, the lack of stimulation to the residual bone causes a decrease in trabeculae and bone density in the area, with loss in the external width and then height of the bone volume.[49] There is a 25% decrease in width of bone during the first year after tooth loss and an overall 4-mm decrease in height during the first year after extractions for an immediate denture.[50] In a longitudinal 25-year study of edentulous patients, lateral cephalograms demonstrated continued bone loss during this time span, with a fourfold greater loss observed in the mandible.[51] In 1963, Atwood introduced five different stages of bone loss in an anterior mandible after tooth loss[52] (Figure 29-3).

Although the bone loss issue has been noted for a hundred years, the dental profession has most often overlooked the insidious bone loss that occurs after tooth extraction. The patient is often not educated about the anatomical changes and the potential consequences of continued bone loss. The bone loss accelerates when the patient wears a poorly fitting soft tissue–borne prosthesis. Patients do not understand that bone is being lost over time and at a greater rate beneath poorly fitting dentures. Patients do not return for regular visits for evaluation of their condition; instead, they return after several years when denture teeth are worn down or can no longer be tolerated. In fact, the average denture wearer sees a dentist every 14.8 years after having a complete denture. Hence, the traditional method of tooth replacement (dentures) often negatively affects bone loss in a manner not sufficiently considered by the dentist and the patient. The doctor should inform the patient that a denture replaces more bone and soft tissue than teeth, and every 5 years a reline or new denture is suggested to replace the additional bone loss by the atrophy that will occur (Figure 29-4).

Preventive dentistry has traditionally emphasized methods to decrease tooth loss or the surrounding bone supporting a tooth. This bone loss around a tooth is often monitored by the millimeter, yet no therapy had been promoted and accepted by the profession to avoid the bone changes resulting from tooth loss. The bone changes after total tooth loss may be measured by the centimeter. Today the profession must consider the loss of both teeth and bone. The loss of teeth causes remodeling and resorption of the surrounding residual bone and eventually leads to atrophic edentulous ridges.

Almost every girl and woman past the age of 14 years is aware of osteoporosis after menopause. Diet and exercise are encouraged their whole lives to decrease this risk. Yet osteoporosis primarily affects bone density, not bone volume. The only place in the body bone volume is lost to an extreme is in the jaws after tooth loss. Yet nobody in the public and very few in the profession ever address this issue. It is malpractice if a

BOX 29-1 Consequences of Complete Edentulism

- Continued bone loss of jaws
- Negative soft tissue effects
- Negative facial esthetics
- Decreased masticatory performance
- Diet-related health effects
- Psychologic impact



FIGURE 29-2. In 1922, J. Misch described the anatomical consequences of 90-year-old women without teeth.

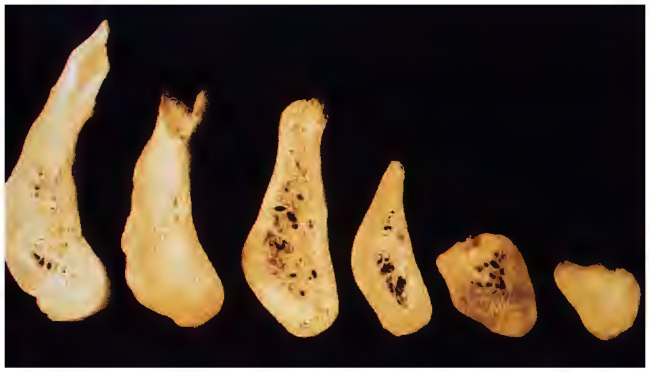


FIGURE 29-3. In 1963, Atwood described five different stages of bone loss in the anterior mandible after the loss of teeth.[52]

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dentist does not monitor the bone loss around teeth by the millimeter with a probe. Yet the centimeter bone losses of the edentulous regions are often ignored.[53]

Consequences of edentulous ridges with bone loss are associated with anatomical problems that often impair the predictable results of traditional dental therapy. Several of these anatomical problems are listed in Box 29-2. Loss of bone in the maxilla or mandible is not limited to alveolar bone; portions of the basal bone may also be resorbed (Figure 29-5), especially in the posterior aspect of the mandible, where severe resorption may result in more than 80% bone loss.[54] The contents of the mental foramen or mandibular canal eventually become dehiscent and serve as part of the support area of the prosthesis.[55] As a result, acute pain and transient to permanent paresthesia of the areas supplied by the mandibular nerve are possible. The body of the mandible also is at increased risk of fracture even under very low impact forces (Figure 29-6). The mandibular fracture causes the jaw to shift to one side and makes stabilization and an esthetic result most difficult to obtain during treatment of the fracture.

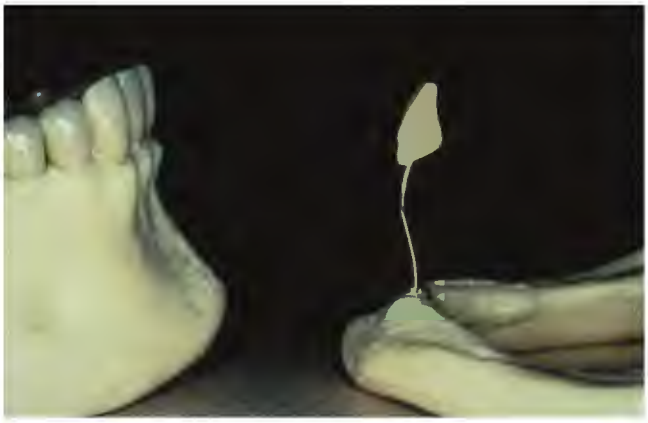


FIGURE 29-4. The patient should understand a complete denture often replaces more bone than teeth after the continued bone loss associated with the loss of teeth.

The average denture patient does not see a dentist regularly. In fact, more than 10 years usually separates dental appointments of edentulous patients. As a consequence, the patient is unaware of the insidious loss of bone in the edentulous jaw. The bone loss that occurs during the first year after tooth loss is 10 times greater than in following years. In the case of multiple extractions, this often means a 4-mm vertical bone loss within the first 6 months. This bone loss continues over the next 25 years, with the mandible experiencing a fourfold greater vertical bone loss than the maxilla.[56,57] During the long hiatus between dental visits after dentures are used to replace the dentition, the amount of resorption from initial denture delivery to the next professional interaction already has caused the destruction of the original alveolar process.

BOX 29-2 Anatomic Problems of Edentulous Ridges

- Decreased width of denture-supporting bone
- Decreased height of denture-supporting bone
- Prominent mylohyoid and internal oblique ridges with increase in denture sore spots
- Progressive decrease in keratinized attached mucosa
- Prominent superior genial tubercles with increased denture movement
- Muscle attachments near crest of edentulous ridge
- Posterior elevation of prosthesis with contraction of mylohyoid and buccinator muscles during function
- Forward movement of prosthesis from anatomical inclination with moderate to advanced bone loss
- Thinning of surface mucosa with increased sensitivity to abrasion
- Loss of basal bone
- Paresthesia from dehiscent mental foramen and neurovascular canal
- Increased risk of mandibular body fracture from advanced bone loss

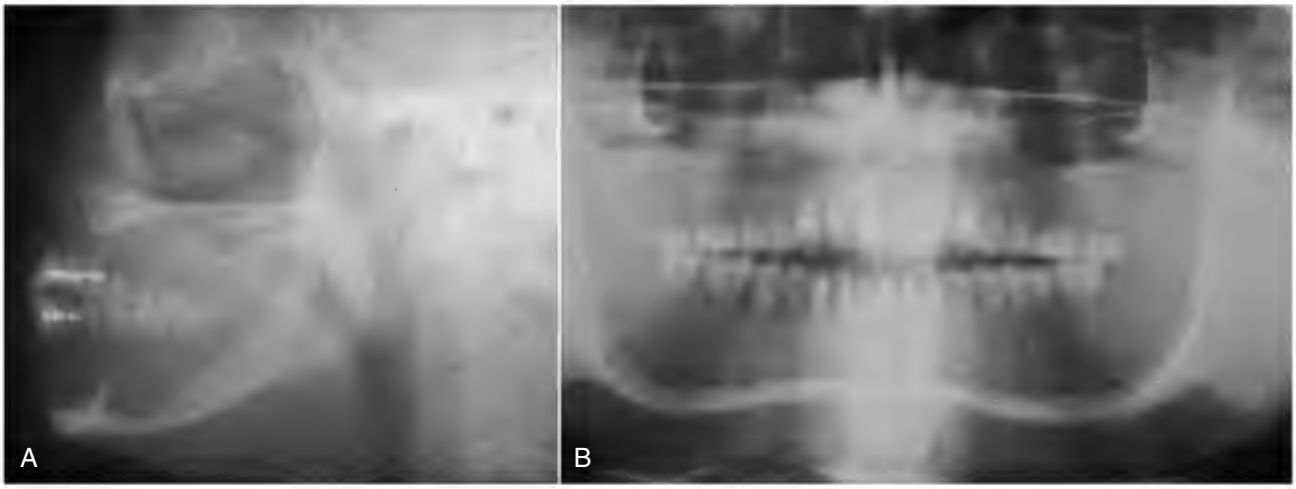


FIGURE 29-5. **A,** The bone loss associated with loss of teeth may include both the alveolar bone, which was formed to house the teeth, and the basal bone of the jaws. This panoramic radiograph with the dentures in place demonstrates the advanced atrophy of the residual bone. **B,** Long-term complete edentulism can result in severe bone atrophy. This cephalometric radiograph demonstrates the body of the mandible is less than 5 mm high, and the superior genial tubercle is 10 mm above the crest of the ridge.

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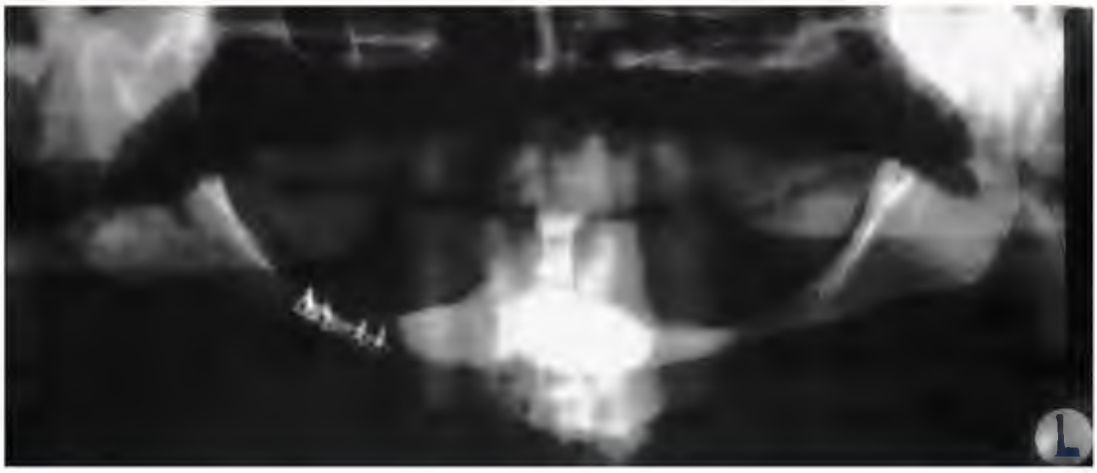


FIGURE 29-6. Advanced atrophy of the mandibular body may result in fracture of the jaw.

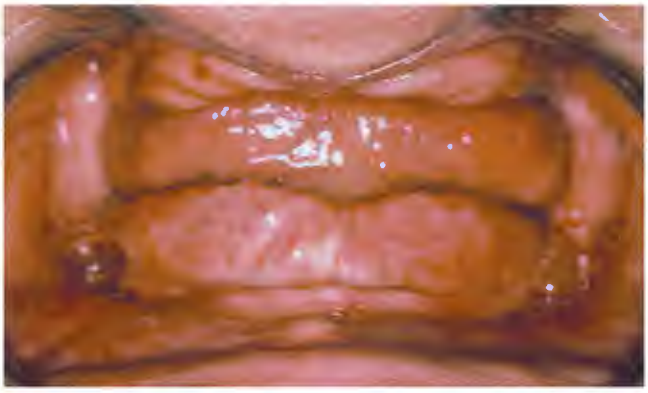


FIGURE 29-7. The soft tissue consequences of bone loss often include muscle attachments at the crest of the residual ridge. In this mandible, the floor of the mouth is superior to the remaining bone, and the mentalis and buccinator muscles are level with the bone crest.

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The anterior residual alveolar process also continues to resorb during this time frame, and the superior genial tubercles (which are 20 mm below the crest of bone when teeth are present) eventually become the most superior aspect of the anterior edentulous ridge. The more often a patient wears a denture, the greater the bone loss, yet 80% of denture patients wear their dentures day and night.

Soft Tissue Consequences

The loss of bone first causes decreased bone width. The remaining narrow residual ridge often causes discomfort when the thin overlying tissues are loaded under a soft tissue–borne removable prosthesis (RP). As bone loses width, then height, then width and height again, the attached gingiva gradually decreases. A very thin attached tissue usually lies over the advanced atrophic mandible or is entirely absent. The increasing zones of mobile, unkeratinized gingiva are prone to abrasions caused by the overlaying prosthesis. In addition, unfavorable high muscle attachments and hypermobile tissue often complicate the situation.

As the bony ridge resorbs in height, the muscle attachments become level with the crest of the edentulous ridge (Figure 29-7). The continued atrophy of the posterior mandible eventually causes prominent mylohyoid and internal oblique ridges covered by thin, movable, unattached mucosa. There is little to prevent the prosthesis from moving forward against the lower lip during function or speech. This condition is further compromised by the vertical movement of the distal aspect of the prosthesis during contraction of the mylohyoid and buccinator muscles and the anterior incline of the atrophic mandible compared with that of the maxilla.[58] Yet these compromised tissues are the support and stability system of the denture (Box 29-3).

BOX 29-3 Soft Tissue Consequences of Edentulism

- Attached, keratinized gingiva is lost as bone is lost.
- Unattached mucosa for denture support causes increased soft spots.
- Thickness of tissue decreases with age and systemic disease, which causes more sore spots for dentures.
- The tongue increases in size, which decreases denture stability.
- The tongue has more active role in mastication, which decreases denture stability.
- There is decreased neuromuscular control of the jaw in elderly adults.

Masticatory Function

The difference in maximum occlusal forces recorded in a person with natural teeth and one who is completely edentulous is dramatic. In the first molar region of a dentate person, the average force has been measured at 150 to 250 psi.[59] A patient who grinds or clenches the teeth may exert a force that approaches 1000 psi. The maximum occlusal force in the edentulous patient is reduced to less than 50 psi. The longer patients are edentulous, the less force they are able to generate. Patients wearing complete dentures for more than 15 years may have a maximum occlusal force of less than 6 psi.[60]

As a result of decreased occlusal force and the instability of the denture, masticatory efficiency also decreases with tooth loss. Ninety percent of the food chewed with natural teeth fits through a no. 12 sieve; this is reduced to 58% in a patient wearing complete dentures.[61] A study of 367 denture wearers (158 men and 209 women) found that 47% exhibited low masticatory performance.[62] The 10-fold decrease in force and

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BOX 29-4 Negative Effects of Complete Dentures

- Bite force is decreased from 200 psi for dentate patients to 50 psi for edentulous patients.
- 15-year denture wearers have reduced bite force to 6 psi.
- Masticatory efficiency is decreased.
- More drugs are necessary to treat gastrointestinal disorders.
- Food selection is limited.
- Healthy food intake is decreased.
- The life span may be decreased.
- Reduced prosthesis satisfaction.
- Speech difficulty
- Psychologic effects

BOX 29-5 Advantages of Implant-Supported Prostheses

- Maintain bone
- Restore and maintain occlusal vertical dimension
- Maintain facial esthetics (muscle tone)
- Improve esthetics (teeth positioned for appearance vs. decreasing denture movement)
- Improve phonetics
- Improve occlusion
- Improve or regain oral proprioception (occlusal awareness)
- Increase prosthesis success
- Improve masticatory performance or maintain muscles of mastication and facial expression
- Reduce size of prosthesis (eliminate palate, flanges)
- Provide fixed versus removable prostheses
- Improve stability of removable prostheses
- Improve retention of removable prostheses
- Increase survival times of prostheses
- No need to alter adjacent teeth
- More permanent replacement
- Improve psychological health
- Improved health related to diet
- Improve maxillofacial prostheses

the 40% decrease in efficiency affect the patient's ability to chew. Lower intakes of fruits, vegetables, and vitamin A by women are noted in this group. Denture patients also take significantly more drugs (37%) compared with those with superior masticatory ability (20%), and 28% take medications for gastrointestinal disorders.[63] The reduced consumption of high-fiber foods could induce gastrointestinal problems in edentulous patients with deficient masticatory performance. In addition, the coarser bolus may impair proper digestive and nutrient extraction functions.

Mandibular discomfort was listed in a study by Misch and Misch with equal frequency as movement (63.5%), and surprisingly, 16.5% of the patients stated they never wear the mandibular denture.[64] In comparison, the maxillary denture was uncomfortable half as often (32.6%), and only 0.9% were seldom able to wear the prosthesis. Function was the fourth most common problem reported by these 104 denture wearers. In persons with dentures, 29% are able to eat only soft or mashed foods; 50% avoid many foods; and 17% claim they eat more efficiently without the prosthesis.[64] The psychological effects of the inability to eat in public can be correlated with these findings. Other reports agree that the major motivating factors for patients to undergo treatment were related to the difficulties with eating, denture fit, and discomfort[63] (Box 29-4).

Advantages of an Implant Overdenture

The use of dental implants to provide support for an IOD offers many advantages compared with the use of removable soft tissue–borne restorations (Box 29-5). A primary reason to consider dental implants to replace missing teeth is the maintenance of alveolar bone. The most common position to insert implants for an overdenture is in the anterior mandible. After the implants are inserted, the anterior bone under an overdenture may resorb as little as 0.6 mm vertically over 5 years, and long-term resorption may remain at less than 0.05 mm per year.[35,40] Stress and strain may be applied to the bone surrounding the implant. As a result, the decrease in trabeculation and volume of bone that occurs after tooth extraction is reversed. There is an increase in bone trabeculae and density when the dental implant is inserted and functioning. The overall volume of bone around the implants is also maintained. An endosteal implant can maintain bone width and height as long as the implant remains healthy.[47] As with a tooth, periimplant bone loss may be measured in tenths of a millimeter and may represent a more than 20-fold decrease in lost bone structure compared with the resorption that occurs with removable prostheses.

The features of the inferior third of the face are closely related to the supporting skeleton. When vertical bone is lost, the dentures only act as "oral wigs" to improve the contours of the face. The dentures become bulkier as the bone resorbs, making it more difficult to control function, stability, and retention. With implant-supported prostheses, the vertical dimension may be restored, similar to natural teeth. In addition, the implant-supported prosthesis allows a cantilever of anterior teeth for ideal soft tissue and lip contour and improved appearance in all facial planes. This happens without the instability that usually occurs when an anterior cantilever is incorporated in a traditional denture. The facial profile may be enhanced for the long term with implants rather than deteriorating over the years as can occur with traditional dentures.

The complete mandibular denture often moves during mandibular jaw movements during function and speech. In addition to the lack of retention from bone loss, a mandibular denture often moves when the mylohyoid and buccinator muscles contract during speech or mastication. The maxillary teeth are often positioned for lower denture stability rather than where natural teeth usually reside. With implants, the maxillary teeth may be positioned to enhance esthetics and phonetics rather than in the neutral zones dictated by traditional denture techniques to improve the stability of a lower prosthesis.

Occlusion is difficult to establish and stabilize with a completely soft tissue–supported prosthesis. Because the mandibular prosthesis may move as much as 10 mm or more during function, proper occlusal contacts occur by chance, not by design.[65,66] An implant-supported restoration is stable. The patient can more consistently return to centric relation occlusion rather than adopt variable positions dictated by the prosthesis' instability.

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Proprioception is awareness of a structure in time and place. The receptors in the periodontal membrane of the natural tooth help determine its occlusal position. Although endosteal implants do not have a periodontal membrane, they provide greater occlusal awareness than complete dentures. Whereas patients with natural teeth can perceive a difference of 20 microns between the teeth, implant patients can determine 50-micron differences with rigid implant bridges compared with 100 microns in those with complete dentures (either one or two).[67] As a result of improved occlusal awareness, the patient functions in a more consistent range of occlusion.

With an implant-supported prosthesis, the direction of the occlusal loads is controlled by the restoring dentist. Horizontal forces on removable prostheses accelerate bone loss, decrease prosthesis stability, and increase soft tissue abrasions. Therefore, the decrease in horizontal forces that are applied to implant restorations improves the local parameters and helps preserve the underlying soft and hard tissues. An IOD provides improved retention and stability of the prosthesis, and the patient is able to consistently reproduce a determined centric occlusion.[43]

In a randomized clinical trial by Kapur et al., the implant group of patients demonstrated a higher level of eating enjoyment and improvement of speech, chewing ability, comfort, denture security, and overall satisfaction.[68] The ability to eat several different foods among complete denture versus mandibular overdenture patients was evaluated by Awad and Feine.[69] The IOD was superior for eating not only harder foods, such as carrots and apples, but also softer foods, such as bread and cheese. Geertman et al. evaluated complete denture wearers with severely resorbed mandibles before and after mandibular IODs. The ability to eat hard or tough foods significantly improved.[70,71]

Researchers at McGill University evaluated blood levels of 30 patients who had complete dentures and 30 patients with maxillary dentures opposing mandibular implant prostheses 6 months after treatment.[72] Within this rather short period, implant patients had higher B_{12} hemoglobin (related to an iron increase) and albumin levels (related to nutrition). These patients also had greater body fat in their shoulders and arms, with decreased body fat in their waists. Beneficial effects such as a decrease in fat, cholesterol, and the carbohydrate food groups have been reported, as well as significant improvement in eating enjoyment and social life.[73–75]

The maximum occlusal force of a traditional denture wearer ranges from 5 to 50 lb. Patients with an implant-supported fixed prosthesis (FP) may increase their maximum bite force by 85% within 2 months after the completion of treatment. After 3 years, the mean force may reach more than 300% compared with pretreatment values.[60] As a result, an implant prosthesis wearer may demonstrate a force similar to that of a patient with a fixed restoration supported by natural teeth.

Chewing efficiency with an implant prosthesis is greatly improved compared with that of a soft tissue–borne restoration. The masticatory performance of dentures, overdentures, and natural dentition was evaluated by Rissin et al., and the traditional denture showed a 30% decrease in chewing efficiency.[61] The tooth-supported overdenture loses only 10% of chewing efficiency compared with natural teeth. These findings are similar with implant-supported overdentures. Geertman et al. reported similar results comparing chewing ability of conventional complete dentures with mandibular IODs.[70,71] In addition, rigid implant-supported prostheses may function the same as natural teeth.

The stability and retention of an implant-supported prosthesis are great improvements over soft tissue–borne dentures. Mechanical means of implant retention are far superior to the soft tissue retention provided by dentures or adhesives and cause fewer associated problems. The implant support of the final prosthesis is variable, depending on the number and position of implants; yet all treatment options demonstrate significant improvement.

Phonetics may be impaired by the instability of a conventional denture. The buccinator and mylohyoid muscles may flex and propel the posterior portion of the denture upward, causing clicking, regardless of the vertical dimension.[66] As a result, a patient in whom the vertical dimension already has collapsed 10 to 20 mm may still produce clicking sounds during speech. Often the tongue of the denture wearer is flattened in the posterior areas to hold the denture in position. The anterior mandibular muscles of facial expression may be tightened to prevent the mandibular prosthesis from sliding forward. The implant prosthesis is stable and retentive and does not require these oral manipulations. The implant restoration allows reduced flanges or palates of the prostheses. This is of special benefit to new denture wearers, who often report discomfort with the bulk of the restoration.

Patients treated with implant-supported prostheses judge their overall psychological health as improved by 80% compared with their previous state while wearing traditional, removable prosthodontic devices. They perceived the implant-supported prosthesis as an integral part of their body. For example, Raghoebar et al. evaluated 90 edentulous patients in a randomized multicenter study.[76] Five years after treatment, a validated questionnaire targeted patient esthetic satisfaction, retention, comfort, and the ability to speak and eat with a complete mandibular denture, complete mandibular denture with vestibuloplasty, or mandibular two-implant overdenture. IODs had significantly higher ratings, but no significant difference was found between the two complete-denture groups.

For patients with the inability to afford a fixed implant prosthesis, the IOD is a significant improvement compared with their traditional denture. In a randomized clinical report, Awad et al. compared satisfaction and function in complete denture patients versus patients with two implant-supported mandibular IODs.[11] There was significantly higher satisfaction, comfort, and stability in the IOD group. A similar study in a senior population yielded similar results.[12] Thomason et al., in the United Kingdom, also reported a 36% higher satisfaction for the implant IOD patients than the complete denture wearers in the criteria of comfort, stability, and chewing.[13]

The success rate of implant prostheses varies, depending on a host of factors that change for each patient. However, compared with traditional methods of tooth replacement, the implant prosthesis offers increased longevity, improved function, bone preservation, and better psychological results.

Advantages of Implant-Supported Overdentures versus Fixed Prostheses

The IOD provides some practical advantages over the implant-supported complete fixed partial denture (Box 29-6). Fewer implants may be required when a RP-5 restoration is fabricated because soft tissue areas may provide additional support. The overdenture may provide stress relief between the superstructure and prosthesis, and the soft tissue may share a portion of the occlusal load. Regions of inadequate bone for implant

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BOX 29-6 Implant Overdenture Advantages versus Fixed Prosthesis

- Fewer implants (RP-5)
- Less bone grafting required before treatment
- Less specific implant placement
- Improved esthetics
- Labial flange
- Soft tissue drape replaced by acrylic
- Improved periimplant probing (follow-up)
- Improved hygiene
- Reduced stress to implant system
- Nocturnal parafunction (remove prosthesis at night)
- Lower cost and laboratory cost (RP-5)
- Easy repair
- Laboratory cost decrease (RP-5)
- Transitional device is less demanding than a fixed restoration

placement therefore may be eliminated from the treatment plan rather than necessitating bone grafts or placing implants with a poorer prognosis. As a result of less bone grafting and number of implants, the cost to treat the patients is dramatically reduced.

The implant position is less specific for an overdenture compared with a FP. The cervical contours of the prosthesis are controlled by implant position in a fixed restoration. The implants have a greater demand for parallelism for a FP, especially when a cemented restoration is desired. The postoperative evaluation and hygiene of an IOD is easier than for a FP, especially when cervical ridge laps are used in the restoration.

The overdenture restoration is easier to repair because it is already readily removable. The FP may be difficult to remove when cement retained and even when screw retained takes considerable time and effort. The transitional restoration during fabrication of the final prosthesis is typically the complete denture the patient was wearing before treatment. A fixed restoration often requires an additional restoration to be fabricated during the treatment process.

The IOD may be removed at night to reduce the noxious effects of nocturnal parafunction. These cyclic forces increase the risk of biomechanical problems not only of the implants but also of the entire implant system, including the prosthesis occlusal material, the screws and cements that retain the prosthesis, the abutment screws, the crestal marginal bone, the complete bone–implant interface, and fracture of any of the prosthetic components or even the implants themselves.

An overdenture may be more esthetic than a FP, especially in the maxillary arch when the soft tissues of the face need additional support as a consequence of bone loss. Hygiene procedures are also not compromised when additional facial support is gained with a labial flange of the overdenture compared with the situation with a FP.

When cost is a factor, a two-implant–retained IOD may improve the patient's condition at a lower overall treatment cost than a fixed implant–supported prosthesis. A survey by Carlsson et al. in 10 countries indicated a wide range of treatment options.[19] The proportion of IOD selection versus fixed implant dentures was highest in the Netherlands (93%) and lowest in Sweden and Greece (12%). Cost was cited as the number one determining factor in the choice.

BOX 29-7 Overdenture Disadvantages

- Psychological (need for nonremovable teeth)
- Greater crown height space required
- More long-term maintenance required
- Attachments (change)
- Relines (RP-5)
- New prosthesis every 7 years
- Continued posterior bone loss (RP-5)
- Food impaction
- Movement (RP-5)

In conclusion, the primary indications for a mandibular IOD relate to problems found with lower dentures such as lack of retention or stability, decrease in function, difficulties in speech, tissue sensitivity, and soft tissue abrasions. If an edentulous patient desires a RP, an IOD is often the treatment of choice. If cost is a problem for a patient who desires a fixed restoration, the overdenture may serve as a transitional device until additional implants may be inserted and restored.

Disadvantages of Implant Overdentures

Implant overdentures also have disadvantages compared with fixed prostheses (Box 29-7). This aspect of overdenture treatment should be reviewed with the patient to reduce patient complaints after treatment. Whereas an overdenture is a prosthesis, a fixed restoration is considered a body part. Patients with an IOD respond, "These are much better than my denture." When patients have a fixed restoration, they often state, "These are better than my teeth."

A greater crown height space (CHS) is required for an overdenture. Hence, when abundant bone is present and implants are already inserted, a FP will have less issues of fracture or positioning teeth over a bar.

More maintenance is required for an overdenture. Attachments wear and need to be replaced, relines are necessary for RP-5 restorations, and denture teeth wear more rapidly on an IOD than a denture. As a result, a new IOD may need to be fabricated every 7 years.

A side effect of an IOD is food impaction under the prosthesis. The denture is border molded, so the muscles are in their contracted position. Otherwise, because the prosthesis is more rigid than a denture, sore spots develop during function. In the relaxed muscle state, food goes beyond the denture border. Then when the patient swallows, the food is pushed under the denture. Because the IOD moves less than a denture, the food remains under the IOD.

The majority of mandibular IODs used by the profession are supported by two implants anterior to the mental foramina and soft tissue support in the posterior regions (Figure 29-8). Yet posterior bone loss occurs four times faster than anterior bone loss.[51,52] In a completely edentulous patient, the eventual paresthesia and mandibular body fractures are primarily from posterior bone loss. Dental implants placed in the anterior mandible help retain a lower denture and are a benefit over a complete denture. But the posterior bone loss will continue and may eventually lead to significant complications.[77–79] The anterior implants allow improved anterior bone maintenance, and the prosthesis benefits from improved function, retention, and stability. However, the lack of posterior support in two- and

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three-implant overdentures allows continued posterior bone loss.

A primary concern for RP-5 overdentures (soft tissue support in the posterior regions) compared with RP-4 or fixed restorations (restorations completely supported, retained, and stabilized) should be the continued bone loss in the posterior regions. Not only does the posterior bone resorb faster than the anterior bone, but the implant prostheses with posterior soft tissue support may also accelerate posterior bone resorption two to three times faster than in a complete denture wearer.[80] Therefore, the short-term benefit of decreased cost for RP-5 overdentures may be offset by the accelerated bone loss that is a primary consideration, especially in the younger edentulous patient (Figure 29-9).

Patients wearing complete fixed implant–supported prostheses show little to no posterior bone loss and usual occurrences of bone apposition. For example, studies by Davis et al.,[81] Reddy et al.,[82] Wright et al.,[83] found that prostheses completely supported by implants in the edentulous mandible actually may increase the posterior bone volume (even though posterior implants are not inserted) (Figure 29-10). Misch has noted a similar condition of posterior and anterior bone maintenance with complete implant-supported overdentures even though no implants were positioned behind the mental foramina (Figure 29-11). He observed even grafts of iliac bone to the jaws, which usually resorb without dental implant insertion within 5 years, are instead stimulated and maintain overall bone volume in both the anterior and posterior regions while also maintaining implant integration. Therefore, the next progression in the implant philosophy is to convert all mandibular implant and soft tissue–supported restorations to a completely implant-supported prosthesis (fixed or removable).

In conclusion, the profession should treat bone loss after tooth extraction in a similar fashion as bone loss from periodontal disease. Rather than waiting until the bone is resorbed or the patient complains of problems with the prostheses, the dental professional should educate the patient about the bone loss process after tooth loss. In addition, the patient should be made aware that the bone loss process can be arrested by a dental implant. Therefore, most completely edentulous patients should be informed of the necessity of dental implants to maintain existing bone volume and improve prosthesis function, masticatory muscle activity, esthetics, and psychologic health.

From a bone volume conservation standpoint in the jaws, completely edentulous patients should be treated with enough implants to completely support a prosthesis whether the patient is partially or completely edentulous. The continued bone loss after tooth loss and associated compromises in esthetics, function, and health make all edentulous patients implant candidates. As a result, complete implant–supported restorations should be the restoration of choice.

As a consequence of continued posterior bone loss with a two- or three-implant overdenture, the recommendation is to consider a RP-5 prosthesis as an interim device designed to



FIGURE 29-8. The majority of mandibular implant overdentures use two independent implants anterior to the mental foramina with soft tissue support in the posterior regions.



FIGURE 29-9. A 25-year-old postoperative panoramic radiograph of implants placed in the anterior mandible to support a mandibular implant overdenture. The maxillary arch has almost no residual bone, the posterior mandibular bone loss has exposed the mental foramina, and severe atrophy has occurred to the mandibular body. The anterior mandible has maintained the bone volume during this time frame.

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FIGURE 29-10. Davis et al., Wright et al., and Reddy et al. found that full-arch implant–supported prostheses may prevent posterior bone loss and even may cause some gain in bone volume even though implants are not inserted in the posterior regions.[81-83] This 25-year-old fixed implant prosthesis has maintained anterior and posterior bone in the mandible.



FIGURE 29-11. A 25-year-old postoperative radiograph of a RP-4 mandibular implant overdenture with bone maintenance in the anterior and posterior bone regions.

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enhance the retention of the prosthesis. These restorations should not be considered as an end result for all patients. Instead, a regular evaluation of each patient's performance paired with patient education should enable the transformation to a RP-4 or FP-3 restoration.

Financial considerations have been identified as the reason for the selection of a limited treatment, which may consist of two or three implants to support the overdenture.[13,24] These RP-5 restorations may be used as transitional devices until the patient can afford to upgrade the restoration. When a partially edentulous patient cannot afford to replace four missing first molars, the dentist often will replace one molar at a time over many years. Likewise, the dental implant team can insert one or two additional implants every few years until finally a complete implant–supported prosthesis is delivered. The ultimate goal of bone maintenance with a complete implant-supported prosthesis may be designed in the beginning of treatment even though it may take many years to complete.

The advantage of developing a treatment plan for long-term health, rather than short-term gain, is beneficial to the patient. As such, if finances are not an issue, the dentist should design a prosthesis that is completely supported, retained, and stabilized by implants. If cost is a factor, a transitional implant-retained restoration with fewer implants greatly improves the performance of a mandibular denture. Then the dentist may establish a strategy for the next one or two steps to obtain the final complete implant-supported restoration.

Review of the Literature

Chapter 23 provides a review of the literature related to implant survival for mandibular overdentures. Articles related to the fabrication and maintenance of the restoration are also available. For example, Naert et al. reported greater than 97% implant survival with mandibular overdentures and noted that complications were more related to overdenture technique.[20] Later reports confirmed these results and stated that less maintenance was required for the bar-clip attachment system compared with individual implants.[32] Splinted and unsplinted Brånemark implants were compared for mandibular overdentures in three groups: magnets, ball, or clip and bar.[33] Prosthesis retention was rated as good in all three groups. More complications were found for independent ball attachments, separate attachments (balls or magnets) were less retentive than bars, and bars had the fewest maintenance requirements.

Mericske-Stern evaluated 62 mandibular overdentures with two implants (connected or independent) or four implants.[21] Implant survival rates were similar to those in other studies. The most common complication was the need to replace the prosthetic retentive plastic components. A prospective study of 127 patients by Johns et al. yielded survival rates similar to those for FPs, with higher survival rates in the mandible than in the maxilla.[83] The most common complication was reactivation or fracture of retentive clips during the first year. Wright et al. compared bar designs for overdentures and found that removable prostheses presented similar problems regarding clips and retention.[36] Hemmings et al. also compared the maintenance of fixed and removable prostheses.[27] Overdentures needed more postinsertion maintenance during the first year. However, for all the successive years (in a 5-year study), the FPs had greater complication rates. In contrast, Walton and McEntee reported three times more maintenance and adjustments for removable prostheses compared with FPs.[84]

Chan et al. reported high levels of maintenance on IMZ bar and clips in mandibular overdentures.[34] Davis et al. compared stud and magnet retention for four implant-supported mandibular overdentures and found no statistically significant difference between the two groups.[28] Bergendal and Engquist

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reported on 32 two-implant mandibular overdentures splinted with a bar and clip or ball attachments in function for 7 years with a 100% success rate.[35] Problems with the retentive systems occurred in the early years, which correspond to the development period for the authors. Bilhan et al. evaluated maintenance requirements associated with 59 mandibular overdentures during the first year of service in 2011.[29] Twenty-five overdentures used ball attachments, 18 used Locator type attachments, and 16 patients had a bar connect the implants. Only 33.9% of the IODs had no prosthetic complications. The most common complications were ulcerations, fracture of the denture base, dislodged attachment clip, and screw loosening. The fewest complications were found in the three-implant overdentures connected with a bar.

Therefore, reports seem to concur that the mandibular overdenture modality is successful, with the concern that retentive components may be the weak link of the system. In general, splinted implants with an attachment system for the prosthesis have fewer prosthetic and maintenance issues than individual implants and attachments. However, early learning curves for the restoring dentist resulted in a higher prosthetic complication rate regardless of the prosthesis design.

Overdenture Treatment Options

Traditional overdentures must rely on the remaining teeth to support the prosthesis. The location of these natural abutments is highly variable, and they often comprise past bone loss associated with periodontal disease. For a mandibular implant-supported overdenture, the implants may be placed in planned, specific sites, and their number may be determined by the restoring doctor and patient. In addition, the overdenture implant abutments are healthy and rigid and provide an excellent support system. As a result, the related benefits and risks of each treatment option may be predetermined.

Fewer than 10% of dentists regularly treat edentulous patients. Fewer than 6% of dentists have a supervised learning curve for IODs, and fewer than 15% have taken courses after graduation specifically related to this treatment option. Therefore, the vast majority of dentists use the training gained in dental school for dentures and limited clinical experience to treat overdenture patients. As a result, most dentists attempt to restore all patient conditions with the same overdenture approach with limited implant number and individual implants because this is perceived as the easiest treatment option (which is also associated with the lowest fee). This is a mistake that often leads to an increase in complications.

In 1985, the author presented five organized treatment options for implant-supported mandibular overdentures in completely edentulous patients. The author reported less than 1% implant failure and no prosthesis failure over a 7-year period with 147 mandibular overdentures (IOD) when using the organized treatment options and prosthetic guidelines presented in this chapter.[18] Kline et al. reported on 266 implants for mandibular splinted implant-supported overdentures for 51 patients with the Misch protocol.[85] An implant survival rate of 99.6% and a prosthesis survival rate of 100% were reported.

The IOD treatment options range from primarily soft tissue support and implant retention (RP-5) to a completely implant-supported prosthesis (RP-4) with rigid stability and retention gained primarily from overdenture attachments. The prostheses are supported by two to five anterior implants for these five treatment options. There are four RP-5 options that have a range of retention, support, and stability. The RP-4 restoration has a rigid cantilevered bar that completely supports, stabilizes, and retains the restoration (Figure 29-12). These five options are presented in detail in Chapter 21. This chapter is designed to discuss the methods for the restoration of the IOD.

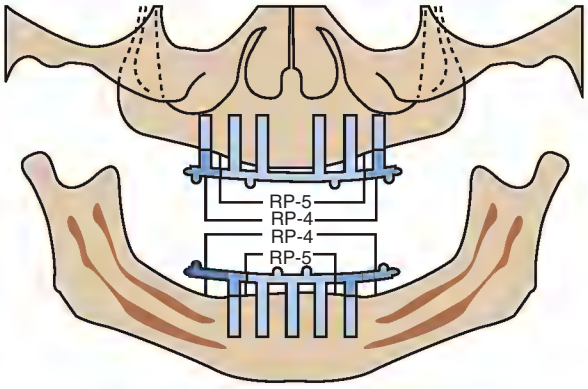


FIGURE 29-12. Five prosthetic options are designed for the mandibular overdentures. Four options are RP-5 (posterior soft tissue support), and one option is RP-4 (prosthesis completely supported by implants and connecting bar).

The overdenture options presented in this chapter err on the side of safety to reduce the risk of implant failure and prosthetic complications. The initial treatment options are presented for completely edentulous patients with division A (abundant) or B (sufficient) anterior bone, treated with division A anterior root form implants of 4 mm or greater diameter. Modifications related to posterior ridge support and arch form also are discussed. After discussion of these standardized conditions, anterior bone volume conditions of moderate atrophy (division C minus height [C–h]) are presented.

Overdenture Movement

To develop a mandibular IOD with reduced complications, the final prosthesis should be predetermined related to the necessary retention, support, and stability required for the restoration. Retention of the restoration is related to the vertical force necessary to dislodge the prosthesis.[58] The amount of overdenture retention is related to the number and type of attachments. Support is related to the amount of vertical movement of the prosthesis toward the tissue. Stability of a prosthesis is evaluated with horizontal or cantilevered forces applied to the restoration. The stability of the IOD is more related to implant (and bar) position, and support is primarily related to implant number and bar design in the posterior region.

The patient's complaints, anatomy, desires, and financial commitment determine the amount of implant support, retention, and stability required to predictably address these conditions. Because different anatomical conditions and patient force factors influence these factors for an IOD, not all prostheses should be treated in the same manner. In other words, the two-implant overdenture should not be the only treatment plan offered to a patient. One should emphasize that most mandibular overdentures should be designed to eventually result in a RP-4 prosthesis, as previously discussed.

The most common complications found with mandibular IODs are related to prosthetics and an understanding of retention, support, and stability of the prosthesis. When a fixed restoration is fabricated on implants, it is rigid, and cantilevers or offset loads are clearly identified. Rarely will a practitioner place

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a full-arch fixed restoration on three implants, especially with excessive cantilevers because of implant positioning. However, three anterior implants with a connecting bar may support a completely fixed overdenture, solely because of attachment design or placement. The restoring doctor thinks the three-implant overdenture has less prosthetic occlusal load but does not realize that an overdenture that does not move during function is actually a fixed restoration. Therefore, an overdenture with no prosthesis movement (PM) should ideally be supported by the same number, position, and design of implants as a fixed restoration.

Many precision attachments with varying ranges of motion are used in IODs. The motion may occur in zero (rigid) to six directions or planes: occlusal, gingival, facial, lingual, mesial, and distal.[86,87] A type 2 attachment moves in two planes and a type 4 attachment in four planes. An IOD may also have a range of movement during function. It should be understood that the resulting overdenture movement during function may be completely different from the one provided by independent attachments and may vary from zero to six directions depending on the position and number of attachments even when using the same attachment type.[18] For example, an O-ring attachment may allow six directions of movement. However, when four O-rings are placed on a bar, the PM during function or parafunction may have no directions of movements (Figure 29-13). Therefore, attachment and PM are independent from each other and should be evaluated as such. An important item for the IOD treatment plan is to consider how much PM the patient can adapt to or tolerate on the final restoration.

An important aspect of overdenture PM is also related to the height of the attachment connection. There are two crown height dimensions for RP-5 overdentures: (1) the occlusal plane to the height of the attachment rotation and (2) the height of the attachment to the level of the bone (Figure 29-14). The occlusal plane to attachment height is a force magnifier to the overdenture with any lateral or cantilevered force. When an attachment is connected to an implant directly, the crown height above the attachment is greater than when the attachment is placed on a bar. If you double the crown height, the force is increased 200%. Hence, the individual implant attachment has a greater crown height above the attachment and greater lateral force to the prosthesis. Therefore, the overdenture is less stable.

When the attachment is placed on a bar, the stability of the prosthesis is improved because less lateral force is applied to the prosthesis (because the crown height above the attachment is reduced). Hence, whenever possible, the implant should be connected with a bar and an attachment placed on top of the bar. Rotation of the prosthesis should be as far off the bone as practical. However, there should be 3 mm or more of acrylic space between the attachment and the denture teeth. This allows adequate dimension to decrease prosthesis fracture or dislodgement of teeth.

The second CHS is the attachment to the bone height. The greater the attachment-to–bone height, the greater the force placed on the implant abutment screw, marginal bone, and implant–bone interface with any lateral load. When the attachment-to–bone height is greater than 7 mm, the implants should be splinted together to decrease the risk of complication of the implant system.

Classification of Prosthesis Movement

The classification system proposed by the author in 1985 evaluates the directions of movement of the implant-supported prosthesis, not the overall range of motion for the individual attachment; therefore, the amount of PM is the primary concern.[18] An overdenture is by definition removable, but in function or parafunction, the prosthesis may have a range of movement from 0 to 6. The dentist should determine the amount of PM the patient desires or that the anatomy may tolerate.

If the prosthesis is rigid when in place but can be removed, the PM is labeled PM-0 regardless of the attachments used. For example, O-rings may provide motion in six different directions. But if four O-rings are placed along a complete arch bar



FIGURE 29-13. Prosthesis movement (PM) for overdentures is often different than "attachment" movement categories. In this RP-4 overdenture bar, O-rings (a class 6 attachment movement) and Hader clip (a class 2 attachment movement) support a rigid overdenture. The PM is PM-0.



FIGURE 29-14. There are two crown height space aspects for an implant overdenture. The occlusal plane to the attachment is a crown height force magnifier to the overdenture. Any lateral or offset load will be magnified in relation to the crown height above the attachment.

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and the prosthesis rests on the bar, the situation may result in a PM-0 restoration (see Figure 29-13).

A hingelike PM permits movement in two planes (PM-2) and most often uses hingelike attachments. For example, the Dolder bar and clip without a spacer or Hader bar and clip are the most commonly used hingelike attachments.[88,89] A Dolder bar is egg shaped in cross-section, and a Hader bar is round. A clip attachment may rotate directly on the Dolder bar. A Hader bar is more flexible because round bars flex to the power of 4 related to the distance between the abutments, and other bar shapes flex to the power of 3. As a result, an apron often is added to the tissue side of the Hader bar to limit metal flexure, which might contribute to unretained abutments or bar fracture.[90] A cross-section of the Hader bar and clip system reveals that the apron, by which the system gains strength compared with a round bar design, also limits the amplitude of rotation of the clip (and prosthesis) around the fulcrum to 20 degrees, thus transforming the prosthesis and bar into a more rigid assembly (Figure 29-15). Therefore, the Hader bar and clip system may be used for a PM-2 when posterior ridge shapes are favorable and soft tissue is firm enough to limit prosthesis rotation.

It should be noted that for these systems to function efficiently, the hinge attachment needs to be perpendicular to the axis of prosthesis rotation so the PM also will be in two planes (i.e., PM-2). If the Hader or Dolder bar is at an angle or parallel to the direction of desired rotation, the prosthesis is more rigid and may resemble a PM-0 system (Figure 29-16). As a consequence, the implant system may be overloaded and cause complications such as prosthetic screw loosening or fracture, implant crestal bone loss, and even implant failure. A Hader bar-clip system is an ideal low-profile attachment for a RP-4 prosthesis with PM-0. Usually, these clips are placed on the bar in different planes of rotation around the arch.

A prosthesis with an apical and hinge motion is PM-3. An example is a Dolder bar with a space provided over the bar. As a result, the prosthesis moves toward the tissue and then rotates. A PM-4 allows movement in four directions, and the PM-6 has ranges of PM in all directions. The most common overdenture attachments for a PM-6 is independent O-rings or Locator attachments (Figure 29-17).

The Hidden Cantilever

The hidden cantilever applies to that portion of the RP that extends beyond the last implant or connecting bar.[18] If the RP does not rotate at the end of the implant or bar to load the soft tissue, a hidden cantilever exists. For example, if a cantilevered bar extends to the second premolar but forces on the second molar of the restoration do not result in movement of the restoration (down in the back and up in the front), the cantilever really is extended to the second molar position. Therefore, the cantilever length is measured to the point of PM, not to the end of the bar and attachment system (Figures 29-18 and 29-19). The teeth on the final overdenture restoration usually do not extend beyond the first molar. This helps prevent a hidden cantilever from extending beyond this position. Removable prostheses with hidden cantilevers can result in marginal bone loss and even implant failure (Figure 29-20). In many of these cases, the attachment system does not wear because the RP is



FIGURE 29-16. A Hader bar and clip is a class 2 attachment system. However, when the clips are placed parallel or at an angle to the desired prosthesis movement (PM), the prosthesis is rigid. In this case, two implants are not enough to support a PM-0 implant overdenture. Screw loosening, bone loss, and implant failure resulted.

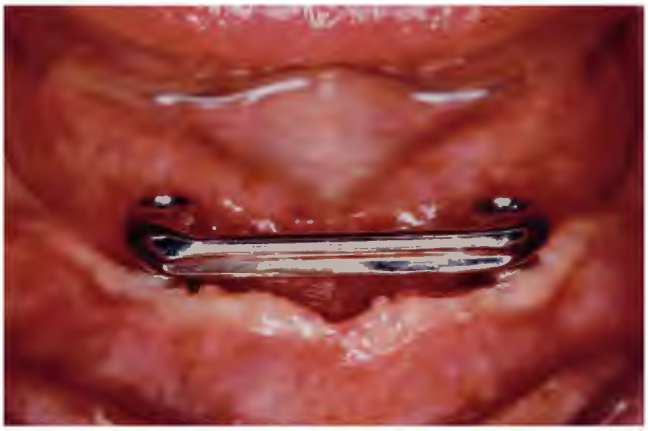


FIGURE 29-15. A Hader bar and clip attachment may be used for an implant overdenture (IOD). The apron below the round bar restricts the rotation of the clip. An IOD with a Hader clip may rotate 20 degrees around a bar when the bar is perpendicular to the midline of the mandible.



FIGURE 29-17. The most common implant overdenture attachment for independent implants or PM-6 prosthetic movement is an O-ring or Locator attachment. The Locator attachment is lower profile and has the male portion in the denture and the female component of the attachment in the mouth.

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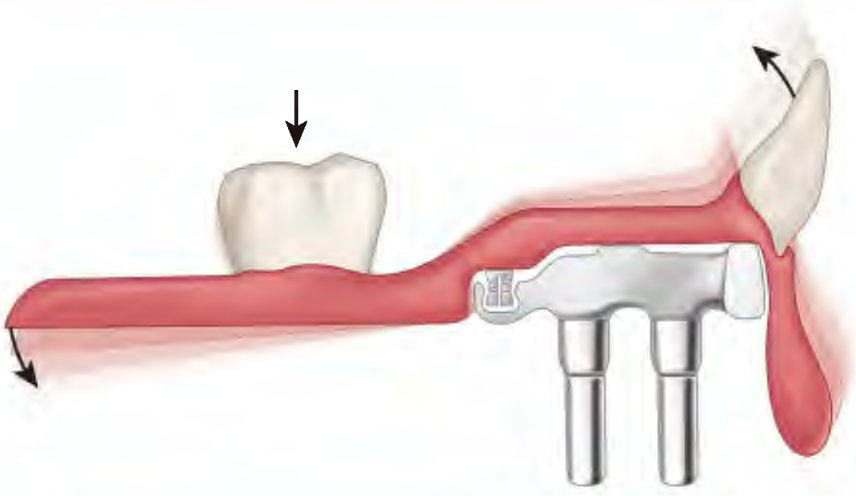


FIGURE 29-18. The hidden cantilever is that portion of the removable prosthesis that extends beyond the connecting bar, which does not rotate. If the prosthesis rotates at the first molar position and the bar extends to the premolar, the true cantilever length is the first molar position.

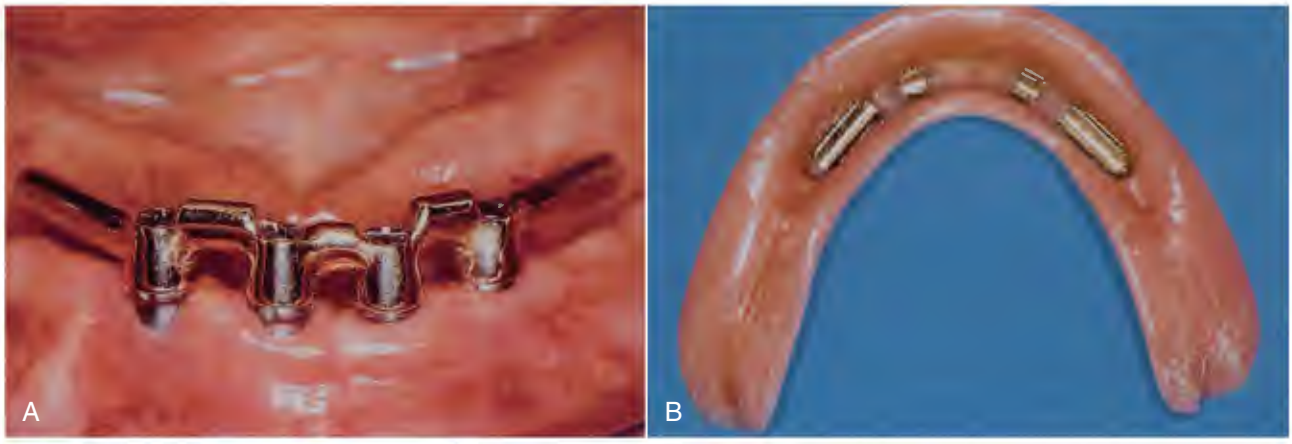


FIGURE 29-19. **A,** Four anterior implants with a cantilevered bar of 10 mm. Hader clips in four different rotation positions are placed around the arch. **B,** The implant overdenture with four Hader clips with different paths of rotation. Hence, the prosthesis movement is PM-0, and the hidden cantilever extends to the second molar.

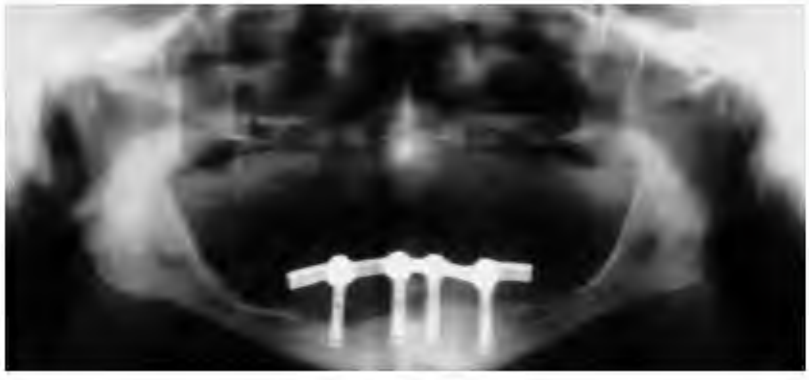


FIGURE 29-20. A panoramic radiograph with four anterior implants connected with a cantilevered Hader bar. A PM-0 resulted in significant bone loss of the patient's distal right implants.

PM-0, but prosthetic and abutment screws and marginal bone are more at risk.

Overdenture Attachments

Among the multitude of attachments offered to the profession, the author has elected to use proven, simple, predictable, and cost-effective devices, limited to a minimum of hardware. The more sophisticated the attachment, the more complex the fabrication and maintenance procedures.

An ideal overdenture attachment should have several features to decrease clinical complications. An overdenture attachment permits movement during function or removal from the mouth.[86,89,91] As a result, all overdenture attachments wear and become less retentive. The portion of the attachment in the prosthesis, not the portion connected to the superstructure or implant, should be designed to wear and be replaced. Hence, plastic or silicone components are often used in the prosthesis, which engage metal components that are found attached to bars or implants in the mouth.

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The replacement of the attachment in the prosthesis should not use a chairside, cold-cure acrylic procedure because it may lock the prosthesis to the implant and bar and add considerable time, risk, and frustration every time the attachment is changed. A metal encapsulation unit within the prosthesis, which retains a plastic or rubberlike device, eliminates most unpredictable aspects of the attachment replacement.

Ideally, the overdenture attachment should offer the possibility of controlling the degree of retention. A loose attachment used at initial delivery ensures PM and decreases screw loosening during the first few months. A gradual increase in retentive capability may be achieved later by replacing the component within the encapsulator by a more retentive one. Likewise, if more retention is required in the future, a stiffer element, which is held by the same encapsulator, easily solves the problem. The more stiff component also may be necessary as the metal portion of the attachment wears from long-term use.

The ideal overdenture attachment is able to be replaced by the patient. Because all attachments wear, the patient will return to the dentist to have the attachment replaced. The time to make an appointment, clean a treatment room, talk to the patient, replace the attachment, and reclean the room costs the restoring dentist hundreds of dollars. The attachment may be changed at a hygiene appointment to eliminate these additional costs. If the patient maintains his or her hygiene appointment schedule and an attachment prematurely wears, it may be mailed to the patient and replaced by the patient.

An ideal overdenture attachment has the male component in the mouth and the female in the prosthesis. The male can be more easily cleaned while in the mouth, and the more difficult component to clean may be performed with direct vision and access out of the mouth. When the female component is part of the implant or connecting bar, if any plaque or food accumulates within the component, the overdenture does not seat completely, and there is a loss of retention, and the occlusion of the prosthesis is also affected. Hence, the O-ring attachment system has become popular because it has a range of different retention strengths, has a metal encapsulator, can be changed or replaced by a layperson, and has the male component in the mouth. The O-ring post may also be fabricated with the same metal as the connecting bar, which reduces the overall initial costs (Figure 29-21).



FIGURE 29-21. Two implants connected with a bar and two male components of the same material for the O-ring attachment system.

O-Ring Attachment System

The O-ring attachment system is composed of an elastic O-ring, a metal encapsulator, and a metal post. It may be used as an independent unit or part of a connecting bar that joins the implants together (Figure 29-22).

O-Rings

O-rings are doughnut-shaped, synthetic polymer gaskets that possess the ability to bend with resistance and then return to their approximate original shape. In part, this feature results from a three-dimensional network of flexible elastomeric chains. The O-ring attaches to a post with a groove or undercut area for the O-ring. The O-ring is compressed radially between two mating surfaces consisting of a post and a metal encapsulator into which the O-ring is installed.[92] The O-ring has been used primarily in removable prosthetics as a retentive device.[93] The O-ring has seen a resurgence in popularity with overdentures supported by endosteal implants and is widely available in a variety of implant systems.[92]

The O-ring originally was made of natural rubber. The latex was heat treated with sulfur (vulcanization) to improve its properties. The resultant polymer, known as polyisoprene, is still used in the industry today. The advantages of O-rings are ease in changing the attachment, the wide range of movement, low cost, different degrees of retention, and possible elimination of the time and cost of a superstructure for the prosthesis.

All O-ring applications are categorized in terms of relative motion. In situations that require few or no moving parts or movement, the O-ring is classified as static (e.g., gasket or washer). In situations involving reciprocation, rotation, or oscillating motion relative to the O-ring, it is classified as dynamic. The dynamic movement of the O-ring allows one of the most resilient or mobile types of attachments.

O-rings may allow motion in six different directions. However, if a superstructure connects the implants, the range of



FIGURE 29-22. An O-ring attachment has a resilient O-ring gasket *(top right)*, a metal encapsulator *(top left)*, and a male post *(middle)*.

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motion decreases. If the O-ring is placed on a complete arch bar in four different sites and the prosthesis rests on the superstructure bar, the restoration may have PM of 0 (PM-0) (Figure 29-23). Two O-rings placed on a bar perpendicular to the midline may have two to six directions of PM, depending on the resilient depression of the O-rings, whether a spacer is over the post head, or space is over the connecting bar (Figure 29-24).

Metal Encapsulator

A metal or plastic encapsulator permits the easy replacement of the O-ring after wearing or damage. This eliminates the need for chairside cold curing of a new attachment in place. Virtually every O-ring encapsulator has an undercut region that houses the O-ring, called the internal cavity. The O-ring volume must be larger than the internal cavity. As a result, the O-ring is compressed into position in the encapsulator and prevents the ring from moving or rolling while in place, which prematurely damages and wears the ring. The overall size of the encapsulator is larger than the O-ring and should be placed with the O-ring on the O-ring post during fabrication of the prosthesis to ensure adequate room (2 mm or more of acrylic is present for the volume of the restoration) (Figure 29-25).

In general, the use of soft metals such as aluminum, brass, bronze, or gold should be avoided for the metal encapsulator. Stainless steel is recommended because it prevents damage to the encapsulator. Rounding of all corners of the encapsulator is recommended to prevent cutting or nicking of the O-ring during insertion or operation.

O-Ring Post

The O-ring post usually is made of machined titanium alloy when used as an independent attachment or a Delrin post that is waxed and cast in precious metal along with the connecting superstructure bar joining root forms (Figure 29-26). The post has a head, neck, and body. The head is wider than the neck, and the O-ring is compressed over the head during insertion. Under the head of the post there is an undercut region called the neck or groove, which the ring engages after it stretches over the head. The body of the post is connected to the implant abutment or superstructure bar.



FIGURE 29-23. When O-rings are positioned around an arch and connected with a bar, the prosthesis movement (PM) may be PM-0.



FIGURE 29-24. When O-rings are positioned on a bar perpendicular to the midline, the implant overdenture may rotate in two to six directions depending on whether space exists over the post or connecting bar.

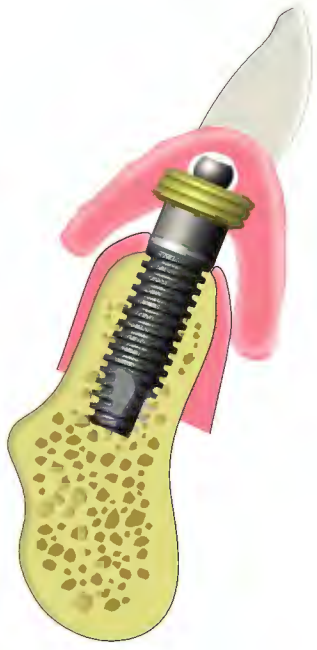


FIGURE 29-25. The metal encapsulator of the O-ring should fit within the contours of the implant overdenture, so at least 2 mm of acrylic exists around this structure.



FIGURE 29-26. The O-ring post may be a Delrin material, which is waxed as part of the connecting bar and will burn out and allow the same metal as the bar to be used as the O-ring post.

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The inside surface of the O-ring rides against the post neck or groove. The internal diameter (hole diameter) of the O-ring must be smaller than the post neck and fit snugly in the groove diameter. The O-ring inside diameter will be stretched to 1% to 2% (not to exceed 5%) when in place against the post neck.[94] If not, the O-ring will roll or wobble and increase wear and tear of the attachment. Overpolishing of a cast post neck region may unwittingly cause this complication.

The O-ring attachment system needs 5 mm or more height, the greatest of any attachments for overdentures. In addition, a space of 1 to 2 mm above the O-ring post is suggested to ensure that the ring seats completely over the post head of the post. This space also prevents the post from penetrating or fracturing the restoration over the head and allows apical movement for a partial soft tissue–supported RP (RP-5).

The height requirements of the O-ring attachment present several disadvantages. A decreased CHS may require a lower-profile attachment (Figure 29-27). A denture tooth, O-ring, post, bar, and hygiene clearance often require at least 12 to 15 mm of CHS to allow sufficient room for the acrylic base of the restoration to resist fracture. In addition, the higher the freedom of movement of a stress-relief attachment (required for all partial soft tissue–supported prostheses), the greater the moment of force on the attachment. Because the rotation point of O-rings is at the neck of the O-ring post, the point of rotation is not as high as first perceived. However, if the prosthesis is made incorrectly and places lateral forces on the post, the lever arm of the post height can increase the force to the bar, screws, implants, and bone.

Size

O-rings and posts may come in a variety of diameters depending on the space available within the volume of the prosthesis. The larger the diameter of the O-ring system, the easier it is to place the O-ring within the encapsulator. Troubleshooting retention complications is also easier, and greater retention is possible with a larger-diameter system. Typically, three sizes of O-rings are used in implant prostheses (small, medium, and large).

O-Ring Hardness

O-ring hardness is measured with a durometer, which measures surface resistance to the penetration of an indentation point. The resultant numerical rating of hardness ranges from 0 to 100 in a Shore A Scale.[94] The softest O-rings are usually 30 to 40, and the hardest are 80 to 90. Color is not indicative of hardness. In fact, most O-rings are black. Sometimes, however, for production coding or cosmetic reasons, nonstandard colors are desired. Replacement of carbon black with tinted fillers (i.e., clay, calcium carbonate, or silicates) may result in undesirable alteration of working and physical properties. Increased wear and complication rates result.



FIGURE 29-27. The O-ring on a connecting bar has a higher profile than most attachments. As a result, denture or denture base fracture may occur if inadequate crown height space is available.

O-Ring Materials

The U.S. Food and Drug Administration has issued guidelines for O-rings used in medicine.[94] The elastomeric materials meeting these requirements include silicone, nitrile, fluorocarbon, and ethylene-propylene. The materials are available from a variety of industrial manufacturers.[95–102]

Silicone is composed of a group of elastomers made from silicone, oxygen, hydrogen, and carbon. Silicones are known for their retention of flexibility and low-compression set characteristics. Silicones are also fungus resistant, odorless, tasteless, and nontoxic. However, poor tensile and tear strength, low abrasion resistance, and high friction characteristics preclude silicones from effective O-ring use in most implant dynamic situations. In addition, silicone is not compatible with petroleum-based products such as petroleum jelly.[102,103] Ethylene-propylene is a co-polymer of ethylene and propylene, sometimes combined with a third co-monomer. Similar to silicone, this elastomer performs poorly when exposed to petroleum-based products.

Nitrile is one of the more widely used elastomers for implant O-ring use. Nitrile combines excellent resistance to petroleum-based products, silicone greases, water, and alcohols, with a good balance of desirable properties such as high tensile strength and high abrasion resistance.[102] Fluorocarbon also combines excellent resistance to petroleum products with outstanding chemical resistance. Fluorocarbon-based compounds approach the ideal for a universal O-ring material.[103]

Surface treatment of O-rings with lubricants helps protect them from abrasion, pinching, and cutting during performance. External lubrication also helps seat the O-rings easily into the metal encapsulator with minimal twisting or damage and maximal assembly speed. In all cases requiring O-ring lubrication, a lubricant should be selected that is compatible with the O-ring compound and the oral environment. Nitrile O-rings may be lubricated with petroleum jelly or petroleum-based ointments. Petroleum-based products will damage silicone O-rings, so a water-based lubricant (e.g., KY-Jelly [Johnson & Johnson]) that has a glycerin component should be used.

Troubleshooting O-Rings

O-rings typically fail in their application because of the combined adverse effects of stress and environmental elements (i.e., friction, heat, and swelling).[104–106] Such environmental factors may be compounded by incorrect O-ring size, improper laboratory technique, installation damage during final component assembly, and failure to properly maintain or lubricate the O-ring.

Extrusion and Nibbling

Extrusion and nibbling occur with forced extension of part of the O-ring into the clearance gap of the metal encapsulator. The problem is identified by O-ring diameter enlargement or many small bites (nibbles) taken from the internal diameter of the O-ring, which results when O-ring materials are too soft, oral fluids degrade the O-ring, or the O-ring is too large for the metal

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encapsulator. The clinical solution for this problem is to use a harder O-ring material or install a properly sized O-ring.

Spiral Failure

A spiral failure results when certain segments of the O-ring slide while other segments simultaneously roll (Figure 29-28). At a single point on its periphery, the O-ring gets caught on an eccentric component or against the metal encapsulator wall, causing twisting, spiraling, or surface cuts. Problem sources include an uneven surface or finish of the post by the laboratory, inadequate lubrication, or excessive O-ring material softness. The suggested solutions are evaluation of the post to ensure that it is not out of round, increasing O-ring hardness, and making sure the patient uses a lubricant daily.

Abrasion

Abrasion may occur in dynamic O-rings involved in reciprocating, oscillating, or rotary motion. This failure pattern can be identified by a flattened, worn surface on the inner diameter of a cross-section of the O-ring. The most common cause is bruxism by the patient or lifting and seating of the overdenture as a nervous habit. Another source of the problem includes a rough metal surface on the post (acting as an abrasive). The suggested solutions are to use the recommended metal finishes; change to a more abrasion-resistant O-ring material; or eliminate abrasive contamination, which may be found in the diet (e.g., the abrasive particles found in chewing tobacco).[107]

Compression Set

Compression set failure produces flat surfaces on both sides of the cross-section of the O-ring (Figure 29-29). The most common cause of this type of failure is parafunctional clenching on the prosthesis. Other problem sources include selection of an elastomer with poor compression set properties or excessive "squeezing" or biting of the prosthesis into place to seat the restoration. The suggested solution is to make sure the prosthesis is removed at night or to reduce the O-ring hardness, which reduces the compression required to insert the prosthesis.

Installation Damage

Installation damage is one of the most common types of O-ring complications. This failure mode is marked by short cuts, notches, or a skinned or peripherally peeled surface (Figure 29-30). The problem sources include sharp edges on the encapsulator from poor laboratory technique, sharp edges on the O-ring post head, too large an O-ring for the encapsulator, twisting or pinching of the O-ring into the encapsulator, attempting to insert the O-ring with a sharp instrument, too small an O-ring for the post, or lack of O-ring lubrication during installation. The suggested solutions include installing properly sized O-rings, using a blunted insertion instrument, and using lubrication during assembly.

Hader Bar and Clip

Helmut Hader developed the Hader bar and rider system in the late 1960s, and this system was unchanged for almost 30 years. English, Donnel, and Staubli modified the system in 1992 to form the Hader EDS system.[90,108] Whereas the EDS bar is only 3 mm high, the original was 8.3 mm in height. The total height of the Hader bar and clip assembly may be as low as 4 mm rather than the 5 to 7 mm required for an O-ring system (Figure 29-31). Therefore, a greater moment of force is placed on the bar during rotation, and clearance is required under the denture base. However, the increase in CHS above the attachment may make the prosthesis less stable to lateral loads for PM-2 type prostheses (Figure 29-32).

The clips have three different retention strengths and a 20-degree clip rotation, which greatly improves the flexibility of the system for a range of patient needs or desires. In addition, a gold-plated stainless steel housing maintains the clip, which reduces the need to cold cure new attachments in place. This is a significant advantage. The gold plating minimizes the

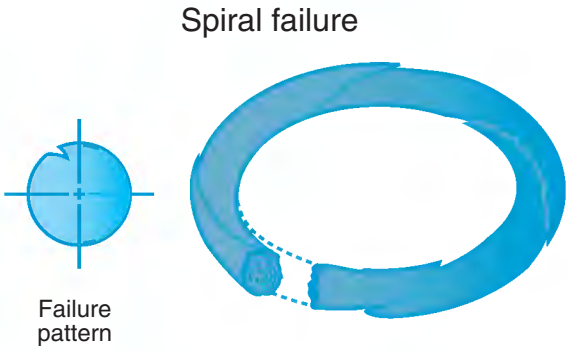


FIGURE 29-28. Spiral failure of an O-ring exhibits a series of deep spiral cuts on the surface.

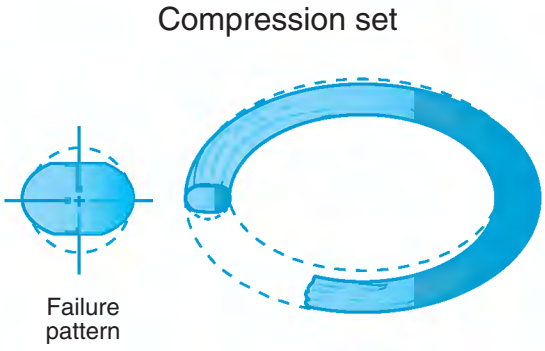


FIGURE 29-29. Compression set failure is demonstrated as flat surfaces on the top and bottom of the O-ring.



FIGURE 29-30. A common source of O-ring failure occurs during the installation of the O-ring. Sharp instruments should not be used for this intent.

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FIGURE 29-31. The Hader bar (mid distal) is a lower-profile attachment than the O-ring (mesial and distal attachments).



FIGURE 29-33. When the Hader bar is perpendicular to the midline and parallel to the occlusal plane, a PM-2 system is created.



FIGURE 29-32. The Hader clip and metal encapsulator is a class 2 attachment that may be used in a PM-0 to PM-2 system, may be low profile, and have three different retention clip strengths. The Hader clip and bar may have a lower profile, so it may be used in situations of reduced crown height space (CHS). However, when the low-profile system approach is used in situations of a larger CHS, the prosthesis may be less stable to any lateral loads.



FIGURE 29-34. A Hader bar and clip may be used for an implant overdenture with PM-0 for a RP-4 prosthesis. Studies by Bidez and Misch and by English evaluated the cantilevered Hader bar at 10, 15, and 20 mm, with 1-, 2-, and 3-mm stiffiner heights.[115,116]

color bleeding through the prosthesis. The Hader bar and clip is a type 2 attachment and may be used for PM-0 or PM-2 treatment plans.

The standard or EDS Hader bar has a round superior aspect and an apron toward the tissue below. The apron acts as a stiffener to improve the strength of the bar and limit its flexibility. Round bar designs flex in relation to X^4. In other words, a bar twice as long flexes $|2| \times |2| \times |2| \times |2| = 16$ times more. Other bar shapes flex to X^3 or $|2| \times |2| \times |2| = 8$ times more. This is a considerable improvement. The height of the apron or stiffener is related to the amount of clearance between the bar and gingiva.

The clip rotation compensates for the resilience of the posterior soft tissue, which is usually 0.5 to 1 mm in the mandible. Highly mobile tissue, more often seen in the maxilla, requires a greater range of clip movement. For a bar and clip to rotate, several important design features must be considered. For example, the bar should be aligned perpendicular to a line bisecting the angle between the posterior arches and should be parallel to the plane of occlusion[86] (Figure 29-33).

The Hader bar and clip may also be used for a PM-0 IOD. Bidez et al. performed a finite element analysis of Hader bars on four abutment designs with stiffener heights of 1, 2, and 3 mm, with three different cantilever lengths (10, 15, and 20 mm) and of three dental alloys, gold (type IV), 85% gold, and cobalt–chromium–molybdenum[109,110] (Figure 29-34). With a 1-mm stiffener height, increasing the cantilever length from 10 to 20 mm raised the maximum stresses at the superior aspect of the bar to the coping junction by 111%. Cantilever length was more significant than the stiffness of the alloys tested, and predictions of failure occurred. Although 2- and 3-mm stiffeners improved the results, a 20-mm cantilever reached the fatigue level established for the study within an estimated 5 to 10 years. Therefore, the recommendation is that when a cantilever is used with a Hader bar system, it should be less than 10 to 12 mm with a stiffener height of 3 mm.

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Mandibular Implant Site Selection

Anterior rather than posterior retention and stability for an overdenture prosthesis offer several advantages. An axiom in removable partial denture design for a class IV Kennedy-Applegate partial edentulous arch (bilateral posterior teeth missing and anterior missing teeth across the midline) is to gain rigid prosthetic support in the anterior region. When the prosthesis has poor anterior and good posterior stability, it rocks back and forth during function. This rocking action applies torque to the abutments and increases stresses on the overdenture components and bone–implant interface. Hence, the retention and stability of the prosthesis should be primarily from the anterior region of the mouth.

This concept is fortunate because almost always implants in the mandible are inserted in the anterior region of the jaw. It should be noted, however, that in maxillary overdentures, implants are often inserted into posterior regions (after sinus grafts) when there is inadequate bone in the anterior region of the mouth. This often causes an unstable restoration and may even be worse than the complete denture.

Overdentures with posterior movement gain better acceptance than removable restorations with anterior movement. The anterior denture teeth are most often slightly anterior to the edentulous ridge. As a result, although the prosthesis is more stable with anterior implants, horizontal or vertical forces to the mandibular anterior teeth cause the prosthesis to rock down in the front (and up in the back). The range of movement is limited by the implants because there is no bone under the anterior teeth. In the posterior regions, the posterior denture teeth may be positioned over the bone (over the ridge or buccal shelf of bone), which is often parallel to the occlusal plane. As such, when posterior vertical bite forces are applied, the posterior PM is limited to the movement of the tissue. Therefore, anterior forces to the IOD should be resisted by implants or bars, but posterior forces may be directed on a soft tissue area, such as the mandibular buccal shelf.

The greatest available height of bone in an edentulous mandible is located in the anterior mandible between the mental foramina. This region also usually presents optimal density of bone for implant retention, stability, and support of the prosthesis. Therefore, the IOD treatment options presented are designed for anterior implant placement between the mental foramina because the prostheses movement will be more limited and the available bone volume and density are more favorable than when implants are inserted more posterior.

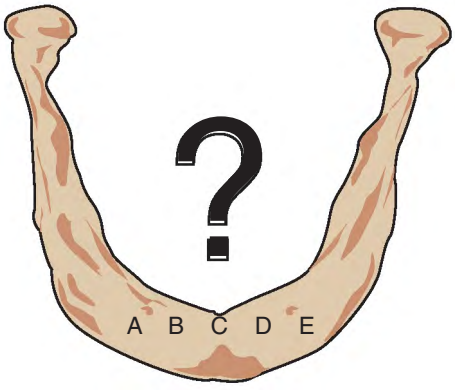


FIGURE 29-35. The anterior mandible is divided into five equal columns of bone between the mental foramina: A, B, C, D, and E.

The available bone in the anterior mandible (between the mental foramina) is divided into five equal columns of bone serving as potential implant sites, labeled A, B, C, D, and E, starting from the patient's right side[18,111] (Figure 29-35). Regardless of the treatment option being executed, all five implant sites are mapped at the time of treatment planning and surgery. There are four reasons for this treatment approach.

1. The patient always has the option to obtain additional implants and prosthesis support and stability in the future if all five sites were not initially used for implant support. For example, a patient may receive adequate retention, stability, and support for an IOD with four implants. However, if the patient desires a FP in the future, these four implants may fall short of the new prosthetic requirements. If the implant surgeon did not plan an additional implant site during the initial surgery but instead placed the four implants an equal distance apart, the additional interimplant space may not be available without removing one of the preexisting implants.
2. A patient may desire a completely implant-supported restoration (e.g., RP-4 or FP) but cannot afford the treatment all at once. Three implants in the A, C, and E positions and an IOD may be provided first. After all, the IOD offers considerable advantages over a complete denture. Two more implants may be added in the B and D locations later, and a completely implant-supported overdenture or fixed restoration may then be fabricated (Figure 29-36).

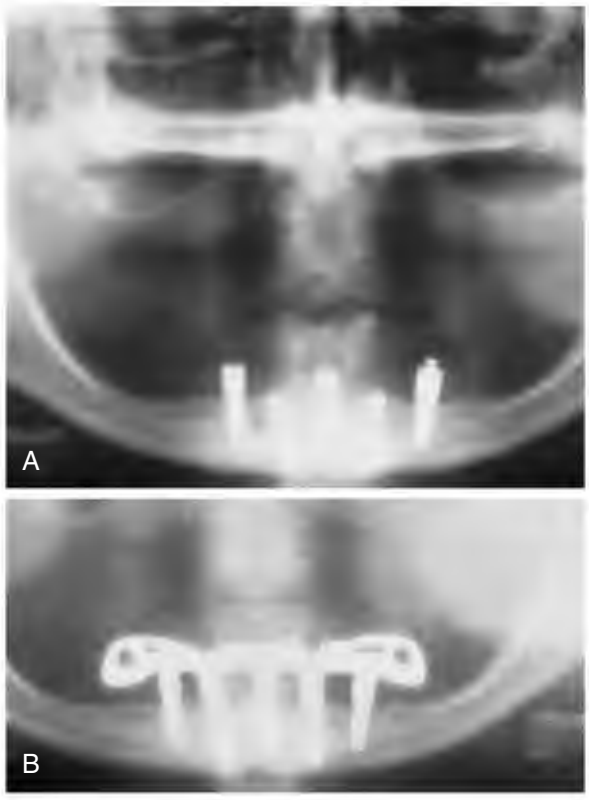


FIGURE 29-36. **A,** This patient wore a three-implant overdenture for several years. She then decided to improve the overdenture support, stability, and retention. The implant sites B and D could be added later because all five implant sites were initially planned. **B,** A hybrid fixed prosthesis was fabricated after the two additional implants were placed.

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3. If an implant complication occurs, the preselected option sites permit repeatable corrective procedures. For example, if implants were placed in the A, B, D, and E positions and an implant fails to achieve rigid fixation, the failed implant may be removed and an additional implant placed in the C position at the same time. This saves an additional surgery and eliminates the time required for bone grafting and healing before another implant could be reinserted (Figure 29-37).
4. The fourth reason the five implant sites are repeated for each treatment option is for the experience of the restoring dentist. In overdentures supported by natural teeth, the dentist is forced to choose the best remaining teeth to support the restoration. These remaining teeth have a wide range of clinical conditions and locations. As a consequence, each tooth-supported overdenture is slightly different in regard to retention, stability, and support. In implant dentistry, healthy predictable abutments in preselected locations and the range in the number of implants permit the restoring dentist to obtain more similar clinical results for each treatment option selected. Hence, a more predictable predetermined treatment may be established for each patient, depending on psychologic need, anatomical conditions, and financial restraints.

Screw-Retained Superstructures

There are five treatment options for mandibular IODs. Overdenture options 1 to 4 have posterior soft tissue support, primarily from the buccal shelf region as with traditional mandibular dentures. Therefore, the clinical techniques for overdentures include the classic formulas for denture fabrication. Because the majority of mandibular overdenture options have screw-retained connecting bars, the fabrication of passive screw-retained restorations is addressed.

The overdenture bar may be retained by cement or screws. A primary advantage of a screw-retained prosthesis is when the abutments are less than 5 mm in height. Cemented restorations require enough surface area and resistance form to provide predictable fixation to prevent uncementation. Therefore, conditions with short abutments are an indication for a screw retention system. Several conditions result in shorter abutment height, including (1) CHS and (2) overdentures.

The CHS is measured from the crest of the ridge to the occlusal plane. In the posterior regions of the mouth, the CHS is less than the anterior regions because it is closer to the hinge of the temporomandibular joint. The opposing landmarks in

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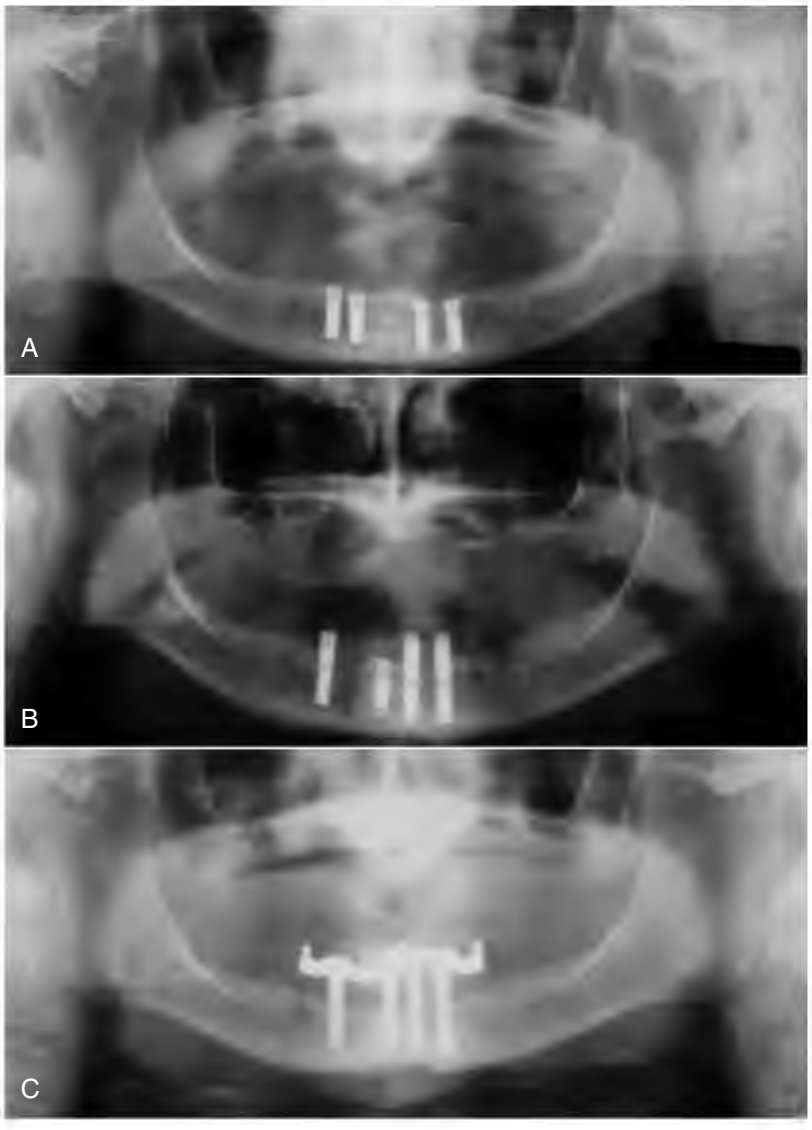


FIGURE 29-37. **A,** A panoramic radiograph of implants in the A, B, D, E position. **B,** A postoperative panoramic radiograph of the removal of implant B and insertion of implant C (and uncover of A, D, E). **C,** An overdenture option 4 with a RP-5 prosthesis was fabricated.

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the posterior regions (i.e., maxillary sinus and mandibular neurovascular canal) limit the bone height for implant insertion. As such, osteoplasty to increase CHS may be contraindicated. For fixed restorations, when less than 8 mm of CHS is available, a screw-retained restoration is recommended, unless an osteoplasty to increase crown height is performed.

Overdentures require more CHS than fixed restorations. Denture teeth may lose retentive form when hollow ground to fit over attachments. Acrylic needs bulk for strength and 3 mm or more of space is desired. Implant abutments are usually 2 mm above the tissue. The connecting bar copings and attachments require 3 to 7 mm of height, depending on type and design. Clearance under a bar requires at least 1 mm of space for hygiene (Figure 29-38). A screw-retained abutment reduces the crown height requirement and permits additional bulk of acrylic for strength for the overdenture. As a result, a minimum of 12 mm of CHS from the gingiva to the occlusal plane usually is required for an overdenture (Figure 29-39).

Overdenture Treatment Options

There are five treatment options for a mandibular overdenture (OD 1–5) (Figure 29-40). These alternative treatments are presented in Chapter 23 and should be reviewed, along with Chapter 28 on principles of screw-retained prostheses, before reading this chapter. In addition, Chapter 33 on maxillary dentures opposing an implant prosthesis should be understood to establish the correct occlusal vertical dimension (OVD) and position of the posterior teeth (medial-positioned lingualized occlusion).

The doctor and staff can explain to the patient the amount of support each treatment option can provide by comparing them with the support system of a chair. Treatment option OD-1 is similar to a one-legged chair. A one-legged chair can support your weight but provides very little stability. Treatment options OD-2 or OD-3 are related to a two-legged chair. The prosthesis provides some vertical support but can still rock back

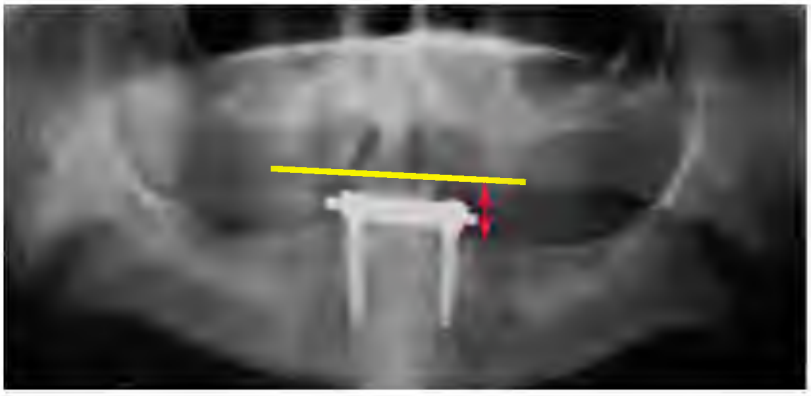


FIGURE 29-38. Panoramic radiograph of a two-implant overdenture (IOD) and connecting bar. The occlusal plane *(yellow line)* to crest of bone *(red line)* is only 5 mm. Fracture of the IOD and denture tooth "pop off" were common complications.

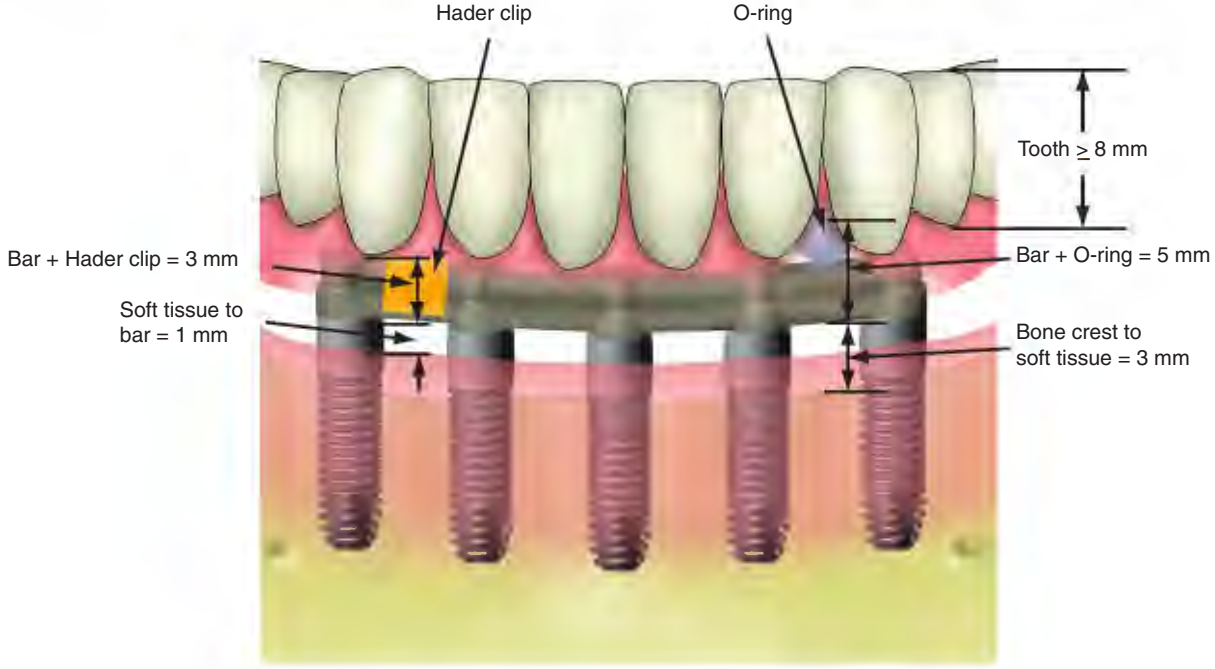


FIGURE 29-39. The mandibular overdenture requires at least 12 mm between the soft tissue and the occlusal plane to provide sufficient space (15 mm from bone level to occlusal plane) for the bar, attachments, and teeth.

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MANDIBULAR TREATMENT OPTIONS

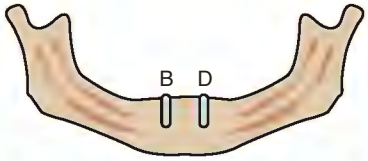
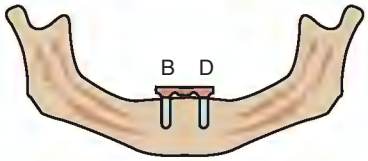
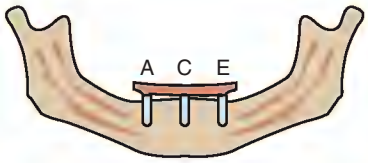
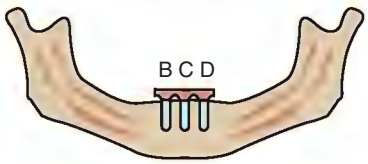
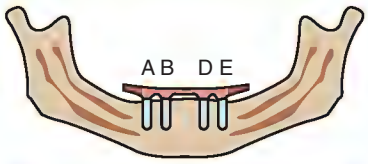
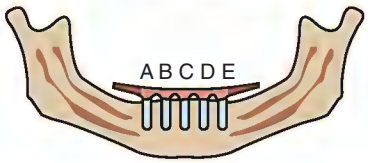
	Option	Description	Removable Prosthesis Type 5
A 	OD-1 (ideal denture)	Implants in the B and D positions, independent of each other.	Ideal anterior and posterior ridge form. Cost is a major factor. Retention only PM-6.
	OD-2	Implants in the B and D positions, rigidly joined by a bar.	Ideal posterior ridge form. Ideal denture. Cost is a major factor. Retention and minor stability PM-3 to PM-6.
B 	OD-3 A	Implants in the A, C and E positions, rigidly joined by a bar if posterior ridge form is good.	Ideal posterior ridge form. Ideal denture. Retention and moderate stability PM-2 to PM-6 (two-legged chair).
	OD-3 B	Implants in the B, C and D positions, joined by a rigid bar when posterior ridge form is poor.	Division C-h anterior bone volume. Poor posterior ridge form. Retention and minor stability PM-3 to PM-6.
C 	OD-4	Implants in A, B, D and E positions, rigidly joined by a bar cantilevered distally about 10 mm.	Patient desires greater retention, major stability and support. PM-2 to PM-6 (three-legged chair).
	OD-5	Implants in the A, B, C, D and E positions, rigidly joined by a bar cantilevered distally about 15 mm.	Patient has high demands or desires. Retention, stability and support PM-0 (four-legged chair).

FIGURE 29-40. **A,** There are five treatment options for a mandibular implant overdenture. Two implants in the B, D position may be independent (OD-1) or splinted together (OD-2). **B,** Three implants may be used, splinted together with a bar (OD-3). **C,** Four implants with a cantilevered bar (OD-4) or five implants and a cantilevered bar (OD-5) may have a RP-5 or RP-4 restoration. *C–h,* Division C minus height bone class; *OD,* overdenture option; *PM,* prosthesis movement class. (From Misch CE: *Misch Implant Institute manual,* Dearborn, MI, 1984, Misch Implant Institute.)

and forth and provides limited stability in the posterior regions. Option OD-4 with four implants is compared with a three-legged chair. This system provides improved support and has improved stability. However, it can be rocked one way or the other under lateral forces. A four-legged chair provides the greatest support and stability and is similar to OD-5, which is maximum for prosthesis support and stability because it is a RP-4 design.

Overdenture Option 1

The first treatment option for mandibular overdentures (OD-1) is indicated primarily when cost is the most significant patient factor. However, it is important to note the patient's desires should also be minimal, and the bone volume in both the anterior and posterior regions should be abundant (division A or B). The posterior ridge form should be an inverted U shape,

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with high parallel walls for good to excellent anatomical conditions for conventional denture support and stability (Box 29-8). The problem associated with the existing denture should relate primarily to the amount of retention, not stability or support. In addition, the opposing arch should be completely edentulous and restored with a traditional complete denture.

Under these more ideal intraoral conditions, two implants may be inserted in the B and D positions (Figure 29-41). The implants remain independent of each other and are not connected with a superstructure. The overdenture attachment primarily improves retention and gives little additional support or stability to the prosthesis. The stability of the restoration is slightly improved in the anterior section by the implants, and the posterior inverted U shape regions from the ridge form are required to improve this factor.

The support of the OD-1 restoration is provided primarily from the buccal shelf in the posterior and the ridge in the anterior, similar to a traditional denture. The IOD must be RP-5 with preferably a PM-3 or more, which means it must be able to rotate and load the posterior soft tissue regions of the mandible (Figure 29-42). The most common type of attachment used in OD-1 is an O-ring or Locator design (see Figure 29-17). The implant support mechanism is poor because stress relief of the attachment is permitted in any plane. In other words, the stability and support of the prosthesis are gained primarily from the anatomy of the mandible and prosthesis design, which is similar to a complete denture.

In the past, most two-implant overdentures positioned the implants immediately anterior to the mental foramen in the A, E position. Positioning of the implants in the B and D position is a much better prosthetic option in OD-1 than positioning in the A and E regions (Figure 29-43). Kennedy-Applegate class 1 patients (with bilateral distal extensions and anterior missing teeth) often are restored with an anterior FP and a class 1 removable partial denture. This eliminates the unfavorable rocking leverages that exist when replacement denture teeth are anterior to the fulcrum line.[112] Independent implants in the A and E positions are implant locations in the first premolar region, which is more posterior to the anterior fulcrum line of the anterior teeth, and allow a greater amplitude of rocking of the restoration (Figure 29-44). When using B and D implants (which is similar to the natural canine positions), the anterior movement of the prosthesis is reduced.

The patient's primary advantage with treatment option OD-1 is reduced cost. The two implants are usually the fewest implant number, and no connecting bar reduces the prosthetic appointments and the laboratory costs. The existing prior denture may even be adapted with an intraoral rebase and pickup procedure around the implants and attachments. This further reduces the fee. On occasion, the connecting bar for the other treatment options may not be passive, and additional complications may ensue. Because this option does not have a connecting bar, there may be fewer bar-related complications. In addition, hygiene procedures are facilitated with independent implants.

BOX 29-8 Patient Selection Criteria: OD-1

- Opposing a maxillary full denture
- Anatomical conditions are good to excellent (division A or B anterior and posterior bone)
- Posterior ridge form is an inverted U shape
- Patient's needs and desires are minimal, primarily related to lack of prosthesis retention
- Edentulous ridge not square with a tapered dentate arch form
- Cost is the primary factor
- Additional implants will be inserted within 3 years

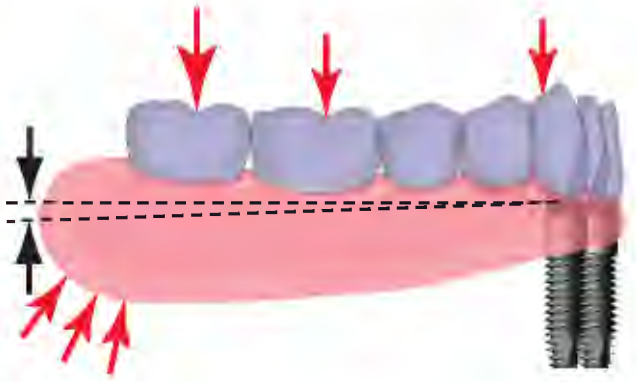


FIGURE 29-42. A RP-5 prosthesis must rotate during function on the anterior implants, so the prosthesis may load the soft tissues of the posterior mandible.



FIGURE 29-41. Overdenture option 1 consists of two independent implants. These are best inserted in the B and D positions to limit the forward rocking of the restoration during function.

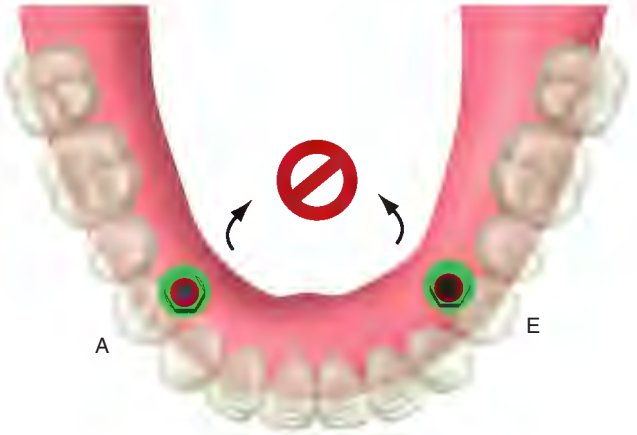


FIGURE 29-43. Independent implants in the A and E positions allow a greater anterior rocking of the restoration and place greater leverage forces against the implants.

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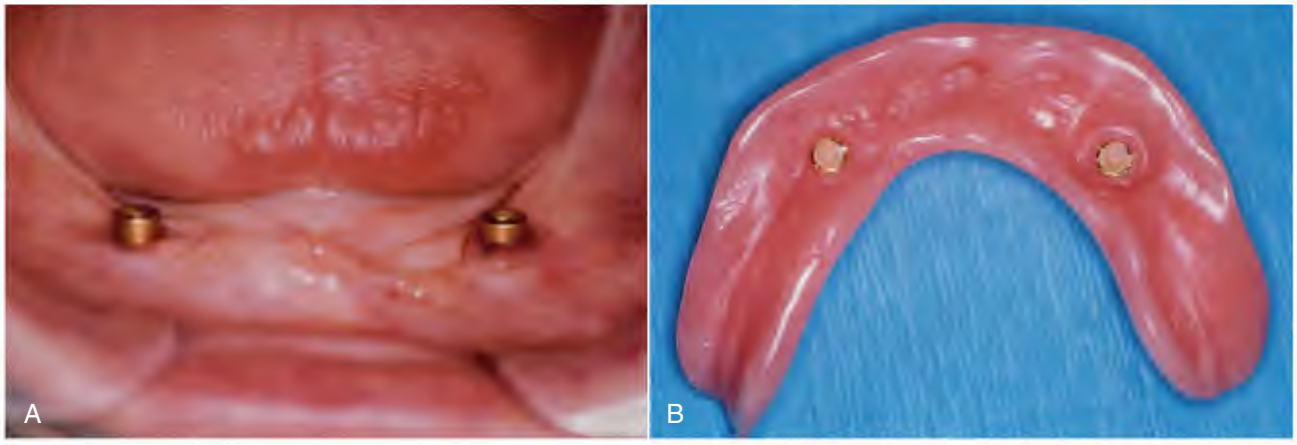


FIGURE 29-44. **A,** Independent implants in the A and E position are distal to the incisal edge of the anterior teeth. **B,** As a result, anterior tipping of the implant overdenture during function is common.

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The two independent implant retention system often has more prosthetic-related complications. There are several reasons the complication risk is increased. The implants should be perpendicular to the occlusal plane because the goal is to allow the posterior regions of the overdenture to rock downward and load the soft tissue over the mandibular buccal shelves for support. The hinge rotation should be at 90 degrees to the rotation path; otherwise, one side is loaded different than the other. In addition, because only two implants sustain the occlusal load during function or parafunction, minimization of the forces to the implant components and crestal bone by placing them in the long axis of the implant body and perpendicular to the occlusal plane is ideal.

The two independent implants should be positioned at the same occlusal height parallel to the occlusal plane. If one implant is higher than the other, the prosthesis will disengage from the lower implant during function and rotate primarily on the higher implant. This situation will accelerate the wear of the O-rings or attachments. In addition, because the higher implant receives the majority of the occlusal load, an increased risk of complications may occur, including abutment screw loosening, marginal bone loss around the implant, and implant failure.

The implants should be equal distance off the midline. If one implant is more distal (farther from the midline), it will serve as the primary rotation point or fulcrum when the patient occludes in the posterior segments. As such, the more medial implant attachment will wear faster, and the more distal implant will receive a greater occlusal load (Figure 29-45). When the patient bites in the anterior region, the more anterior implant acts as the fulcrum, and the posterior attachment more rapidly wears.

The two implants in this treatment option should be parallel to each other. The path of insertion of the prosthesis should also be similar to the path of insertion of the attachments. When the implants are not parallel, the first attachment to engage wears less, and the second attachment rubs along the side of the male and increases the wear rate (Figure 29-46). When the path of insertion of the restoration is different than the attachments (as when a facial undercut below the crest exists), the attachments will wear prematurely. The facial undercut will direct the path of insertion of the restoration (Figure 29-47).

It should be noted that the edentulous residual ridge may be square, ovoid, or tapering. The dentate arch form is also divided into square, ovoid, and tapering categories and may be different than the ridge form. When a tapered dentate arch form is supported by two independent implants in a square residual ridge form, the anterior teeth are cantilevered anteriorly from the implant retentive system. More implants are required in this dentate–ridge form combination to help stabilize the prosthesis, and the OD-1 option will have a considerable disadvantage.

The literature indicates that individual implants have more prosthetic complications than when they are joined together with a bar. As a consequence of additional maintenance risks, independent implants should be used less frequently than implants joined together with a bar. Attachments in a connection bar may be placed by the laboratory in similar horizontal, vertical, and axial planes much easier than the surgeon placing the implants.

It is emphasized the available mandibular bone should be division A or B bone for independent implants. The connecting bar used for OD-3, OD-4, and OD-5 raises the attachment farther from the tissue so the CHS from the incisal edge to attachment is less and the prosthesis is more stable to lateral forces (Figure 29-48).

The opposing arch for an OD-1 mandibular treatment option should be a traditional complete denture. The bite forces are reduced when the patient is completely edentulous before treatment. The maxillary denture has some movement during function and acts as a stress reliever. The instability of the maxillary denture and mandibular OD-1 overdenture is shared. The support requirements of the posterior regions of the mandible are reduced when opposing a complete denture. Hence, the opposing arch should be a complete denture when OD-1 is the treatment option (Figure 29-49).

The OD-1 is used as a treatment option when patients understand that a connecting bar or additional implants are beneficial but financial constraints require a transition period of a few years before placing additional implants. The ultimate goal in the treatment plan is to convert OD-1 patients to a RP-4 or FP with more implant support and stability before the loss of the posterior bone in the mandible occurs behind the foramina. As soon as the patient can afford two more implants, the implants should be placed in the A and E position, and all four A, B, D, and E implants should be connected with a bar that may be cantilevered to the posterior and help reduce the posterior bone loss.

If an additional implant may be inserted (after the A, B, D, E), it may be positioned in the C position or if bone height and

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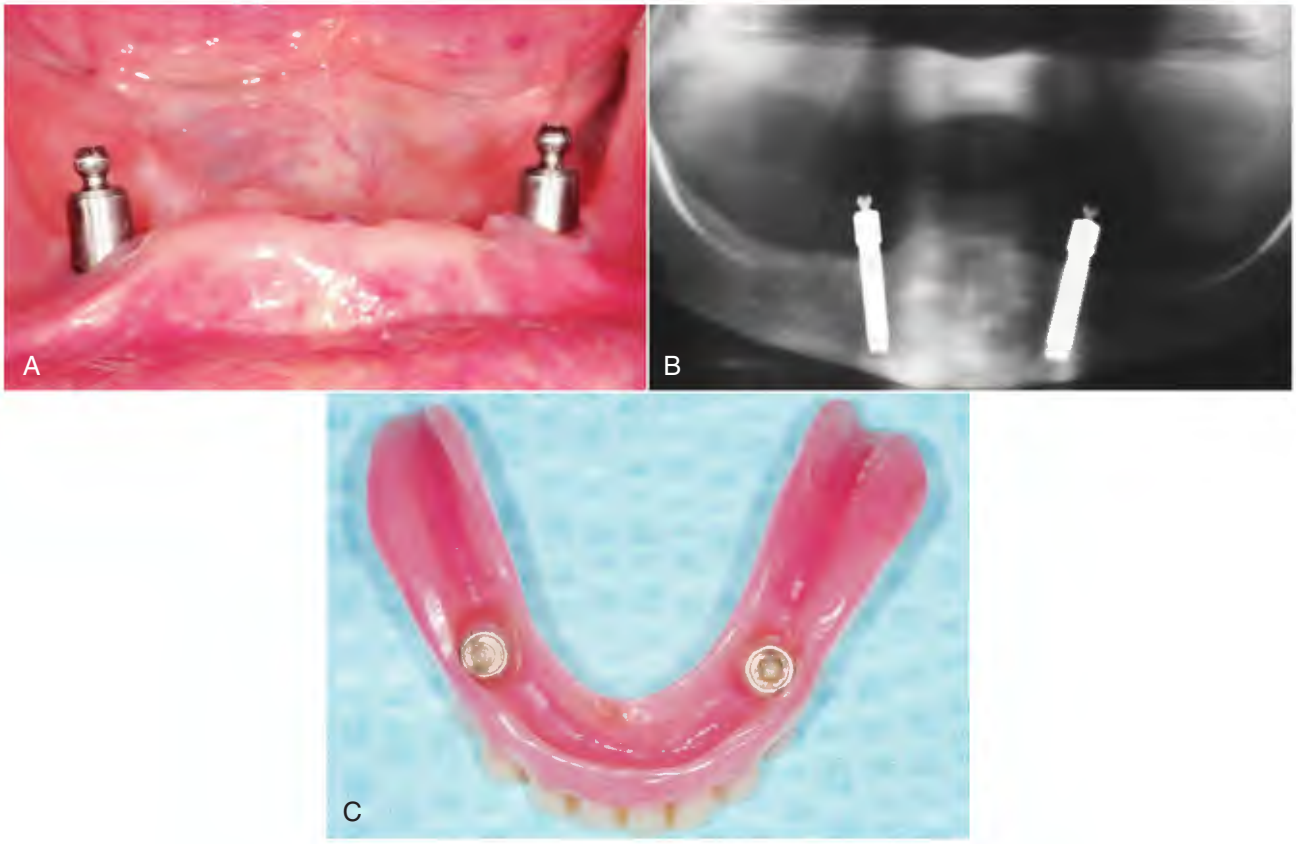


FIGURE 29-45. **A,** When one implant is placed more anterior than the other, the more distal implant is the fulcrum when chewing in the posterior region, and the more anterior implant is the fulcrum for movement when the patient incises food. This causes instability, wearing of the attachments, and loosening of the O-rings from the implant bodies. **B,** A panographic radiograph of two independent implants in the A and E positions at two different occlusal planes and not parallel to each other. **C,** When two independent implants are in the A and E positions, not parallel to each other, equal distance from the midline, and at the same occlusal height, the attachments will more rapidly wear and need to be replaced more often.

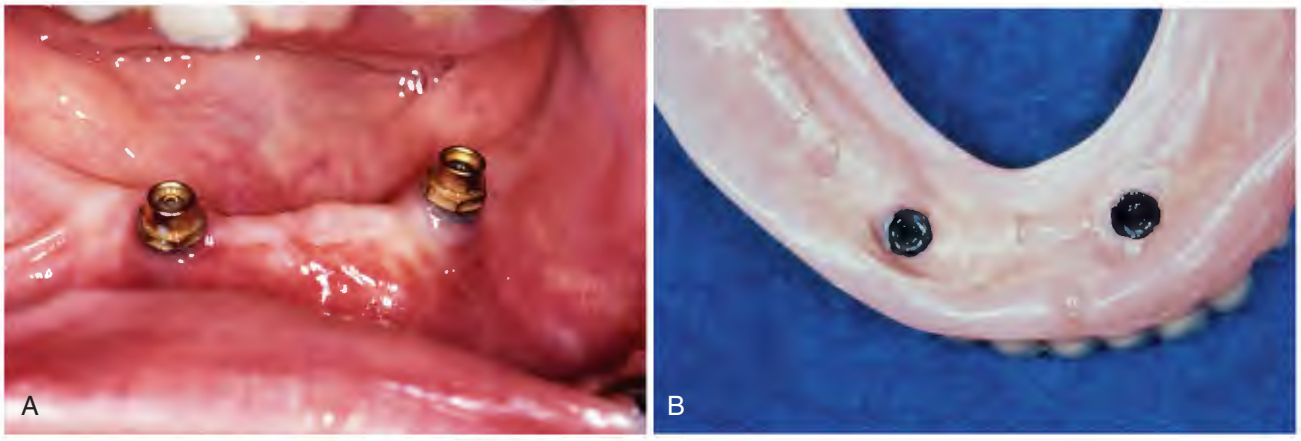


FIGURE 29-46. **A,** Two independent implants should be at the same height, equal distance off the midline, and parallel to each other. When the implants are positioned as in this photo, one implant (not two) becomes the dominant fulcrum and increases the risk of overload complications. **B,** The attachments rapidly wear when the implants are not parallel to each other. This is especially important when force factors are higher than usual. The patient's occlusal plane also should be modified to allow a bilateral balanced occlusion on a RP-5 overdenture.

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width distal to one mental foramen are adequate, the additional implant may be positioned in one of the first molar regions. With implants in the A, B, C, D, E positions or A, B, D, E and molar positions, the connected implants and cantilevered bar will result in a RP-4 or fixed restoration and will help maintain posterior bone. The bar may be cantilevered to provide posterior support with four or more implants because of the greatly improved anteroposterior distance (A-P spread) between splinted implants and the increase in implant number.

Prosthetic Steps

Two independent implants are used most commonly when cost is a primary factor. Under these conditions, the dentist often transforms the patient's preexisting prosthesis into an IOD. When this is the treatment goal, the dentist first evaluates the existing restoration for proper vertical dimension of occlusion and bilateral balance when opposing a maxillary denture. When within clinical guidelines and esthetics are acceptable, the process may continue.

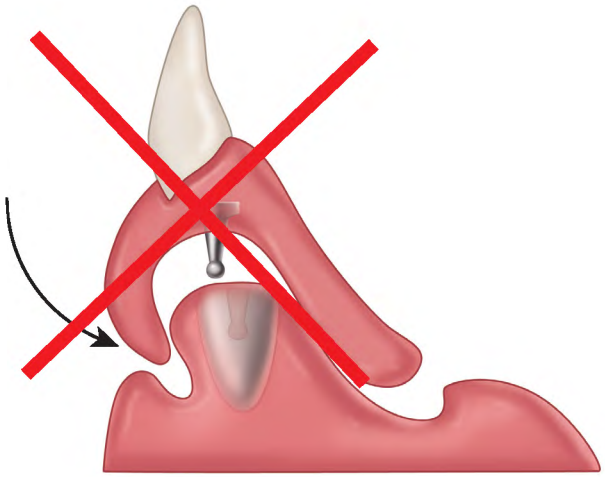


FIGURE 29-47. When an anterior undercut is present, it determines the pathway of insertion of the restoration and should be similar to the pathway of the insertion into the attachment.

The two independent implants most often use an O-ring attachment or Locator system (Figures 29-50 and 29-51). After healing, the dentist removes the permucosal extensions and inserts the premanufactured titanium alloy O-ring or Locator abutments into the implant bodies. The abutment for attachment replaces the permucosal extension. The attachments should be parallel to each other and at the same height. The taller the abutment, the more the lateral stability of the prosthesis. However, at least 2 mm of acrylic should be present between the teeth and borders of the denture around the encapsulator of the attachment.

The abutments for attachments are provided in different heights (Figure 29-52). The abutment should be at least 2 mm above the tissue and 2 mm below the denture teeth so adequate thickness of acrylic is present (Figure 29-53). The attachment and encapsulator are placed into the implants. The abutments are then tightened with a torque wrench at 20 to 30 N-cm (depending on the manufacturer) (Figure 29-54).

A marking transfer stick applies dye to the top of the attachments (Figure 29-55). The denture is placed over the implants and marks the intaglio aspect of the prosthesis. The denture is hollowed out in the region of the attachments. The B and D positions are relieved from the intaglio side of the prosthesis so the restoration may fit over the attachment option without interference (Figure 29-56). One attachment system is tried in at a time and then both at the same time to confirm that the OVD and occlusion are similar to the preexisting condition. The dentist then places the metal encapulator and O-ring over each

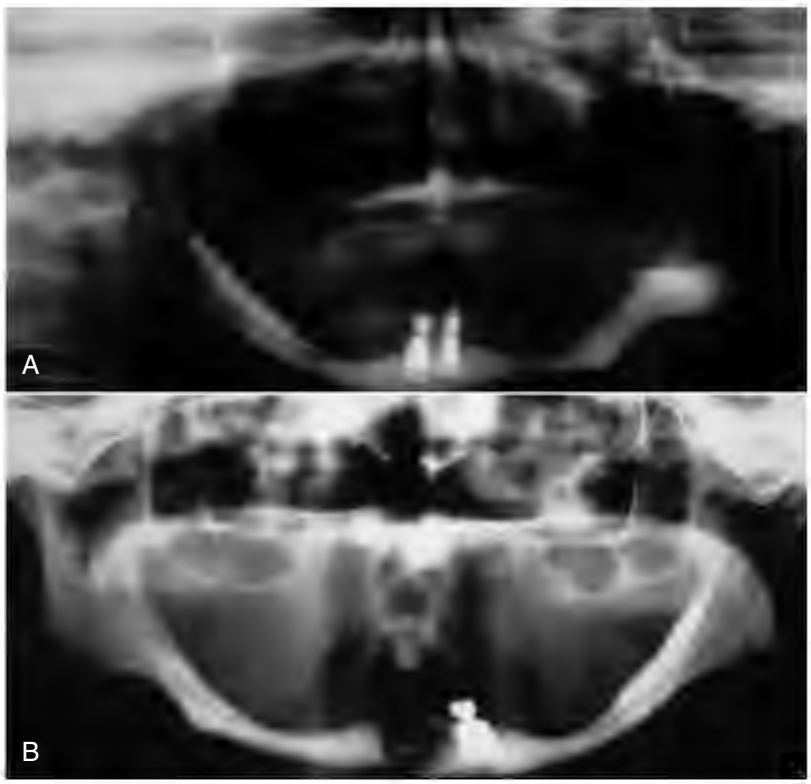


FIGURE 29-48. **A,** A panoramic radiograph of two independent implants in a division D mandible. **B,** One implant failed, and the mandible fractured through the failed implant site.

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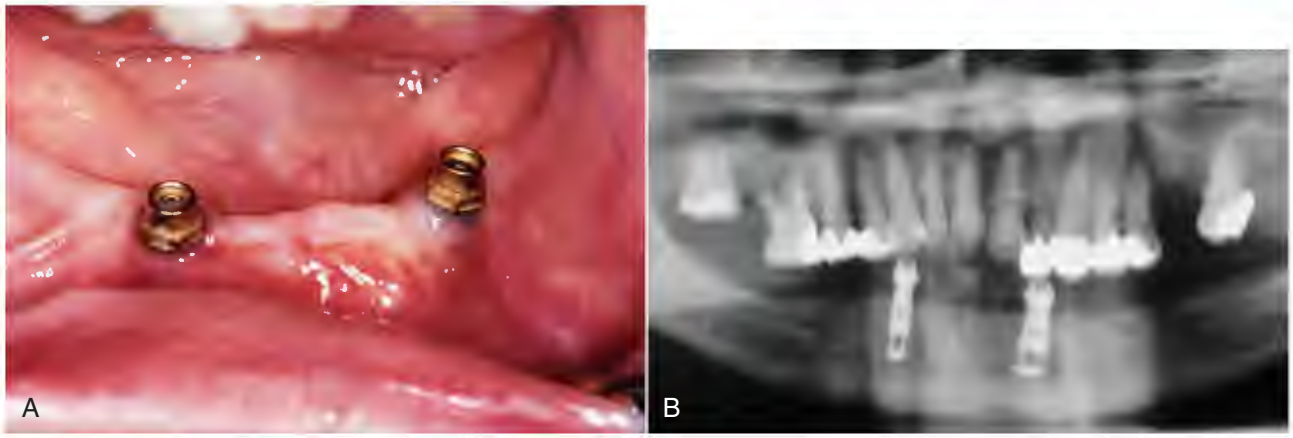


FIGURE 29-49. A mandibular two-implant overdenture should oppose a complete denture. Otherwise, instability and sore spots are common complications related to the implant overdenture.



FIGURE 29-50. The O-ring has a metal encapsulator *(top)*, a resilient O-ring or plastic component *(middle)*, and a male O-ring abutment for attachment *(bottom)*.



FIGURE 29-51. A Locator has an encapsulator *(top)*, a resilient male component within, and a female component in the abutment for attachment.



FIGURE 29-52. The abutment for attachment is provided in different heights.

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FIGURE 29-53. The abutment should be 2 mm or more above the tissue.

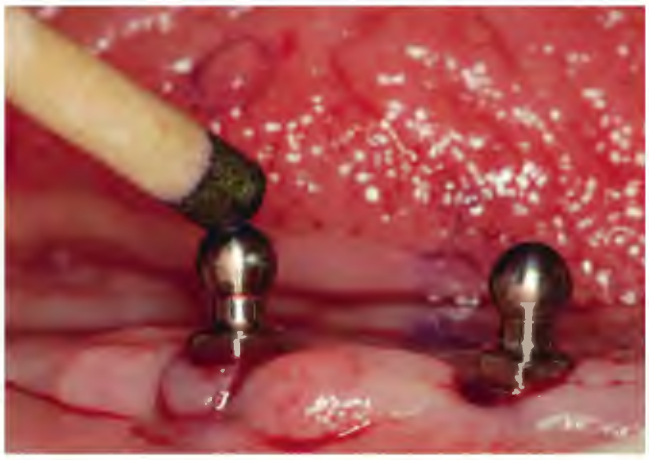


FIGURE 29-55. A dye stick marks the top of the attachment.



FIGURE 29-54. A torque wrench is used to tighten the abutment screw.



FIGURE 29-56. The intaglio surface of the denture is relieved so it may fit over the abutment, attachment, and metal encapsulator.

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attachment post and evaluates the prosthesis again. When removed, the metal encapulator should not tip or be misplaced.

When the occlusion and fit is similar as before, the encapsulators are inserted, and the denture try-in is repeated (Figure 29-57). A hole is then placed through the lingual aspect of the denture to allow excess acrylic to escape and to allow a light-cured acrylic to be used for the pick-up procedure (Figure 29-58).

At this point, a decision is made to either perform a pick-up technique of the attachment directly in the denture or to perform a reline procedure of the denture base. When the denture fulfills the criteria of support on the buccal shelf and posterior stability from the lingual flange, a pick-up procedure may be performed. One attachment is picked up at a time. The intaglio aspect of the restoration is evaluated after the attachments are picked up with the light-cured acrylic. Any voids are filled with resin (Figure 29-59).

When the borders of the denture are insufficient, a reline procedure is performed. The borders of the denture are reduced 2 mm or more. The dentist applies adhesive to the border and uses dental compound or a polyether impression material to border mold the periphery of the restoration similar to a custom impression tray for a complete denture.

The dentist then makes holes on the lingual aspect of the prosthesis site around each O-ring site. These holes serve as a release access for excess impression material. The encapulator or closed-tray impression transfer is placed into the implants (Figure 29-60). The dentist then makes a final impression of the lower arch with polyether or addition silicone, using the existing prosthesis as the customized tray (Figure 29-61). Polyether is an impression material rigid enough to hold the encapsulators and O-rings within the impression when it is removed from the mouth. The O-rings should have the least retention, rather than using one with a higher Brinell index, to make this process easier.

Analogs of the male O-ring posts are inserted into the impression, and then it is poured in dental stone (Figure 29-62). The laboratory rebases the lower denture and incorporates the metal encapsulators into the rebase (Figure 29-63). A relief of 2 mm over each O-ring post is then made to ensure that the encapsulator base does not rotate on the head of the post during processing of the denture.

The dentist inserts the final IOD restoration, making sure the O-rings only retain the restoration. The support of this restoration is on the buccal shelves of the mandible in the posterior section and the crest of the ridge in the anterior section. The lateral stability in the posterior region is gained primarily from

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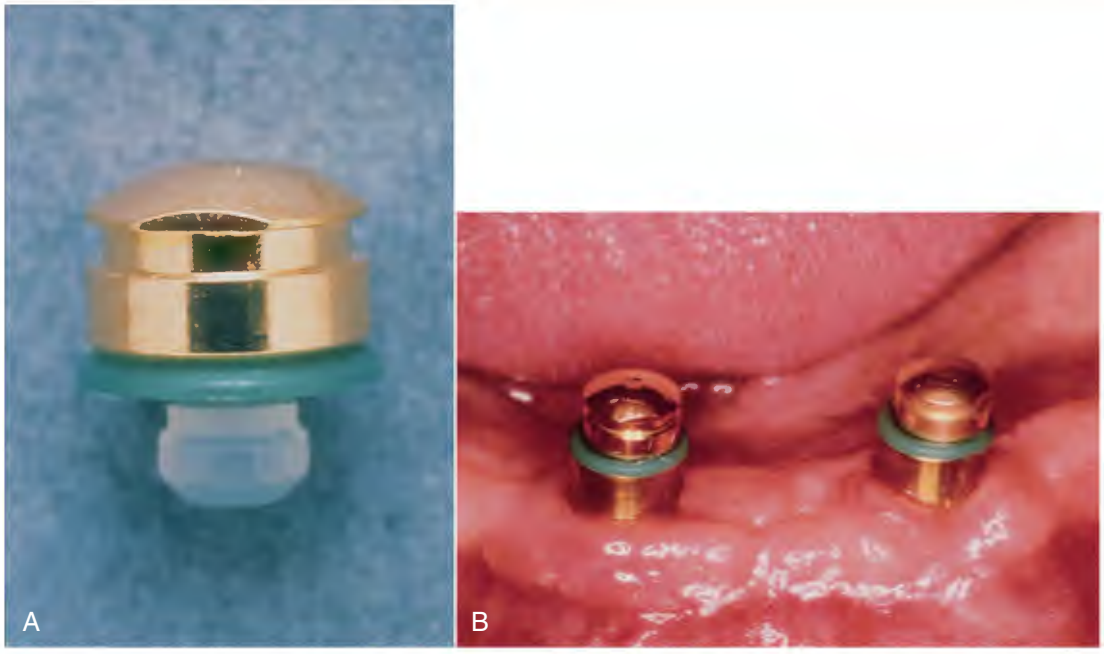


FIGURE 29-57. **A,** An encapsulator and attachment. **B,** The encapsulator and attachment are inserted into the implants.

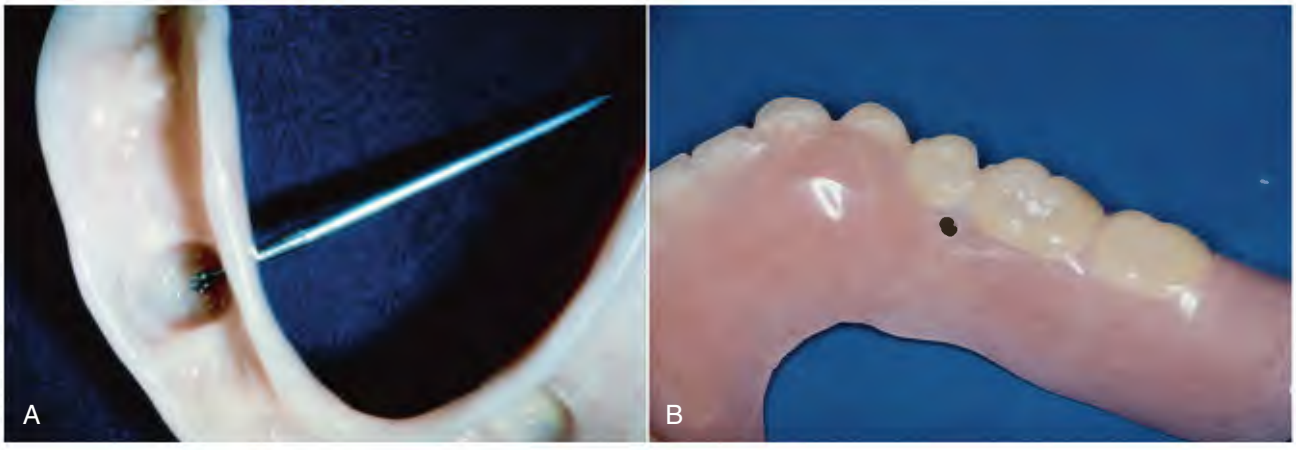


FIGURE 29-58. **A,** A hole is prepared through the lingual aspect of the implant overdenture next to the receptor site. **B,** The lingual hole allows excess acrylic to escape and permits a light cure acrylic to pick up the resilient attachment and encapsulator.

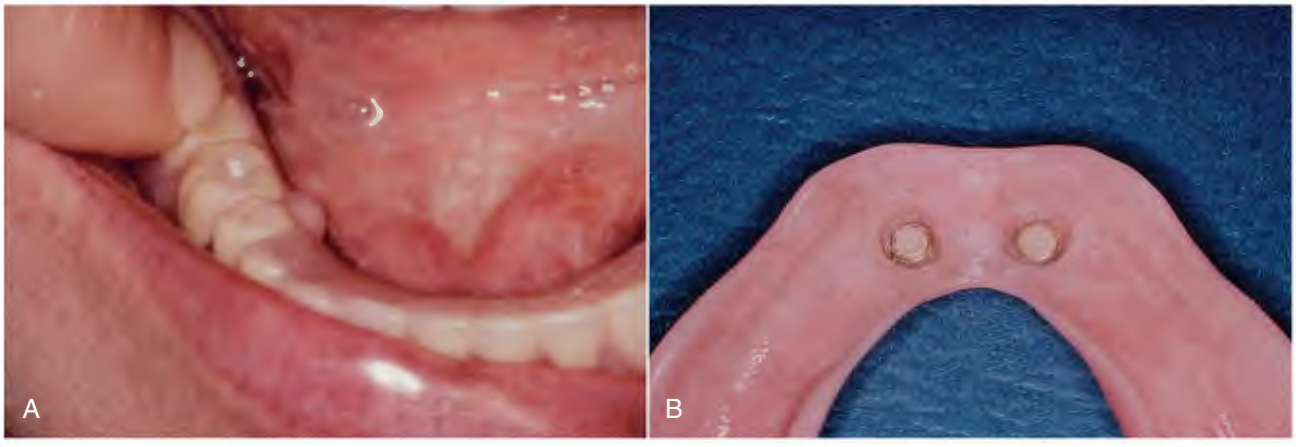


FIGURE 29-59. **A,** When the denture is adequate, a resin pick-up of the encapsulator and resilient attachment may be performed. **B,** The acrylic pick-up procedure is evaluated, and any voids are filled in with additional acrylic.

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the lingual flanges of the prosthesis. The bilateral balanced occlusion helps stabilize the prosthesis during parafunction.

Overdenture Option 2

The implants in OD-2 are also positioned in locations B and D, but in this option, they are splinted together with a superstructure bar without any distal cantilever (Figure 29-64). Reduced loading forces are exerted on two anterior implants when splinted with a bar compared with individual implants.[88,113] The second treatment option for a mandibular overdenture (OD-2) is selected as the initial option more often than OD-1. The anatomical needs and patient desires are similar to the first option, OD-1.

Even when one implant is farther distal than the other, the bar is designed to position the attachments for added retention an equal distance off the midline parallel to each other at the same occlusal height and in a similar angulation (Figure 29-65). The ideal distance between the implants is in the 14- to 16-mm range or B and D positions. It should be noted implants placed closer than the B, D position will result in reduced prosthesis stability during function, whether they are connected or independent units.

The connecting bar should not be cantilevered to the distal from the two implants (Figure 29-66). When a bar is cantilevered off the anterior implants, there is not enough A-P distance between two implants to counter the effect of the cantilever. An increased risk of prosthetic and abutment screw loosening exists with the cantilever (Figures 29-67 and 29-68).

The implants should not be positioned in the A, E position even when connected with a bar. The A, E position is most often the first premolar and may even be in the second premolar position (depending on sex and race) (Figure 29-69). When the implants are joined with a straight bar, the connecting bar is lingual to the anterior ridge. The overdenture flange is often too bulky and may even lie over the submandibular duct (Figure 29-70). This prosthesis design may affect speech. The denture teeth are anterior to the residual ridge and therefore act as a lever on the bar, and the prosthesis is not stable.

The connecting bar between A and E implants flexes five times more than when the bar connects B and D implants; therefore, screw loosening is more of a risk[114] (Figure 29-71). When a curved bar is used to position it more anterior, the prosthesis often rides along the sides of the bar and limits PM. If the prosthesis rests against the sides of the curved bar, the PM may even be reduced to PM-0 (Figure 29-72). This places a much greater vertical and lateral load on the implant system. There are greater lateral forces on the A, E implant position, which may increase screw loosening (Box 29-9). If the patient has implants already inserted into the A and E position, the best treatment option is to insert another implant in the C position and connect the three implants with a bar.



FIGURE 29-60. The encapsulator and attachment (or impression transfers) are positioned into the implant abutments.



FIGURE 29-61. The denture is used as a closed custom tray and picks up the attachment (or transfers) in the impression.

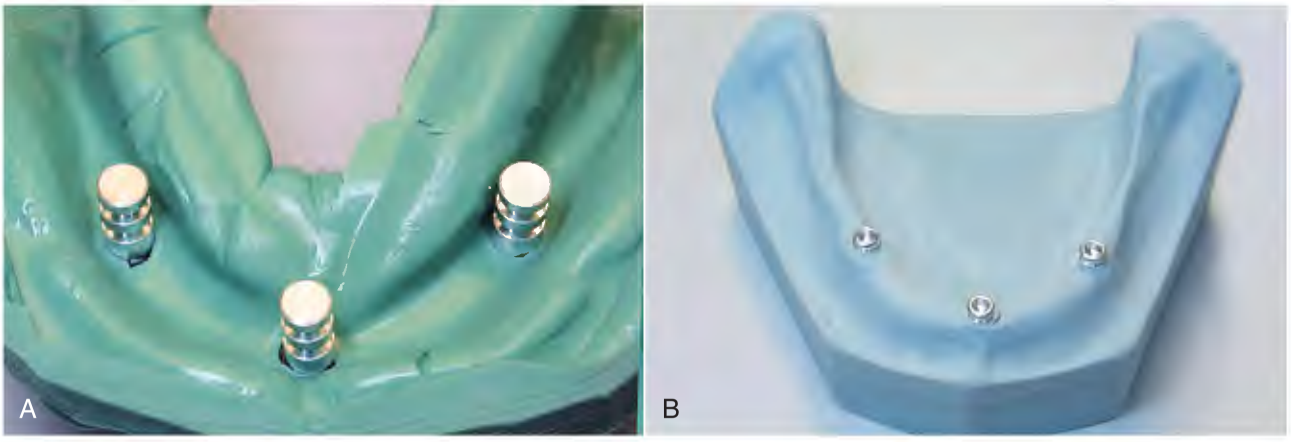


FIGURE 29-62. **A,** Implant abutment analogs are inserted into the encapsulators (transfers) within the denture reline impression. **B,** The impression is poured in dental stone.

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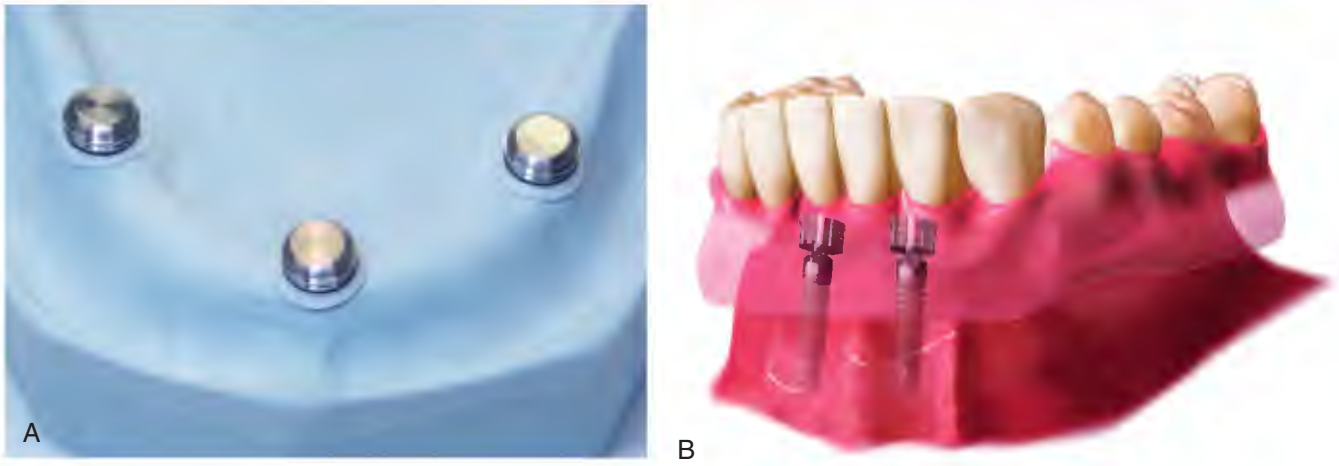


FIGURE 29-63. **A,** The encapsulator and attachments are inserted into the abutment analog. **B,** The denture base is relined and includes the metal encapsulators.



FIGURE 29-64. Treatment option 2 has implants in the B and D positions, and a bar joins the implants. Attachments such as an O-ring or a Hader clip, which allow movement of the prosthesis, can be added to the bar. The attachments are placed at the same height at equal distances off the midline and parallel to each other.

BOX 29-9 Disadvantages of Splinted Implants in the A and E Positions (First Premolar to First Premolar)

- Implants joined with straight bar are lingual to ridge
- Difficulty with speech
- Anterior tipping of overdenture
- Five times greater bar flexure than B and D positions
- Implants are joined with anterior curved bar
- Greater bar flexibility (nine times the B and D positions)
- Increased screw loosening
- Increased moment forces on anterior aspect of prosthesis
- Attachment of curved bar may prevent prosthesis movement
- Bite force is higher than for B and D positions
- Greater lateral load from prosthesis to implants than B and D positions

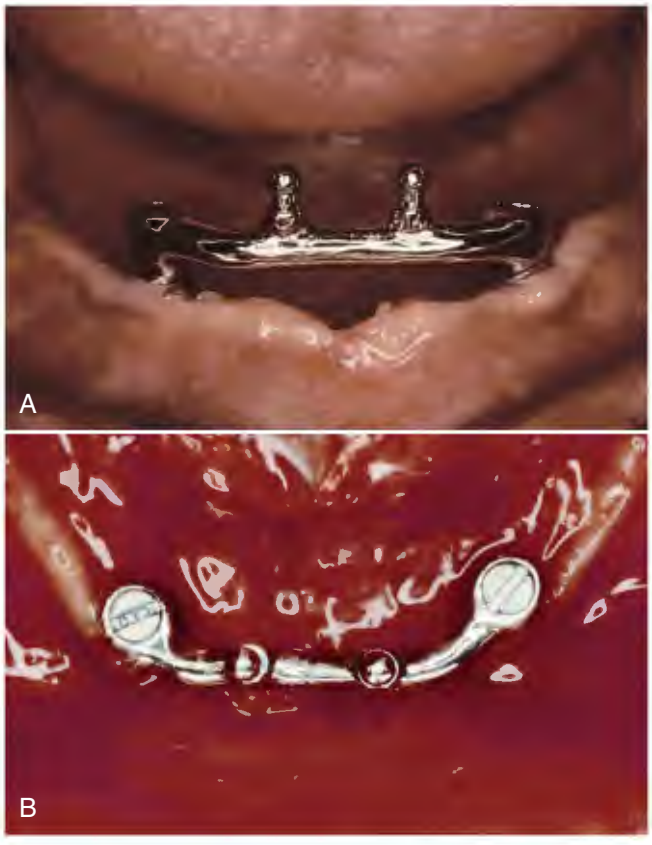


FIGURE 29-65. **A,** When O-rings are used for OD-2, the attachments are placed parallel to each other and at the same occlusal height. **B,** The O-ring attachments are positioned equal distance off the midline even though one implant may be more distal than the other.

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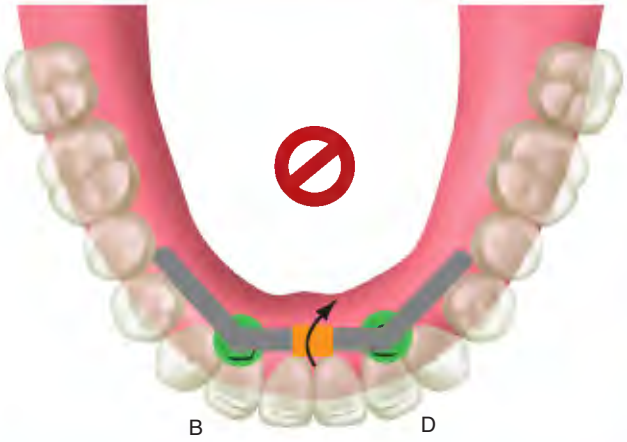


FIGURE 29-66. The connecting bar between implants B and D should not be cantilevered to the distal.



FIGURE 29-67. Implants in the B and D position and a connecting bar that is cantilevered to the distal. The Hader clips in the prosthesis do not allow prosthesis movement. Hence, this is a PM-0 implant overdenture and will cause repeated biomechanical complications.



FIGURE 29-68. Two implants connected with a bar with no anteroposterior distance and poor biomechanics for a bilateral cantilever.



FIGURE 29-69. This patient had an overdenture constructed on the two first premolar teeth. The bar became uncemented on the patient's right side and then acted as a cantilever on the patient's left premolar. This situation is similar to implant positions A and E because the mental foramina are most often between the premolars or distal to the second premolar.



FIGURE 29-70. When a straight bar connects the A and E implants, it is often positioned lingual to the residual ridge and may even lie over the submandibular duct in the floor of the mouth.

Patient selection criteria for OD-2 treatments include the following:

1. The patient's opposing arch is a complete denture.
2. Anatomical conditions for a traditional mandibular denture are good to excellent.
3. The posterior ridge form is an inverted U shape and provides good to excellent support and lateral stability.
4. The patient's complaints are minimal and relate primarily to retention.
5. The patient requires a new prosthesis and is willing to invest slightly more time and expense than the patient with the OD-1 option.
6. The mandibular residual arch is square or ovoid, and the dentate arch form is square or ovoid.
7. When the patient is unable to insert additional implants within a short time frame (within 3 years), an OD-2 is safer than an OD-1 independent implant approach (Box 29-10).

The OD-2 prosthetic design has two primary advantages over the OD-1. Reduced loading forces are exerted on the two anterior implants when splinted together with a bar. This may result in less screw loosening and crestal bone loss than option 1. Second, the laboratory may position the attachments parallel to each other at the same height and equal distance from the

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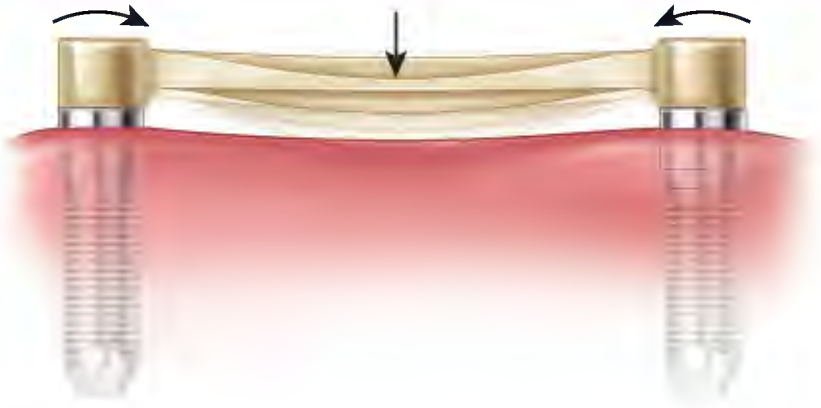


FIGURE 29-71. A bar splinting the A and E positions will flex five times more than a bar connecting implants in the B and D positions. As a consequence, screw loosening risk is increased. Implants in positions A and E should not be splinted together. Instead, an implant in the C position should first be inserted.

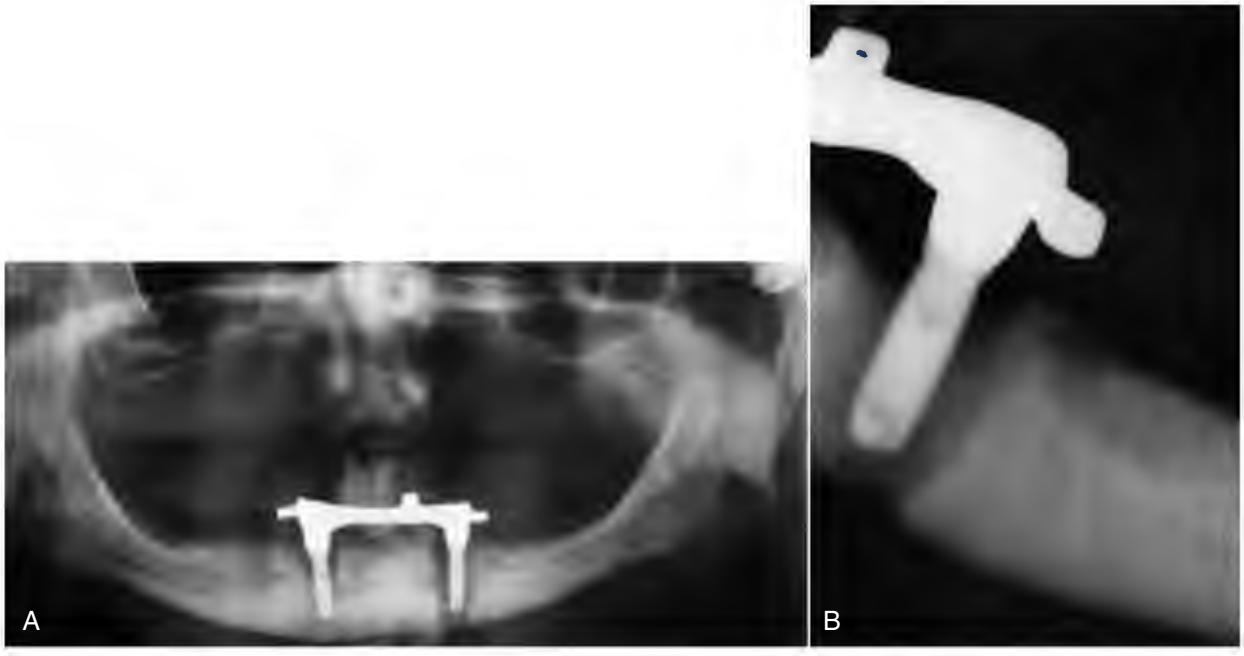


FIGURE 29-72. **A,** A radiograph of implants in the A and E positions that were splinted together with a bar. The prosthesis screw became loose on the A implant, which resulted with a long cantilever on the E implant, which then failed. **B,** The curved bar adapted so close to the lateral sides of the bar that the implant overdenture had PM-0.

BOX 29-10 Patient Selection Criteria: OD-2

- Opposing arch is a maxillary denture.
- Anatomical conditions are good to excellent (division A or B bone in anterior and posterior regions).
- Posterior ridge forms an inverted U shape.
- Patient's need and desires are minimal, primarily related to lack of retention.
- Patient can afford a new prosthesis and connecting bar.
- Additional implants will not be inserted for more than 3 years.
- Low patient force factors (e.g., parafunction)
- The mandibular residual ridge form is square to ovoid, and the dentate arch form is square to ovoid.

midline regardless of the corresponding implant positions, thus reducing prosthetic complications.

The retentive element on the splinted bar may be an O-ring or clip design depending on the crown height distance available. The bar can be similar to those designed by Dolder or Hader.[115–117] The bar cross-section is ideally ovoid (Dolder) or round with an apron so as to increase the strength of the bar and reduce its flexibility. In a vertical dimension, the bar should be more than 1 mm away from the soft tissue to provide easy access for hygiene aids. A narrow space impairs oral hygiene procedures and may also be the cause of food debris impaction and soft tissue inflammation. The bar position may be achieved more easily by the selection of the proper height implant abutments.[117]

The prosthesis attachment system to the superstructure bar is closely scrutinized when Hader and Dolder clips are used for retention. The connecting bar and clips should be perpendicular to the path of rotation and parallel to the occlusal plane. This usually requires a straight bar perpendicular to the midline

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(Figure 29-73). A curved bar often places the clips closer to the implants and prevents rotation of the prosthesis.

The bar and clip should be parallel to the plane of occlusion or the elevated O-rings should be the same height and equal distance off the midline. An angled bar will not permit rotation of the prosthesis to load the posterior soft tissue. The connecting bar should be aligned perpendicular to a line bisecting the angle between the posterior edentulous ridges to allow rotation of the prosthesis. The prosthesis should have a PM-3 or greater if the posterior tissue is mobile. The vertical movement of the anterior attachment (Dolder bar or O-rings) allows a stress relief to compensate for the posterior tissue movement.

The connecting bar of the restoration should be fabricated after the final contours and teeth position are developed for the overdenture. Otherwise, compromises of inadequate room for denture teeth or overcontoured restorations (most often on the lingual surface) result. The bar may be connected on the facial aspect of each implant coping. In this way, the lingual flange of the prosthesis remains within the contour of a traditional denture.

The higher the attachment, the more stable the overdenture. The CHS above the attachment acts as a lever. The greater the crown height, the greater the force and the less stable the overdenture to any lateral force. However, the height of the attachments on the connecting bar should allow 3 mm of acrylic space between the denture teeth and attachment to permit adequate dimension for strength. The internal aspect of a bar-retained overdenture should not be processed against the sides of the abutment or bar because this will limit rotation (Figure 29-74).

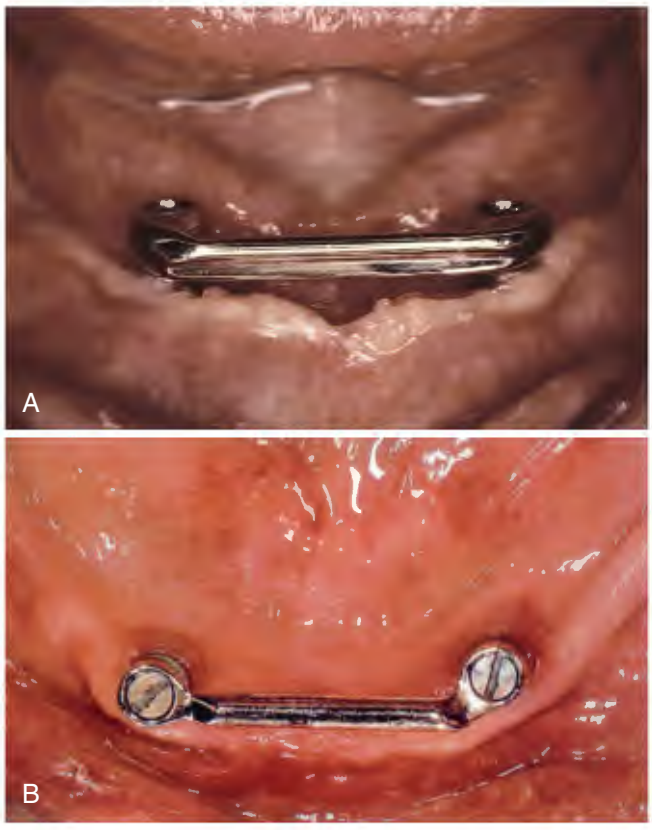


FIGURE 29-73. **A,** A Hader bar and clip may be used to connect implants in the B and D position. **B,** The bar is positioned perpendicular to the midline and parallel to the occlusal plane even though one implant is positioned more distal than the other.

Disadvantages

Two IODs are not indicated in division C–h or D bone and are not indicated when opposing anterior or posterior natural teeth. The increase in crown height and the poorer posterior ridge form or the increase in bite forces and rigid opposing arch place additional stresses on the implant system and increase complications. Additional implants should be used to decrease the implant system and prosthetic risks under these conditions.

Some additional disadvantages of OD-2 treatments compared with OD-1 are possible tissue hyperplasia under the bar, more difficult hygiene under the bar (compared with option 1), and a more expensive initial treatment option compared with option 1. Because a connecting bar is required for OD-2, a new prosthesis most often is indicated. Hence, a bar and new prosthesis increase the fee for the restoration.

Prosthesis Fabrication

The fabrication of the connecting bar follows standard steps of bar fabrication that are similar for all bars on two, three, four, five, or more implants. The first step of the restoration is to remove the permucosal extensions and select the abutments for screw retention (Figure 29-75, *A*). These abutments have various heights. The ideal abutment for screw height is 2 mm above the

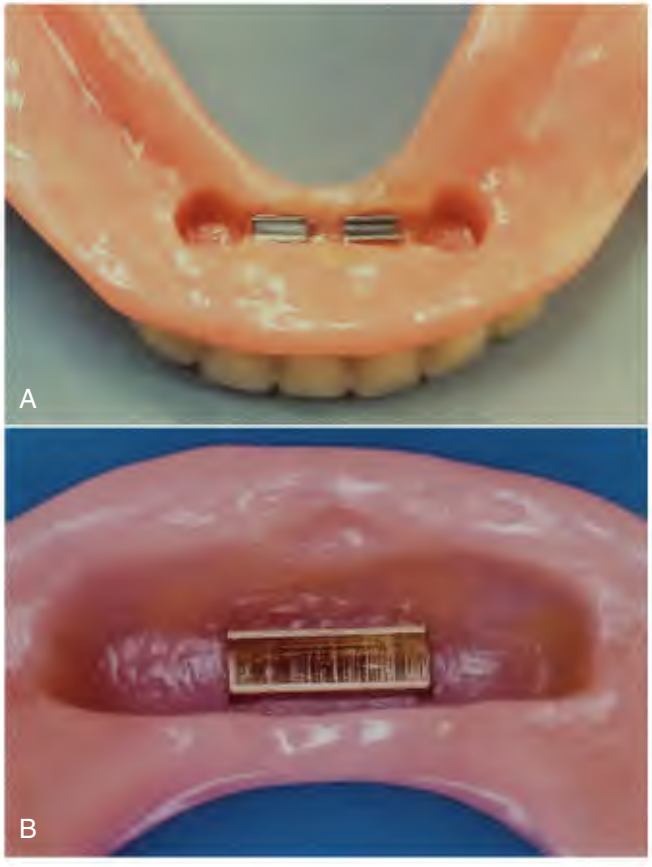


FIGURE 29-74. **A,** This denture is processed with the acrylic receptor sides over the copings and bar too close and will limit (or prevent) rotation of the implant overdenture during function. **B,** The clip should engage the bar, and the denture should not rest on the sides of the implant abutments or bar.

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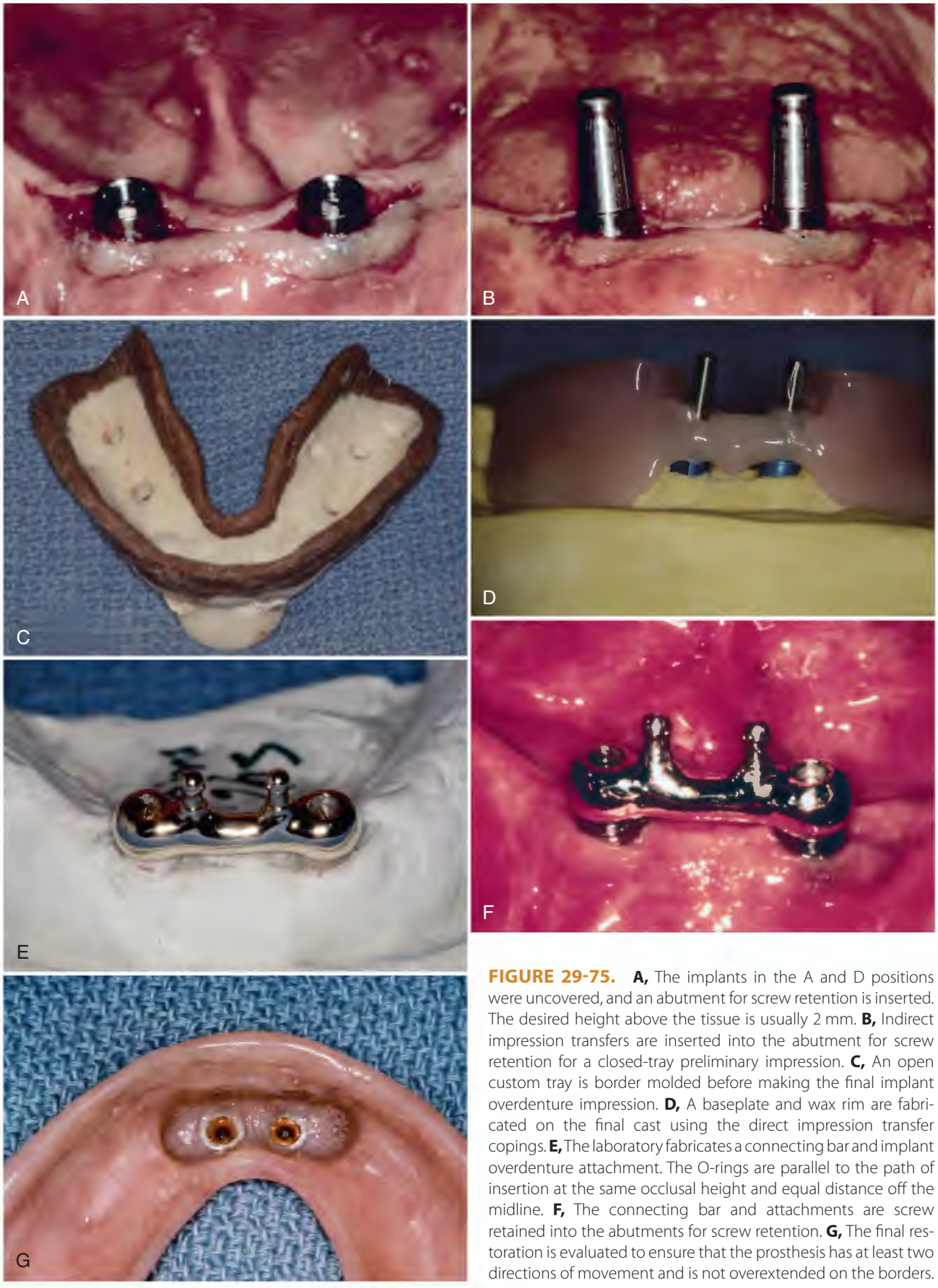


FIGURE 29-75. **A,** The implants in the A and D positions were uncovered, and an abutment for screw retention is inserted. The desired height above the tissue is usually 2 mm. **B,** Indirect impression transfers are inserted into the abutment for screw retention for a closed-tray preliminary impression. **C,** An open custom tray is border molded before making the final implant overdenture impression. **D,** A baseplate and wax rim are fabricated on the final cast using the direct impression transfer copings. **E,** The laboratory fabricates a connecting bar and implant overdenture attachment. The O-rings are parallel to the path of insertion at the same occlusal height and equal distance off the midline. **F,** The connecting bar and attachments are screw retained into the abutments for screw retention. **G,** The final restoration is evaluated to ensure that the prosthesis has at least two directions of movement and is not overextended on the borders.

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tissue. This provides space for hygiene and around the abutment and below the bar. The next step is to insert indirect impression transfers (Figure 29-75, *B*). A closed-tray preliminary impression that is aggressively border molded is then made of the mandible, similar to the preliminary impression for a complete denture. A preliminary impression is also made of the maxilla. Cover screws are then inserted into the abutments for screws to prevent calculus and food from the internal threaded component. The laboratory inserts indirect impression transfers and implant body analogs into the preliminary impression. The impression is poured in dental stone.

The indirect impression transfers are replaced with direct impression transfers on the cast. A 1-mm wax spacer is placed on the soft tissue areas of the cast. A tissue stop is then created in the first molar regions by removing a strip of wax 1 mm × 3 mm. The cast is lubricated so the acrylic will not melt the wax or adhere to the cast. An open custom tray most often is made of Triad (Dentsply, York, PA) to reduce the effect of acrylic shrinkage is then made on the cast.

The second clinical step is to insert the direct impression transfers into the implant abutments. The open custom tray is tried in and confirms that it fits over the long fixation screws of the direct impression transfers and is not overextended. The custom tray is then border molded for all areas of the final soft tissue for an implant-supported prostheses (Figure 29-75, *C*). A final impression is then made, most often with polyether material, which has more body and is more hydrophilic for the soft tissue impression. This impression should include all anatomical limits of a traditional denture such as lingual flanges, retromolar pad, and lingual frenum. The direct impression transfers are then unthreaded and the impression removed and evaluated. A final denture impression is also made of the maxillary arch. The cover screws are inserted into the implant abutments, and the patient's next appointment is scheduled.

The laboratory pours the final impressions after attaching implant abutment analogs to the impression and fabricates a baseplate and wax rim on the final cast incorporating the copings of the direct impression transfers (Figure 29-75, *D*). Access to the coping is made through the wax rim. Hence, the baseplate and wax rim may also be used as a verification jig to evaluate the correct implant abutment positions on the cast. The laboratory also fabricates a maxillary baseplate and wax rim from the maxillary final impression.

At the third clinical appointment, the dentist uses the baseplate and wax rim to determine the OVD and centric relation occlusal bite registration. This baseplate is screw retained using the direct impression transfers, which also is used as a verification jig. The OVD and centric relation occlusal recordings are identical to the techniques for traditional complete denture construction. The dentist also obtains a face-bow and protrusive bite registration. The tooth shade and shape selection are also made at this appointment.

The laboratory mounts the maxillary cast with the baseplate and wax rim with the face-bow transfer and then mounts the lower final cast to the upper cast using the baseplate and wax rim. The denture teeth then are set with a bilateral balanced occlusion when opposing a maxillary denture.

During the fourth clinical appointment, the doctor and patient evaluate the position and contours of the final maxillary and mandibular restoration. After this is acceptable, the laboratory may wax the connecting bar to reside within the contours of the mandibular wax try-in, and the attachment positions may be placed several millimeters away from the teeth or the contours of the overdenture. The final attachments should be set with metal encapsulators to ensure adequate bulk of acrylic exists around them. The laboratory then may cast the connecting bar and attachments (Figure 29-75, *E*). After the fabrication of the connecting bar and attachments, it is positioned on the cast and blocked out around the casting of the bar and undercut regions, and the final denture is processed. An alternative method is to make a duplicate impression of the bar, attachments, and soft tissue and process the denture to the duplicate cast.

At the fifth prosthetic appointment, the connecting bar and final prosthesis are delivered (Figure 29-75, *F* and *G*). The dentist evaluates soft tissue contour as for a traditional denture and performs occlusal adjustments as indicated. The dentist gives the patient written postoperative instructions and instructions to return for adjacent soft tissue and occlusion evaluation.

Overdenture Option 3

Three root form implants are placed in the A, C, and E positions for the third overdenture treatment option (OD-3) (Box 29-11). A superstructure bar connects the implants but with no distal cantilever. A PM-2 or greater can be designed with three A, C, and E anterior implants (Figure 29-76). The third treatment option may be used when the opposing arch is a denture and the patient has moderate to low anatomical needs. The opposing arch should be a denture to limit the amount of bite force. It should be noted that when the posterior ridge form is poor (division C–h or D bone), the OD-3 is the lowest treatment option suggested.

BOX 29-11 Patient Selection Criteria: OD-3

- Opposing arch is a maxillary denture.
- Anatomical conditions are moderate to excellent.
- Posterior ridge forms an inverted U shape.
- The patient's needs and desires require improved retention, support, and stability.
- Cost a moderate factor.
- The patient may have moderate force factors (e.g., parafunction).

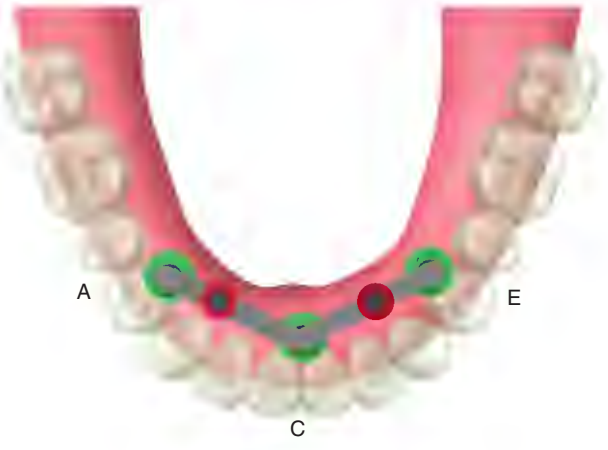


FIGURE 29-76. Overdenture option 3 corresponds to implants in the A, C, and E positions connected with a bar. The attachments should be positioned to allow movement of the distal section of the prosthesis.

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FIGURE 29-77. **A,** A mandible with division A bone and overdenture option 3, with implants in the A, C, and E positions. **B,** The C implant is more anterior than the A and E implants, so anteroposterior stability is improved.

BOX 29-12 Advantages of Splinted A, C, and E Implants

- Six times less bar flexure compared with A and E positions
- Less screw loosening
- Less metal flexure
- Three implant abutments
- Less stress to each implant compared with A and E implants
- Greater surface area
- More implants
- Greater anteroposterior distance
- Half moment force compared with A and E implants
- Less prosthesis movement
- One implant failure still provides adequate abutment support

There are many advantages of splinting A, C, and E implants compared with implants in the B and D positions (Box 29-12). The implants splinted in the A, C, and E positions usually do not form a straight line. The C implant is most often anterior to the more distal A and E implants (in the premolar regions) and ideally directly under the cingulum position of the anterior incisor denture teeth (Figure 29-77). The restoration benefits from direct occlusal load to the implant support in the anterior arch, which reduces tipping and improves stability. As a consequence, when more than two implants are in the anterior mandible, a tripod support system may be established.

To determine the amount of benefit of an A-P distance, the distal of the most posterior implants on each side are connected with a straight line. The distance from this line to the perpendicular position of the center implant is called the A-P spread.[18,117] The greater this dimension, the more biomechanically stable the implants when splinted together. The greater the A-P spread of the A, C, and E implants, the greater the biomechanical advantage of the bar to reduce stress on the implants because they are splinted together.

The splinted A–C–E implant and bar position is more stable than the B–D position for the prosthesis. The lateral stability of the overdenture system is improved because the implants are in the A and E positions and the attachments are in the B and D positions and more distal than OD-2 (Figure 29-78). In addition, the connecting bar can be higher off the tissue when the vertical dimension permits, and the attachment-to–bone height



FIGURE 29-78. The attachments are more distal than the OD-2 and are still equal distance off the midline, parallel and at the same height.

dimension can be greater. As a result, rotation of the prosthesis is more limited compared with OD-1 and OD-2. Therefore, the third implant for OD-3 is a considerable advantage for a mandibular edentulous patient who is division C–h in available bone height.

The IOD option 3 usually does not use two Hader clips for the attachment. Because the two clips do not rotate in the same plane, the prosthesis is usually too rigid, and the clips do not rotate unless they expand (Figure 29-79). Hence, wearing of the clip and bar is a common complication. If a clip attachment is designed for the prosthesis, the bar may connect the facial of the A and E implant copings and the lingual of the C coping. As a result, a straight bar may be fabricated perpendicular to the path of rotation (Figure 29-80).

O-rings attached to the connecting superstructure offer greater leeway in bar design and position (Figure 29-81). An O-ring is often used when CHS permits to increase the crown height attachment–to-bone dimension and decrease the occlusal plane–to-attachment dimension. The smaller the occlusal plane–to-attachment distance, the more stable the overdenture to lateral forces. The intaglio surface of the prosthesis should not contact the sides of the connecting bar because this would result in too rigid a system.

The connecting bar should be parallel to the plane of occlusion, and the attachments should be placed at the same height

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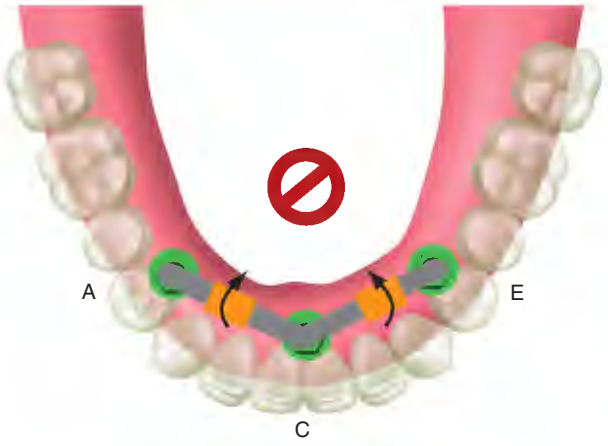


FIGURE 29-79. An implant overdenture option 3 should rarely use a Hader clip for the attachment system.



FIGURE 29-80. When the Hader clips rotate in different planes, it make the prosthesis too rigid for three implants.



FIGURE 29-81. O-ring attachments have a wide range of positions to improve retention and stability.

along the bar. Such placement is needed for the prosthesis to rotate effectively during function. No cantilever of a bar should be designed within this three-implant system. However, the attachments may be placed on the distal of the A and E abutments, similar to a Kennedy class 1 partial denture design (Figure 29-82).

The OD-3 treatment option is usually the first option presented to a patient with minimal complaints who is concerned



FIGURE 29-82. No cantilever of the bar should be used with a three-implant overdenture. However, the attachment may be positioned distal to the A and E implant.

primarily with retention and anterior stability of the IOD when cost is a moderate factor. The posterior ridge form should be evaluated because it determines the posterior lingual flange extension of the denture, which limits lateral movement of the restoration in this treatment option. In the future, when the patient can afford additional implants to those in the A, C, and E positions, the next implant placement is in the B and D positions when the posterior bone is inadequate for implants (C–h). When posterior bone permits, the two new implants are positioned with one in a molar region and the other inserted in the contralateral B or D position. A new overdenture bar and prosthesis then permits a RP-4 (or fixed) restoration.

When three or more implants are used for the overdenture system, passive screw-retained restorations are more difficult to achieve. Hence, the procedures for OD-3, OD-4, and OD-5 are much more specific for each clinical and laboratory step (Figure 29-83). Step-by-step considerations are presented under the OD-5 option.

Overdenture Option 4

In the fourth mandibular overdenture option (OD-4), four implants are placed in the A, B, D, and E positions. This is often the minimum number of implants when the patient has opposing maxillary teeth, or C–h anterior bone volume with CHS greater than 15 mm. These implants usually provide sufficient support to include a distal cantilever up to 10 mm on each side if the stress factors are intermediate to low (i.e., parafunction, CHS, masticatory dynamics, and opposing dentition) (Figure 29-84).

The cantilevered superstructure is a feature of the four or more implant treatment options in a completely edentulous arch for three reasons: The first relates to the increase in implant support compared with OD-1 to OD-3. The second is that the biomechanical position of the splinted implants is improved in an ovoid or tapering arch form compared with OD-1 or OD-2. The third is related to the additional retention provided by the fourth implant for the superstructure bar, which limits the risk of prosthetic screw loosening and other related complications of cantilevered restorations.

In considering a distal cantilever for a mandibular overdenture bar, the implant position is the primary local determinant. Cantilevers may be compared to a class 1 lever in mechanics. The distalmost implant on each side acts as a fulcrum when

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occlusal forces are applied to the distal cantilever. Therefore, the amount of the occlusal force is magnified by the length of the cantilever, which acts as a lever. For example, a 25-lb load to a 10-mm cantilever results in a 250-lb mm force.

This moment force is resisted by the length of the bar anterior to the fulcrum. Therefore, if the two anterior implants (B and D) are 5 mm from the fulcrum (distal implants A and E), the effect of the posterior cantilever is reduced. If the implants are 5 mm apart, the mechanical advantage of the lever is the 10-mm cantilever divided by the 5-mm A-P spread, which equals 2. Because the implants are splinted, a 25-lb distal force is magnified to 50 lb to the anterior implant and 75 lb (50 + 25 = 75) to the distal (fulcrum) implant.

As a general rule, the posterior cantilever from anterior implants may be equal to the A-P distance when other stress factors are low to moderate. The mandibular arch form may be square, tapering, or ovoid. The arch form relates to the A-P distance of AE and BD implants. Square arch forms limit the A-P spread between implants and may not be able to counter the effect of a distal cantilever.

A square arch form often results in an A-P distance of 4 mm or less. Under these conditions, a minimum cantilever should be designed, and a PM-3 to PM-6 restoration is indicated. Therefore, distal cantilevers are significantly reduced for square arch forms (Figure 29-85). In a mandibular ovoid to tapering arch form, the A-P spread between implants in the A, E and D, B positions is greater and therefore permits a longer distal cantilever. This A-P spread is usually 8 to 10 mm in these arch forms and therefore often permits a cantilever up to 10 mm from the A and E positions (Figure 29-86).

It should be emphasized that the A-P spread is only one factor to determine the length of the cantilever. When stress factors such as occluding forces are greater, the cantilever is decreased. Parafunction, opposing arch, masticatory dynamics, and CHS affect the amount of force on the cantilever. For example, when the crown height is doubled, the moment forces are doubled. Therefore, under ideal, low-force conditions (crown height less than 15 mm, no parafunction, older female patient, opposing a maxillary denture), the cantilever may be up to 1.5 times the A-P spread for OD-4 overdentures. When the force factors are moderate, the cantilever should be reduced to one times the A-P spread. The amount of distal cantilever is related primarily to the force factors and to the arch form, which corresponds to the A-P spread.

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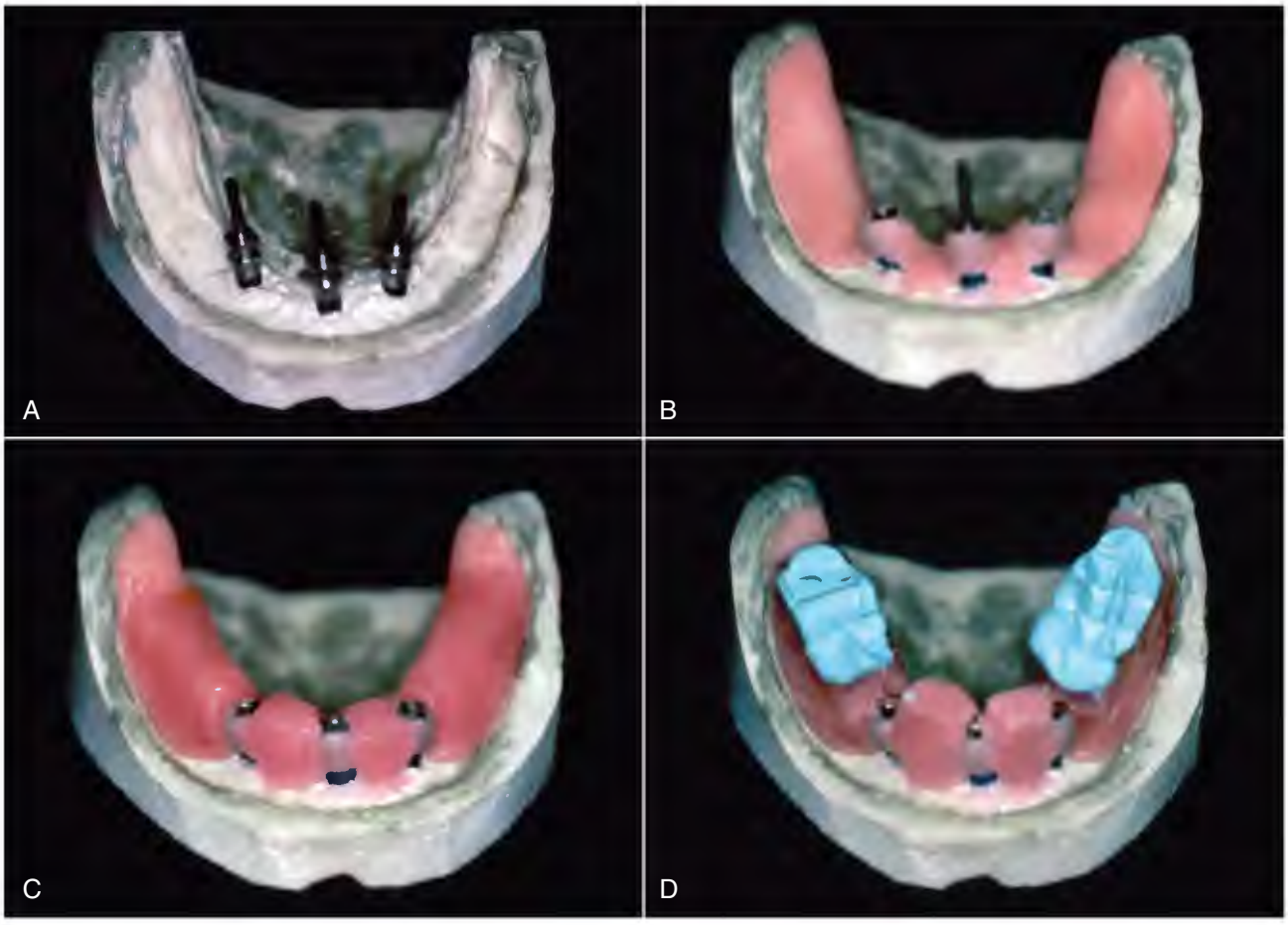


FIGURE 29-83. **A,** The final impression is made with a custom open tray. When the final impression is poured, implant abutment for screw analogs are attached to the direct impression transfer copings. The transfer copings are then reattached to the cast. **B,** A baseplate is made on the cast, incorporating the direct impression transfer copings. **C,** A wax rim is attached to the baseplate. This device also acts as a verification jig to confirm the impression of the implant location is correct. **D,** An occlusal vertical dimension and bite registration are recorded and used to mount the maxillary and mandibular wax rims.

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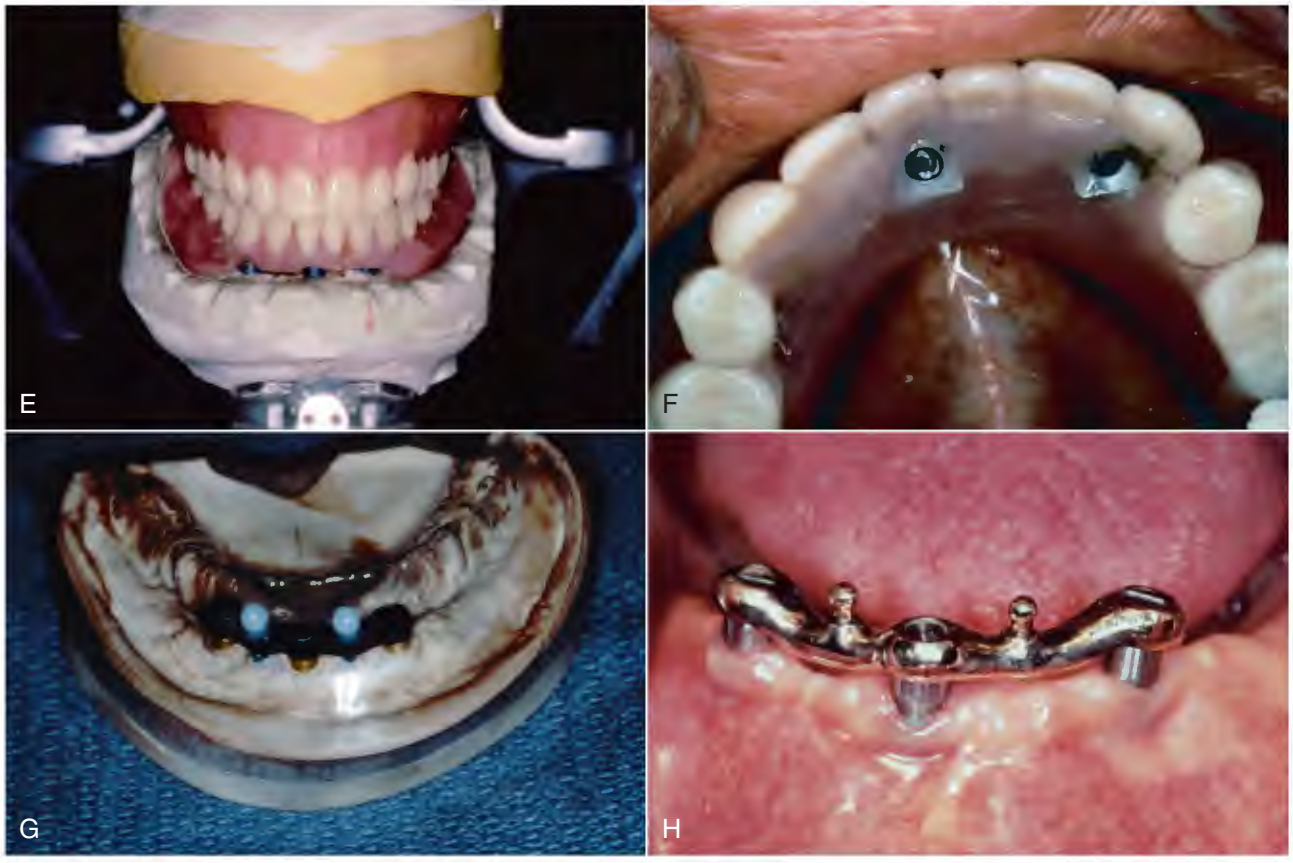


FIGURE 29-83, cont'd. **E,** Denture teeth are inserted into the mounted wax rims. **F,** The wax try-in confirms the esthetics, occlusion, and position of the abutments. **G,** A clear vacuum form of the implant overdenture (IOD) contours, was made, and the connecting bar and attachments are positioned within the denture contours and away from the denture teeth. **H,** The bar and IOD are delivered to the patient.

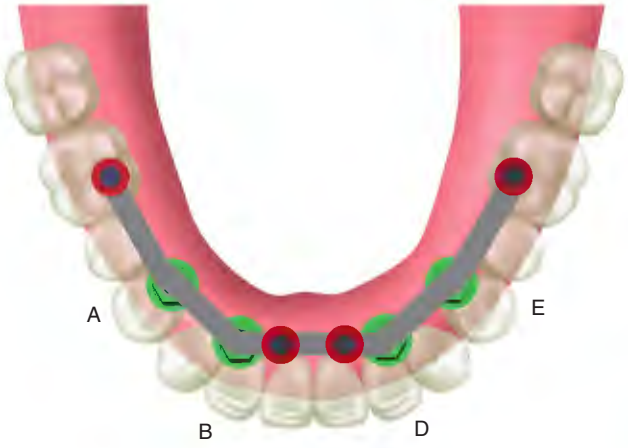


FIGURE 29-84. In overdenture option 4, four implants are placed in the A, B, D, and E positions. The implants usually provide sufficient support for a distal cantilever up to 10 mm.



FIGURE 29-85. These four implants were placed in a square ridge form and have little anteroposterior dimension. Therefore, less cantilever should be extended from the implants.

The patient's indications for the OD-4 treatment option as a minimum requirement include moderate to poor posterior anatomy that causes a lack of retention and stability of the IOD, history of recurrent soft tissue abrasions, or difficulty with speech. Remember that the edentulous posterior mandible resorbs four times faster than the anterior mandible. In the C–h posterior mandible, the external oblique and mylohyoid ridges are high (in relation to the residual ridge) and often correspond to the crest of the residual ridge. The muscle attachments therefore are at or near the crest of the posterior ridge. Other conditions that indicate an OD-4 as a minimum treatment option is when the patient's complaints and desires are more demanding than for the previous treatment options (Box 29-13).

The patient benefits from the four-implant option because of greater occlusal load support, lateral prosthesis stability, and improved retention. The prosthesis loads the soft tissue over the

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buccal shelf and the first and second molars and retromolar pad regions. Therefore, the amount of occlusal force on the implant system is reduced (compared with a fixed restoration or RP-4 prosthesis) because the bar does not extend to the molar position, where the forces are greater.

BOX 29-13 Patient Selection Criteria: OD-4

- Moderate to severe problems with traditional dentures
- Needs or desires are demanding
- Need to decrease bulk of prosthesis
- Inability to wear traditional prostheses
- Desire to abate posterior bone loss
- Unfavorable anatomy for complete dentures
- Problems with function and stability
- Posterior sore spots
- Opposing natural teeth
- C–h bone volume
- Unfavorable force factors (parafunction, age, size six, crown height space >15 mm)



FIGURE 29-86. A mandibular overdenture option 4 in an ovoid arch form. In this option, implants in the A, B, D, and E positions are connected with a cantilevered bar (up to 10 mm). The stress-breaking attachments are designed to allow some movement of the prosthesis during function.

The OD-4 treatment option is the lowest treatment rendered when the patient has maxillary teeth. The greater vertical and horizontal forces to the mandibular IOD require anterior disclusion in excursions to decrease the bite force. As such, more anterior implants are required under these conditions.

The next treatment plan option for the patient with a moderate financial budget is to add an additional implant in the future in one of the first molar positions (preferred) or the C position. Both of these options increase the A-P spread to fabricate a RP-4 prosthesis with an enhanced implant system support. The goal is to convert all patients eventually to a RP-4 or fixed restoration to prevent posterior bone loss and its associated disadvantages (including esthetics of the posterior facial regions).

To reduce the hidden cantilever effect, the second molar is not restored in the mandibular overdenture (Figure 29-87, *A*). In addition, the overdenture must move when loads are placed in the molar region. Therefore, the position and type of attachments on the connecting bar are important. The OD-4 prosthesis is indicated to obtain greater stability and a more limited range of prosthesis motion. The overdenture attachments often are placed in the distal cantilevers with an O-ring attachment in the midline (Figure 29-87, *B*). The prosthesis is still RP-5 but with the least soft tissue support of all RP-5 designs. The anterior attachment must allow vertical movement for the distal aspect of the prosthesis to rotate toward the tissue.

Clips, which permit rotation, are difficult to use on cantilevered superstructures. To allow movement, the clip must be placed perpendicular to the path of rotation, not along the cantilevered bar where its only function then is retention (and limits rotation) (Figures 29-88, *A* and *B*).

The most common attachment type is an O-ring or Locator because its position allows the most freedom. The usual O-ring positions are on the distal aspect of each bar and in between the AB and DE positions. An alternative is to position one O-ring in the C implant position (because no implant is at this site). The two distal O-rings permit rotation of the restoration toward the buccal shelf, and the anterior O-rings permit the restoration to rotate up toward the incisal. The connecting bar gives implant support from the premolar region forward and lateral stability. The O-rings provide adequate retention. A smaller-size O-ring or less retentive material usually is positioned in the anterior, especially when two anterior O-rings are used.



FIGURE 29-87. **A,** A mandibular implant overdenture for option 4 and 5 usually does not have a second molar to reduce the risk of a hidden cantilever. **B,** The attachments on the distal of a cantilevered bar allow rotation so the prosthesis may load the buccal shelf in the molar regions.

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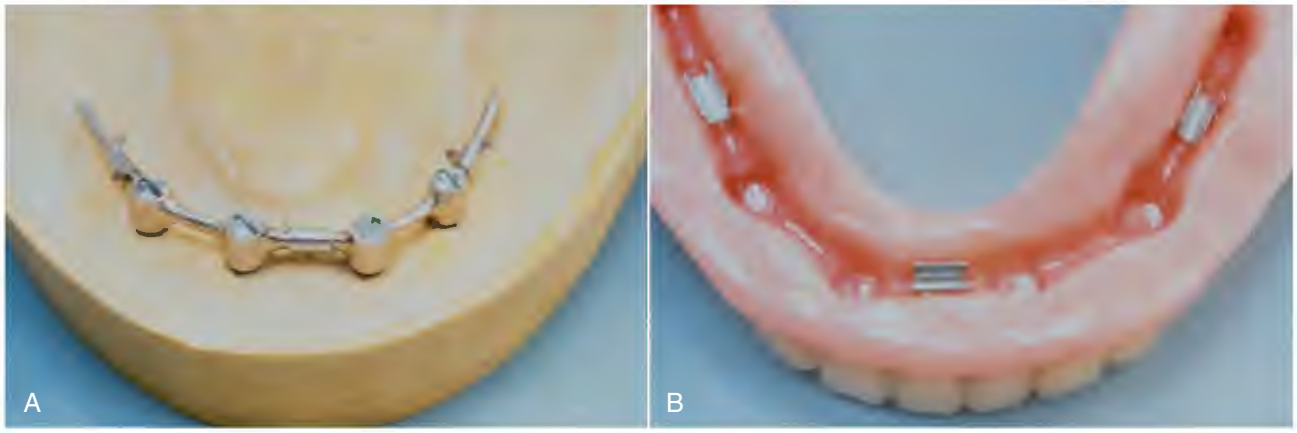


FIGURE 29-88. **A,** Clips are usually not indicated on cantilevered bars because they prevent rotation of the implant overdenture and result in PM-0. **B,** When the clips are positioned around the arch with each having a different path of rotation, the prosthesis has no movement and is similar to a fixed prosthesis.

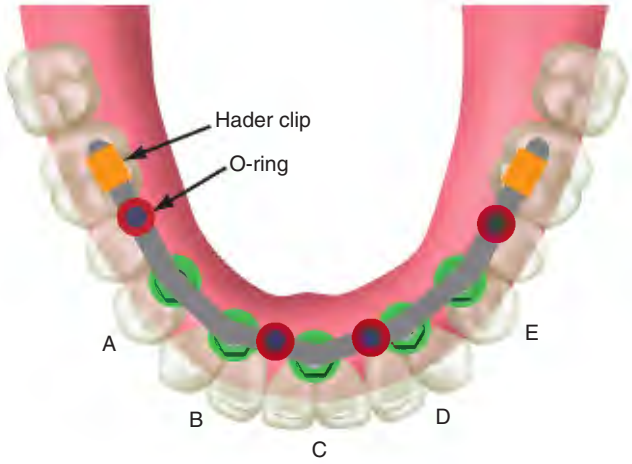


FIGURE 29-89. In the overdenture option 5, implants are placed in the A, B, C, D, and E positions. A bar splints the implants together and is distally cantilevered. The length of the cantilever depends on the anteroposterior distance and the force factors.

Overdenture Option 5

In the OD-5 treatment option, five implants are inserted in the A, B, C, D, and E positions. The superstructure is usually cantilevered distally up to two times the A-P spread (if almost all of the stress factors are low) and averages 15 mm, which places it under the first molar area (Figure 29-89). The amount of the distal bar cantilever is related (in part) to the A-P distance. The forces exerted on cantilevered bar designs and implants have been studied by several authors.[118–124] A constant finding is that the most distal implants receive stresses two to three times greater than the other implants. The highest concentration of stresses is at the level of the crest distal to the most distal implant on the loaded side. No statistical differences were found between different implant lengths. The stresses increase with the length of the cantilever. Therefore, stress factors need to be evaluated carefully and pondered before an extended cantilever is designed.

Stresses are magnified in direct proportion to the length of cantilever and should be planned carefully based on the patient's force factors and the existing anatomy.[119–121] The A-P distance is greater than in OD-4 because the C implant is often more anterior than the B and D implant sites. A square ridge form usually has an A-P spread of less than 5 mm and should have a minimum cantilever even with five implants joined together. An ovoid arch has an A-P spread from 5 to 8 mm, and a tapered arch form more than 8 mm (Figure 29-90). In these situations, a cantilever of two times this distance is indicated when force factors are not excessive (Figure 29-91).

If any major stress factors (e.g., parafunction, opposing arch) are not favorable, the cantilever should be reduced. The patient force factors are as important as the A-P spread. In a study in which the failure criterion was the failure of the screw joint with arrangements of three, four, five, and six implants with a similar A-P spread submitted to forces from 143 to 400 N, the greater transmitted forces to the prosthetic connection always exceeded the yield strength of the system.[118] This study emphasizes the fact that the amount and duration of occlusal load is even more important than the A-P spread to be considered for cantilever length determination.

The superstructure bar may be cantilevered up to two times the A-P distance with low stress factors for three reasons. The additional C implant increases the implant–bone surface area of the system, adds another retentive element to the bar to reduce screw loosening, and increases the A-P dimension. This helps counter the class 1 lever action created by the distal cantilever (Figure 29-92).

The fifth mandibular overdenture option (OD-5) is designed for two types of patients. Most important, this is a minimum treatment option for patients with moderate to severe problems related to a traditional mandibular denture. The needs and desires of the patient are often most demanding and may include limiting the bulk or amount of the prosthesis, major concerns regarding function (mastication and speech) or stability, posterior sore spots, or the inability to wear a mandibular denture. This option is often indicated when maxillary teeth or a fixed implant restoration is in the opposing arch (Box 29-14).

Five implants also allow the superstructure and prosthesis to be cantilevered forward from the anterior ridge. This is of particular benefit for Angle's skeletal class II patients. The lower lip is supported by the maxillary teeth when the jaw is at rest. Traditional mandibular dentures reconstruct the original horizontal overjet, so the lower anterior teeth position does not infringe on the neutral zone during rest or function. However, in a RP-4 restoration, the teeth may be set in a skeletal class I pattern,

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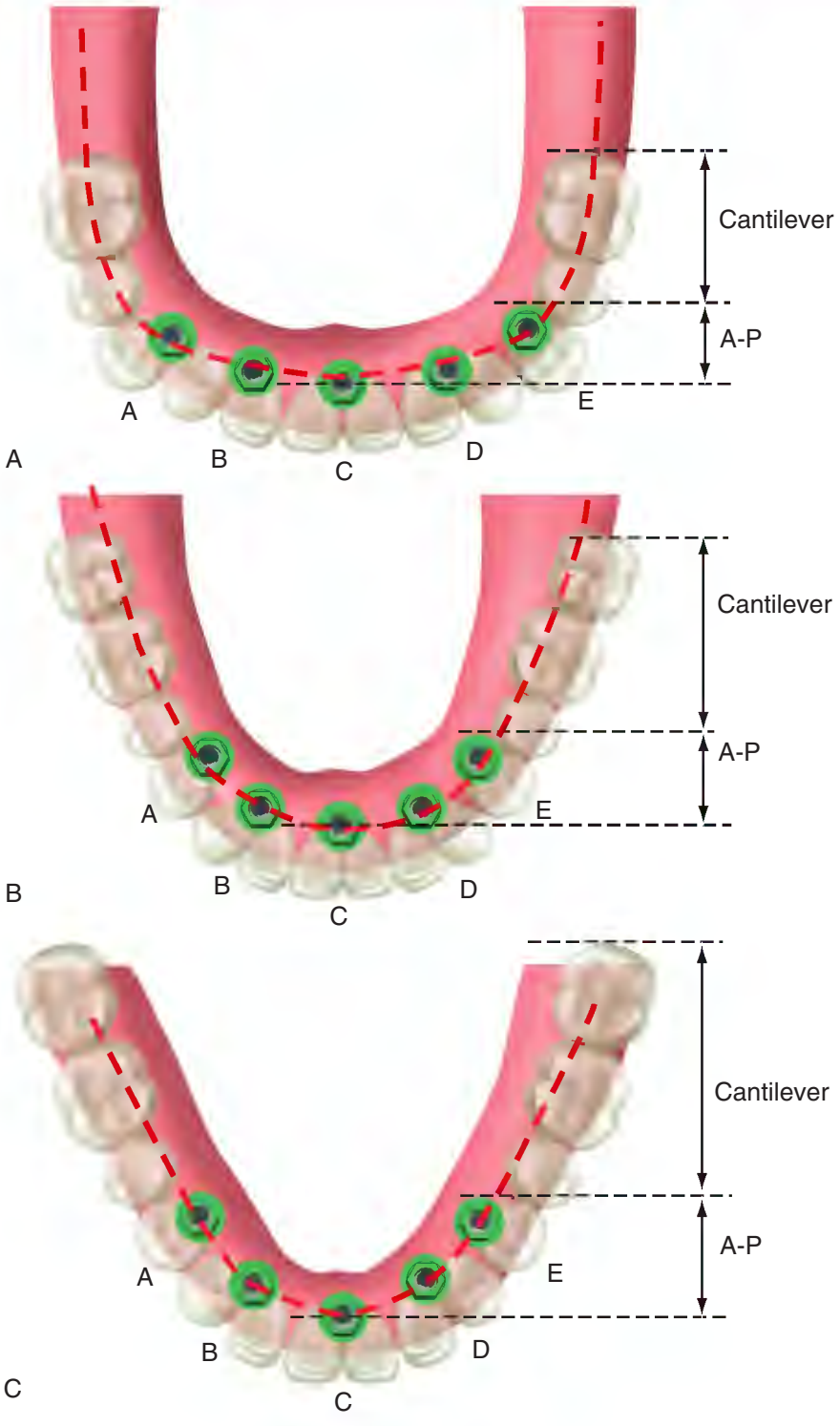


FIGURE 29-90. **A,** Arch shape affects the anteroposterior (A-P) distance. The square arch form is less than 5 mm. **B,** The ovoid arch form often has an A-P distance of 5 to 8 mm. **C,** A tapered arch form has the greatest A-P distance, larger than 8 mm.

where they provide the best esthetic result. This also increases the amount of function in the anterior region. Because these patients are skeletal class II, the forward anterior tooth position also places the molars forward, reducing the need for a more distal cantilever. The distal cantilever reduction also decreases the posterior lever force (Figure 29-93).

The second patient condition that determines this option is for the treatment to stop the continued bone loss in the posterior mandible. If no prosthetic load is on the posterior bone, the resorption process is delayed considerably and often reversed. Even when no posterior implants are inserted, the cantilevered bar and overdenture avoid load to the posterior residual ridge and often halt its resorption process. Recent evidence shows that completely implant-supported prostheses often increase the amount of posterior bone height even when no posterior implants are inserted.[81–83] However, it should be noted that a better option to prevent this posterior bone loss and increase the A-P spread is the insertion of one or more posterior implants before the bone atrophy has occurred. The OD-5 treatment option is also indicated when the patient

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desires a RP-4 or fixed restoration, the arch form is square for a RP-5 prosthesis, or the maxillary arch has natural teeth (especially in a young patient or male).

Usually four to six retentive attachments are included in the cantilevered bar design. The attachments are typically O-rings or Hader clips. Because of their number and distribution, the attachments provide retention and oppose PM. Typically, four O-rings are distributed evenly (two anterior and two posterior to the distal implants). If the OVD is limited or parafunction is present, the IOD may use a metal framework within the prosthesis (similar to a partial denture). This design reduces the risk of IOD fracture (Figure 29-94).

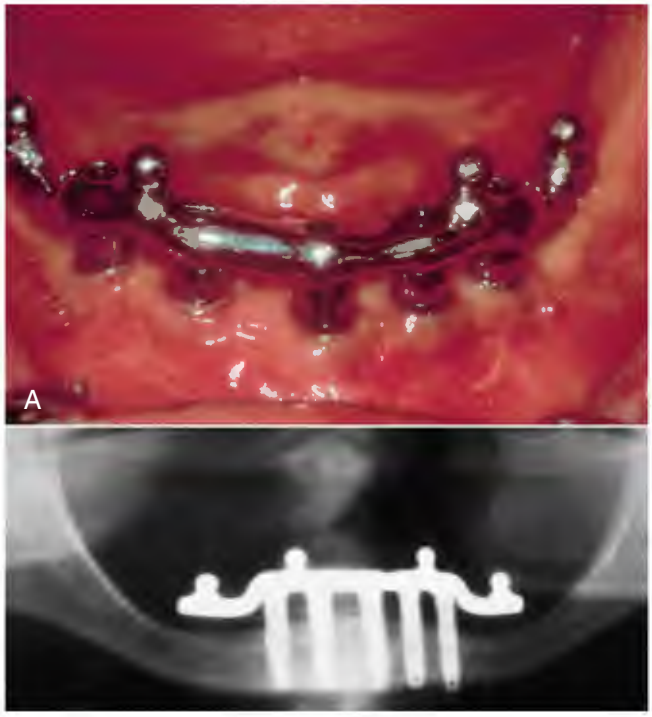


FIGURE 29-91. **A,** A five-implant overdenture for a tapered arch form opposing a denture for an older woman may cantilever the bar two times the A-P distance. **B,** A panoramic radiograph of an option 5 overdenture bar and five implants in the anterior mandible.

A Hader bar clip may be placed distal to the last O-rings on each cantilevered section. At delivery, the O-rings may be the only attachments used. The Hader clip may be added as a backup system for additional retention in case an O-ring stud breaks or in case the vertical dimension of occlusion does not permit the use of high-profile retentive O-rings and causes repeated fracture of the overlying acrylic denture. It can also provide additional retention to prevent sticky food from lifting the posterior aspect of the denture.

The six-attachment bar design also permits a method to decrease stress to the bar and implants if screw loosening or bone loss around the implants is noticed. The Hader clip and bar may be sectioned off the connecting bar. The RP-4 prosthesis then is converted to a RP-5 restoration because it now may rotate on the two O-rings placed just distal to the posterior implants (Figure 29-95).

Step-by-Step Restorative Procedure

Initial Abutment Selection and Preliminary Impression

During the first restorative appointment, the permucosal extensions are removed and the abutments for screw retention are

BOX 29-14 Patient Selection Criteria: OD-5

- Moderate to severe problems with traditional dentures
- Needs or desires are demanding
- Need to decrease bulk of prosthesis
- Inability to wear a traditional prosthesis
- Desire to abate posterior bone loss
- Unfavorable anatomy for complete dentures
- Problems with function and stability
- Posterior sore spots
- Moderate to poor posterior anatomy
- Lack of retention and stability
- Soft tissue abrasion
- Speech difficulties
- More demanding patient type
- Maxillary teeth or fixed implant prostheses
- Angle's class II division I mandible restored to class I



FIGURE 29-92. **A,** A five-implant overdenture in an ovoid arch from in a patient with moderate parafunction may have a distal cantilever that is one time the anteroposterior distance and has some soft tissue support in the molar region. **B,** The mandibular overdenture attachment must allow some movement in order to load the soft tissue in the molar region.

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FIGURE 29-93. **A,** A wax try-in of an implant overdenture (IOD) in a skeletal class II patient with the teeth cantilevered to the anterior. **B,** The wax try-in of the maxillary full denture and mandibular IOD with class I dental occlusion. **C,** A digital fabrication of the connecting bar places the anterior component of the bar under the cantilevered anterior teeth. **D,** The bar is fabricated and inserted into the five implants. **E,** The final maxillary denture and RP-4 mandibular implant overdenture with treatment option 5.

selected and placed into the implant bodies (Figure 29-96, *A*). The abutment for screw platform usually is placed 2 mm above the tissue in the mandible to facilitate daily home care. The CHS is evaluated and must be adequate for placement of the final coping and fixation screw. On occasion, the bar may be connected directly to the implant body without an intermediate abutment.

An indirect impression transfer is placed into the abutment for screw retention (or implant body) and is used to confirm proper angulation and the final restoration outline (Figure 29-96, *B*). An angled abutment for screw retention may be used if indicated to improve the contour of the restoration. If this is still inadequate, the practitioner should consider implant removal and insertion of another implant in the correct position. An indirect impression transfer aids in visualizing implant body angulation, choosing the final prosthetic abutment, and fabricating a custom tray.

A preliminary denture-like elastic impression is made with irreversible hydrocolloid or addition silicone of the indirect impression transfers and surrounding tissues. Syringing the impression material around the impression transfers and tissues facilitates the recording of these transfers. The preliminary impression is similar to those for full or partial removable dentures. If addition silicone is used, the impression may be

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FIGURE 29-94. **A,** An implant overdenture (IOD) with five implants may use a cantilevered bar with four O-ring attachments. **B,** The prosthesis may use a metal framework to reduce the risk of IOD fracture.



FIGURE 29-95. A RP-4 mandibular implant overdenture with treatment option 5 and 6 attachments to retain the prosthesis (four O-rings and two distal Hader clips). When the Hader clip is more distal to the last O-ring, it may be cut off from the bar, the cantilever is reduced, and the prosthesis converted to a RP-5 restoration.

shipped to the laboratory for pouring and mounting. To design the custom tray accurately, the preliminary impression should capture the soft tissue landmarks for denture construction (retromolar pads, surrounding unattached mucosa, and morphology of the residual arch).

After removal of the preliminary impression, the dentist inspects it. No voids should be present over the indirect transfers. The indirect impression transfers then are unscrewed from the abutments for screw retention in the mouth and connected to the abutment for screw retention analogs. Each indirect impression transfer with analog is placed carefully into the corresponding hole in the impression. No discrepancy should be present. Resistance is felt and then a snap, which indicates proper seating (Figure 29-96, *C*). Hygiene cover screws are placed over the abutments to protect the threads from calculus and debris. The final abutments for screw retention may remain in the patient's mouth between appointments if they are above the tissue and the hexagon is protected with a hygiene cover screw (Figure 29-96, *D*).

For patients wearing a RP, the preexisting tissue conditioner is removed and replaced by a soft liner, which is relieved around the abutments. The patient's diet at this time consists of soft foods, and the patient is instructed to leave the prosthesis out of the mouth as much as possible, especially during sleep. The patient is asked to return in 1 to 2 weeks. The faster the framework connects the implants, the less likely that overload of one implant may occur. The second prosthetic appointment is scheduled 1 to 2 weeks after the first appointment, depending on whether soft tissue correction was indicated. Longer time is not indicated because incremental loading of the implant interface is not possible at this time. Extended periods may put the individual implants at risk because they are not splinted and are subjected individually to local forces.

Laboratory Phase I

The first laboratory step for a complete-arch screw-retained prosthesis design is the fabrication of a custom denture impression tray that can incorporate direct impression transfer copings ("modified open tray"). The preliminary impressions, with indirect impression copings and abutment for screw retention analogs, are poured in dental stone (Figure 29-96, *E*).

The indirect impression transfers then are replaced with direct impression transfer copings with long fixation screws on the working cast (Figure 29-96, *F*). These direct impression transfers do not engage the antirotational hex of the abutment (or implant body) analog. The direct impression transfer copings are blocked out 3 mm around and between with baseplate wax or clay and allow the fixation screw to be exposed (Figure 29-96, *G*). A 1-mm wax relief is placed over the soft tissue regions of the residual ridge to be captured in the impression with first molar tissue stops. An impression tray tissue stop is added in the molar region, so the impression tray will not touch the edentulous ridge except at the tissue stop, which ensures room for impression material between the tray and the soft tissue. The cast and wax are lubricated lightly with petroleum jelly to prevent the wax from melting to the custom tray. Soft tissue landmarks to be captured in the impression include those used for RP construction because many of these structures help determine the tooth position regarding esthetics, phonetics, and function. A RP-5 mandibular restoration must include the buccal shelf, retromolar pads, and all other landmarks specific to a mandibular denture because these regions are a primary area of support for the distal component of the prosthesis when two to four implants are splinted together.

An open custom acrylic tray is then fabricated on the working cast (Figure 29-96, *H*). The fixation screws protrude 3 mm or more through the top of the tray, yet the tray is closed between and around each screw. The tray is removed from the cast;

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FIGURE 29-96. **A,** The first restorative appointment is to evaluate the implants, remove the permucosal extensions, and insert abutment for screw retention. **B,** Indirect impression transfers are threaded into the abutments for screw retention (or implant body). **C,** An irreversible hydrocolloid is most often used to make a preliminary impression. The indirect impression transfers are unthreaded from the abutments. The transfers are then connected to abutment analogs and reinserted into the closed-tray impression. **D,** Hygiene cover screws are threaded into the abutments for screw retention. **E,** The abutment analogs, transfers, and preliminary impression are poured in dental stone. **F,** Direct impression transfers replace the indirect impression transfer in the stone cast.

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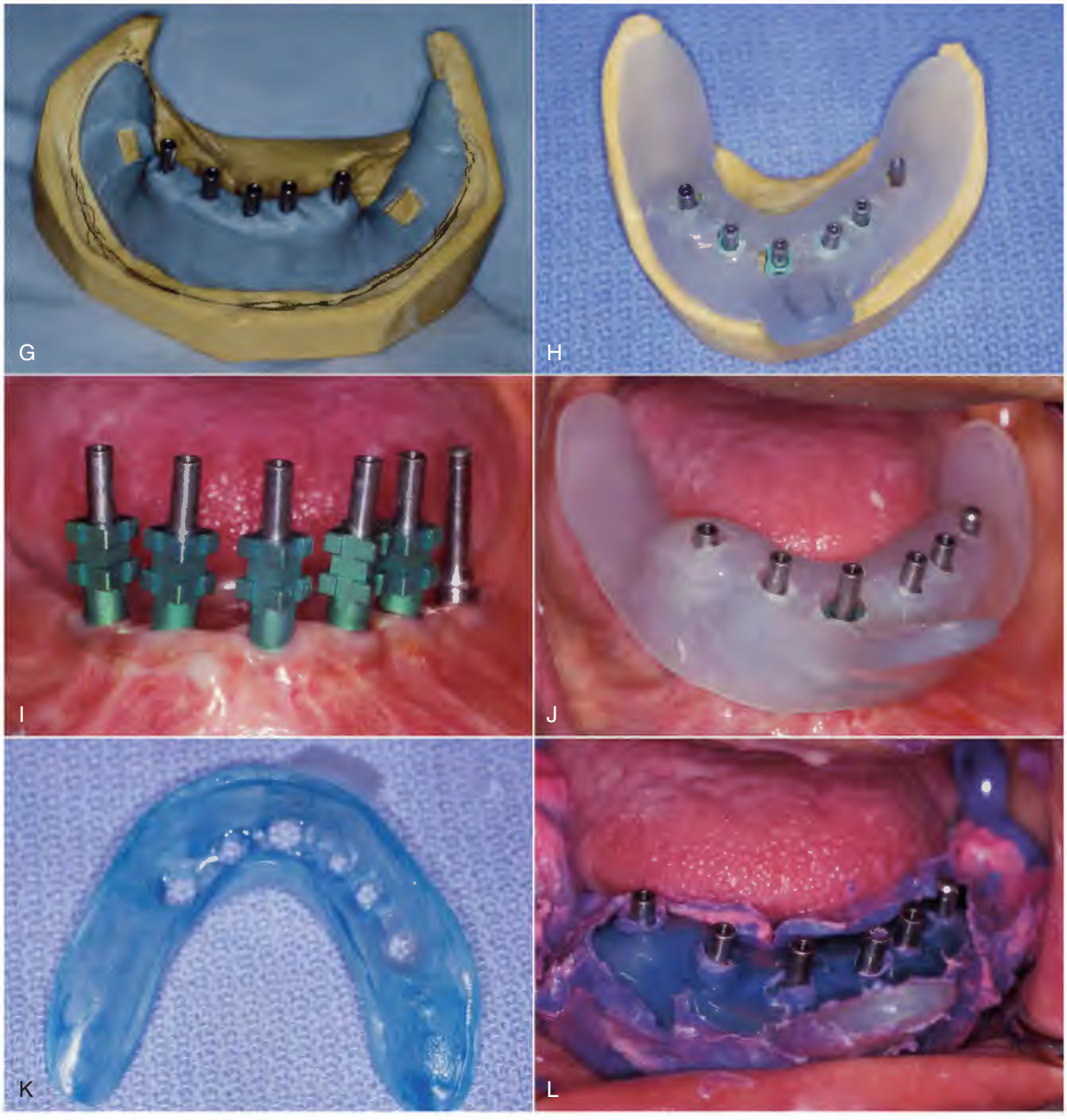


FIGURE 29-96, cont'd. **G,** Clay was used to block out 3 mm of the direct impression transfers and 1 mm (with a tissue stop) over the posterior ridges. The long fixation screws exit the clay at least a few millimeters. **H,** An open custom tray is made on the preliminary cast. The fixation screws exit the open tray several millimeters. **I,** Direct impression transfer copings are threaded into the abutments for screw retention (or implant body). **J,** The custom tray is tried in to confirm proper seating. **K,** Tray adhesive is painted on the internal aspect of the custom tray. **L,** The modified open custom tray is seated and border molded during the final impression.

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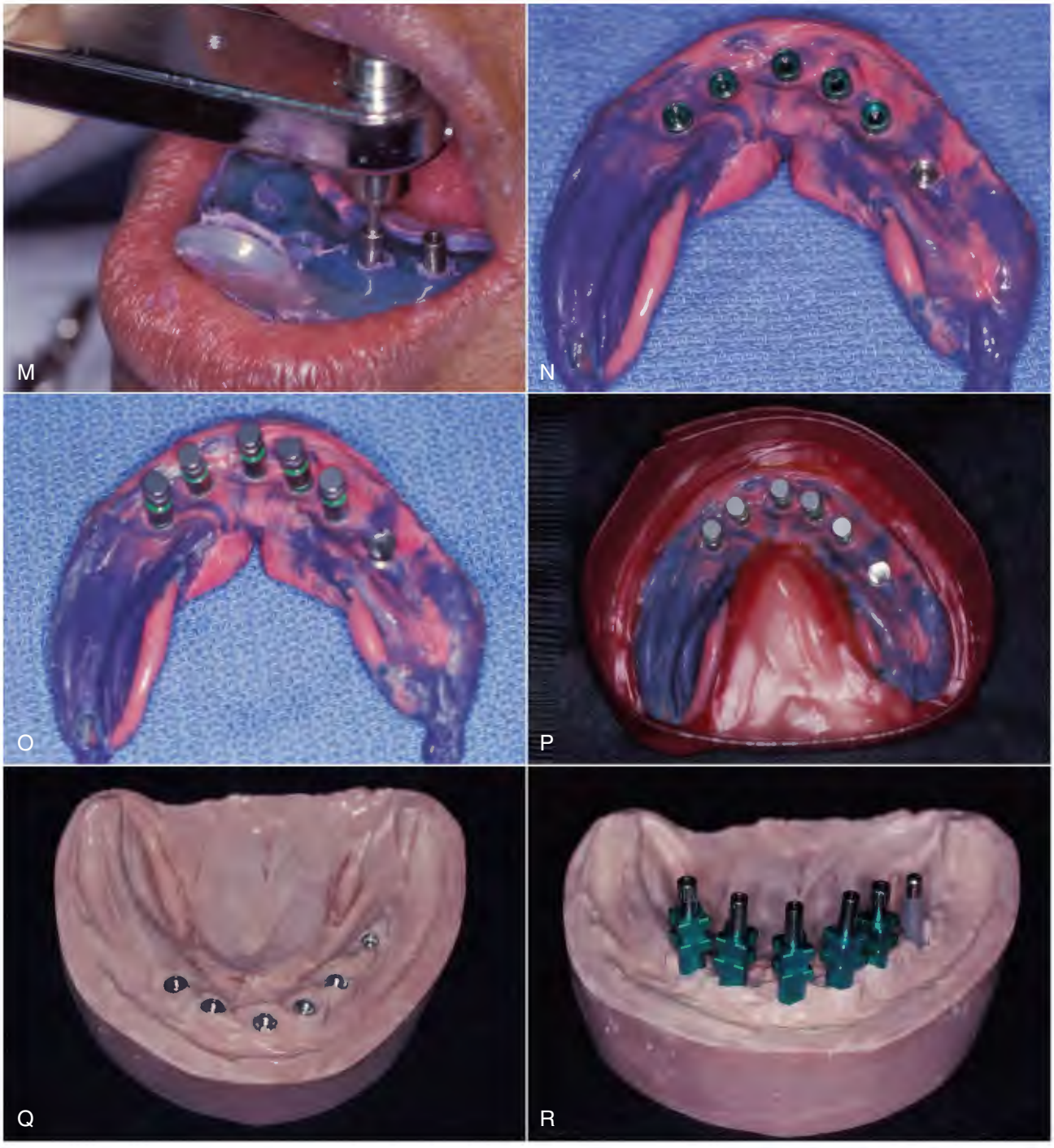


FIGURE 29-96, cont'd. **M,** The long fixation screws are unthreaded from the abutments. **N,** The custom tray, final impression, and direct impression transfer copings are removed from the mouth. **O,** The abutment analogs are threaded into the direct impression transfers within the final impression. **P,** The final impression and analogs are boxed in wax. **Q,** The final impression and transfer copings are removed from the dental stone cast. **R,** The direct impression transfer copings are threaded into the abutment analogs.

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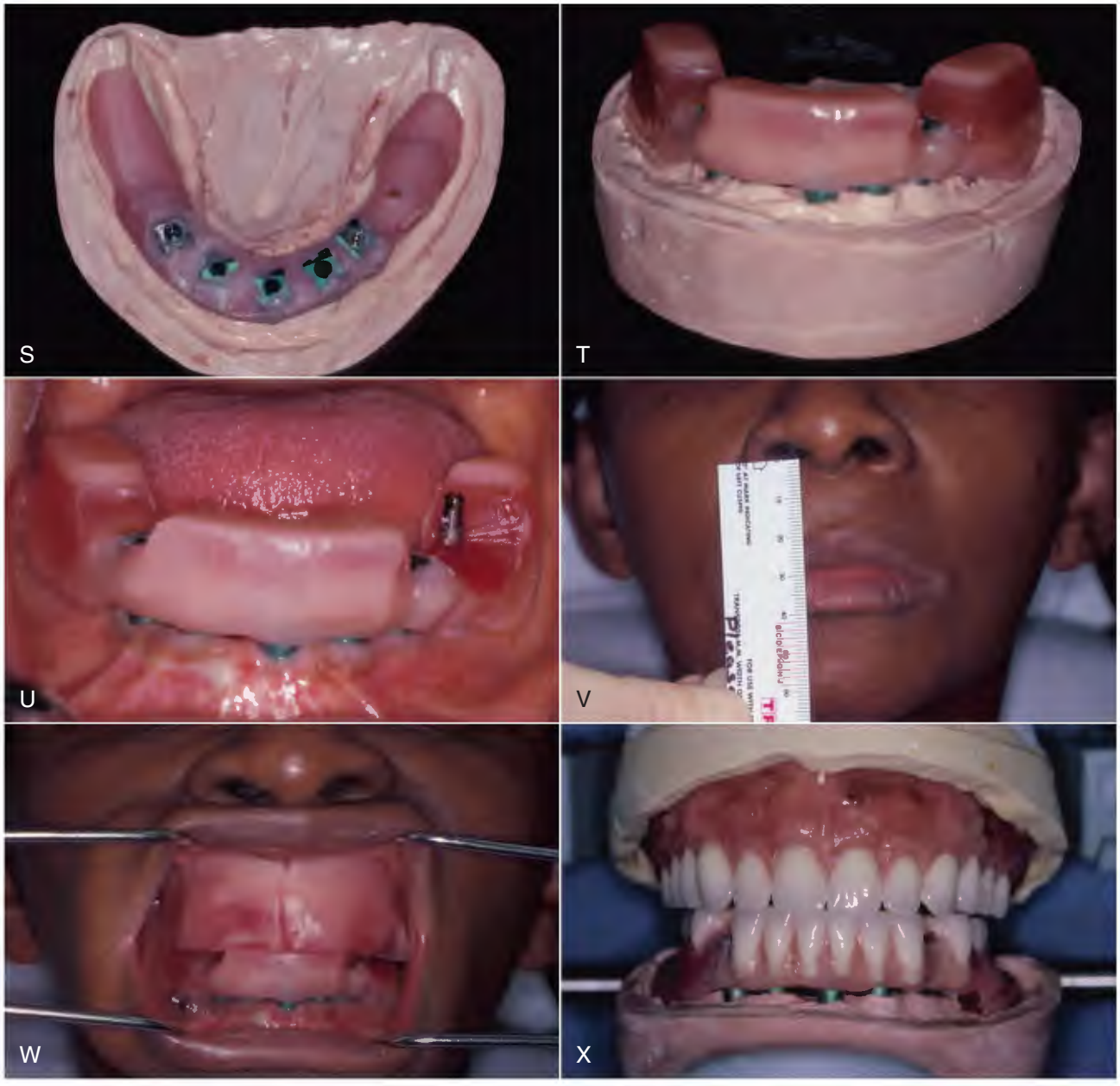


FIGURE 29-96, cont'd. **S,** A baseplate is fabricated on the cast and incorporates the transfer copings. This will be used as a verification jig and a baseplate and wax rim. **T,** Wax is added to the baseplate, and the connections of the transfer copings to the abutment analog are visible. **U,** The verification jig and baseplate and wax rim are threaded into the most distal implants. **V,** The maxillary and mandibular baseplate and wax rims are used to determine the maxillomandibular relationships, including the occlusal vertical dimension (OVD). **W,** A centric bite relationship is recorded with the maxillary and mandibular wax rims at the OVD. **X,** The maxillary and mandibular teeth are set in medial-positioned lingualized occlusion in accordance with concepts developed by the author (see Chapter 34).

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FIGURE 29-96, cont'd. **Y,** The maxillary and mandibular try-in confirms the correct position of the teeth. **Z,** The connecting bar and attachment are waxed according to the templates to remain within the contours of the restoration and away from the teeth. **AA,** The wax-up of the bar and attachments include precious metal copings to connect to the implant abutments. **BB,** The waxed connecting bar is sprued. **CC,** The bar is cast in precious metal. **DD**, The denture is then processed to the bar.

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FIGURE 29-96, cont'd. **EE,** The connecting bar is placed on the abutments, and the center prosthetic screw is partially threaded into position. **FF,** The prosthetic screws are threaded into the bar and abutments starting with the C implant, then the B and D implants, and then the E and A implants. **GG,** A torque wrench tightens the screws in the same sequence as the screws were first threaded into position. **HH,** The connecting bar should have no pain upon insertion. **II,** The final mandibular implant overdenture is inserted onto the attachments and bar. **JJ,** The OD-5 overdenture is designed similar to a complete denture and often has a metal framework incorporated into the prosthesis. **KK,** The occlusion is evaluated and modified as required for bilateral balance (when opposing a denture).

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trimmed 1 to 2 mm short of the periphery, similar to a complete denture custom tray; and polished. The holes for the fixation screws are increased to allow easy insertion and removal from the cast. The openings around the long fixation screws allow the custom impression tray to be seated consistently in the same intraoral position.

The original custom tray technique developed by Zarb et al. used a completely open tray around the direct impression transfers covered with wax.[125] After the impression material set, the wax was removed from the open tray, and the fixation screws were observed. However, the complete open tray may not have been seated enough for direct observation of the fixation screws. The fixation screws with the modified open tray have the direct impression transfers clearly visible for easy removal from the direct impression copings before removing the impression. In addition, the limited-size holes in the impression tray for the fixation screws ensure that the tray is seated in the correct position.

Final Impression: Second Appointment

The primary purpose of the second appointment is to make the final impression for the master cast. The soft tissue is healed completely at this time. The final abutment ideally may be selected and verified for fit and position. Care is needed to avoid trapping any soft tissue between the abutment and implant platform during this process. A radiograph is used to confirm the complete seating of the abutment when the connection is below the soft tissue. Periimplant probing confirms a pocket depth of 4 mm or less. The final abutment for screw retention is tightened with a torque wrench to 20 to 30 N/cm (or manufacturer specification).

The direct impression transfer copings and fixation screws are tightened into the final abutments for screw retention with moderate hand pressure (Figure 29-96, *I*). A radiograph can be used to confirm proper seating of all components before making the impression when the connection is subgingival. The custom tray is seated and inspected intraorally to ensure that space is adequate for impression material and that the fixation screws of the direct transfers are accessible and do not impinge on insertion of the tray (Figure 29-96, *J*). Tray adhesive is painted on the internal surface and borders of the tray (Figure 29-96, *K*). The impression tray is border molded if a RP-5 prosthesis is designed and combines the techniques for denture impressions with the transfer impression. A rigid addition silicone or polyether impression material is injected around the transfers and into the tray. The custom tray is seated, and any excess is removed from the holes around the screws (Figure 29-96, *L*).

After complete setting of the impression material, the fixation screws are unthreaded and pulled several millimeters to check that they disengage from the abutments for screw retention (Figure 29-96, *M*). The direct impression copings are trapped within the impression. The impression and transfer copings are removed and evaluated (Figure 29-96, *N*). No impression material should be present between the impression coping and abutment. Hygiene cover screws are inserted into the abutments for screw retention to protect the internal threads. The denture soft lining is relieved if any risk of loading is present. The diet remains very soft.

Laboratory Phase II

The corresponding abutment for screw retention analog is threaded carefully onto the direct impression transfer coping in the impression (Figure 29-96, *O*). The impression is trimmed and boxed with plaster and pumice for a two-step pour technique (Figure 29-96, *P*). Manufacturer guidelines specify the proper amount of dental stone and distilled water, which corresponds to the shrinkage of the impression material. The dental stone selected is compatible with the shrinkage of the impression material. A vacuum is used to mix the dental stone, and a vibrator is used to pour it into the impression. After the stone has set completely, the long screws are removed from the direct impression transfers, and the impression is taken off the master cast (Figure 29-96, *Q*). The rigid impression transfer copings may be recovered from the impression, sterilized, and reused.

An implant-fixated record base and wax rim then may be fabricated. This device also acts as a verification jig to ensure the final impression was correct relative to the implant abutment position. The impression transfer copings are secured into position on the master cast and will be used in the fabrication of a verification jig (Figure 29-96, *R*). If vertical height is limited, the transfers may be cut in half, or final precious metal copings may be used. Using 8-gauge sprue wax, the areas around, below, and between the butt joint of the impression transfer copings and abutment analogs are blocked out on the cast so they may be observed below the baseplate. The relief wax prevents acrylic from sealing the abutment-to-implant connection and, after being removed, allows the direct vision of the transfer fit to the analogs on the model or the abutments for screw retention intraorally.

The master cast is lubricated lightly with petroleum jelly. To reduce distortion during shrinkage of the record base, increments of acrylic or light-cured resin are applied or a "salt and pepper" technique is used around the copings, incorporating the impression transfer copings. Incremental amounts of acrylic are placed over the posterior residual ridge. Cold-cured acrylic is allowed to set for 24 hours and light-cured acrylic for 8 to 10 minutes followed by air barrier coating and an additional cure of 3 minutes (Figure 29-96, *S*). The record base is removed, and the borders are finished and polished. A pink baseplate wax rim is applied to the record base. The rim is adjusted to about 20 mm from the occlusal plane to the vestibule in the labial frenum area. The posterior rim is adjusted to two thirds up the height of the retromolar pad. Openings in the wax are made for the most distal fixation screw on each side of the arch (Figure 29-96, *T*).

Wax Try-in and Records: Third Appointment

This appointment is used to verify the fit of the verification jig–baseplate to the intraoral abutments for screw retention and to obtain the vertical dimension and centric relation occlusion records of the patient (Figure 29-96, *U*). The abutments for screw retention are checked first to ensure that they are seated completely. The abutment–implant connection may separate, and the abutment screw may unthread a few turns during the week. The baseplate verification jig is then tried in. If the baseplate fits passively, the vertical dimension may be established. If any rock or discrepancy exists in the baseplate, the incorrect abutment is identified. The baseplate is modified by removing the offending transfer coping and is tried again. If a stable, accurate fit may be obtained on the other abutments, the laboratory is instructed to cast the superstructure in two (or more) sections separated in the same region(s) as the baseplate at the proper distance for soldering. At the metal try-in appointment, the metal superstructure may be picked up in a modified impression tray and long fixation screws used for soldering to

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provide a passive fit. An alternative approach is to separate the offending impression transfer coping from the baseplate and remake a final impression and master cast or to separate the abutment for screw analog from the master cast and proceed similar to an altered cast technique (see Chapter 28).

After the maxillary baseplate and wax rim have been adjusted to the proper contour, the vertical dimension (OVD) is established, and the maxillomandibular relations are determined (Figure 29-96, *V*). A centric relation bite registration is obtained, as is a face-bow recording (Figure 29-96, *W*). Protrusive and border movements also are recorded. Anterior tooth selection regarding size, shape, shade, and arrangement is made.

The diet remains soft, and the patient is reminded to remove the temporary dentures as much as possible, especially at night. A soft protective night splint, which can be relieved over the implant abutment, may be required when opposing natural dentition. The next appointment is scheduled for 1 week later.

Laboratory Phase III

The master cast is mounted on the articulator with the occlusal records. The anterior denture teeth are set for esthetics, phonetics, function, and lip support. The incisal guidance should be as flat as esthetics and phonetics will permit when opposing a denture; this corresponds to a protrusive record that enables the condylar guidance of the articulator to be set in relation to the condylar path. This record is necessary to develop a balanced occlusal scheme for an opposing denture. During this laboratory step, the anterior teeth are modified as required, and the posterior teeth are set in a medial-positioned lingualized occlusion (see Chapter 33). This occlusal scheme incorporates the lingualized occlusion concept of Payne and Pound with a more medial position, bilateral balance, and elevated occlusal plane of the posterior teeth as described by the author[126,127] (Figure 29-96, *X*).

Teeth Try-in: Fourth Appointment

The teeth setup is evaluated intraorally for esthetics, phonetics, and lip support. The occlusion is verified for accuracy in centric relation and excursions (Figure 29-96, *Y*). The wax try-in is removed from the mouth, and the hygiene covers are reinserted into the abutments. The patient's diet remains as soft as possible, and the transitional denture is removed at night. The next appointment is scheduled in 1 to 2 weeks, depending on the laboratory schedule.

Laboratory Phase IV

The laboratory fabricates an index of the teeth position on the master cast. One method is to fabricate a vacuum-formed template on a stone cast replica of the setup. Another is to form a facial and lingual index. This template reproduces the facial, occlusal or incisal, and lingual contours of the try-in model. The occlusal and incisal portion of the template also permits the position of the teeth to be identified. The clear template then may be fixed to the opposing cast with sticky wax into the correct occlusal position. In this way, the articulator may be opened to permit access to the working cast with analogs or may be closed to relay the position of the contour of the denture flange and teeth facially and lingually. In this manner, the bar or superstructure design may be waxed and fabricated at the distance for proper contour, strength, and position (Figure 29-96, *Z* and *AA*). Precious metal copings are used in the wax-up to connect the bar to the implants. The superstructure is sprued, invested, and cast in one piece or in sections as indicated by size, technique, and verification fit of the baseplate (Figure 29-96, *BB* to *DD*).

An improved method to fabricate the bar is with digital dentistry. A computer scans the abutments and designs a bar and abutment system within the contours of the final overdenture. The bar is then milled out of titanium or its alloy. This method improves the accuracy of fit because wax distortion, investment expansion, and cast metal shrinkage are eliminated.

Metal Try-in and Final Delivery: Fifth Appointment

The primary purpose of the fifth prosthodontic appointment is to evaluate the superstructure casting, verify passive accurate fit, and deliver the final prosthesis. Intraoral superstructure evaluation for screw-retained implant prostheses is most critical. The abutments for screw retention first are evaluated to ensure that they are seated completely and are threaded into position. Any mobility or tenderness is noted and mandates evaluation of the implant body–hard tissue interface and the soft tissue, which may be present between the implant body and loose abutment for screw retention.

The casting initially is placed and evaluated for stability (Figure 29-96, *EE*). The center screw is inserted partially when multiple abutments are present. End-to-end tipping indicates that the most distal abutment does not fit correctly. If no end-to-end tipping is present, the most terminal abutment coping screws may be inserted about half the screw length. Lateral rocking then is noted and when present indicates that an intermediate abutment of the prosthesis is not passive. Direct vision or a dental explorer evaluates and explores for an open margin between the coping and abutment. The marginal opening may be only on one side and when present represents a tipped coping on the abutment. If no lateral rocking is evident and all margins are approximated, the remainder of the coping screws are inserted.

The prosthetic screws are only moderately tightened first using a counterbalance approach. A common scenario is first to thread the centermost coping screw firmly into position. The intermediary screws then are inserted, one on each side, with firm torque by hand followed by each terminal component.

The prosthetic screws should not be tightened from one end of the prosthesis to the other. This distributes the casting error completely to the last abutment in the system (Figure 29-96, *FF* and *GG*). A torque wrench with final torque is not used at the metal try-in appointment or initial prosthesis delivery. Instead, because most screw-retained restorations are not completely passive, the preload or screw lengthening is accomplished after the bone remodels to the pressure at the initial delivery.

One should note patient discomfort, particularly during this procedure. Local anesthesia is not indicated. Any tension, pressure, pulling, tenderness, or pain signals a nonpassive casting, incorrect placement, looseness of the abutment for screw retention, poor bone-to-implant interface, or casting impingement of the soft tissue.

Castings usually appear passive. The casting is clinically acceptable if the marginal fit is within a horizontal and vertical range of opening of less than 80 microns similar to a crown on natural tooth. For a RP (RP-4 or RP-5), the bar and prosthesis may be delivered at this appointment (Figure 29-96, *HH* and *II*).

The OD-5 overdenture should cover the retromolar pads and extend over the oblique ridge even when the restoration is RP-4. Otherwise, food entrapment is common. A metal framework

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may be inserted when OVD is limited or moderate to severe force factors are present (Figure 29-96, *JJ*). The occlusion is evaluated in addition to esthetics and phonetics (Figure 29-96, *KK*).

Most articles on overdentures report on screw-retained bars connected to the implants. Judy and Richter and Rocha de Carvalho et al. have reported on overdentures with cemented bars in use over a 10-year period.[128,129] Cemented bars present the advantages of more passive fit and reduced cost to the patient and doctor. However, the height of the abutment needed for cement retention may interfere with the interarch space required for denture teeth and bulk of acrylic necessary for fabrication and strength of the restoration. When the abutment post height for cement is less than 5 mm, the retention is reduced, and as a result, cemented bars may require shorter cantilevers to reduce the incidence of uncemented bars. In addition, cantilever bars for overdentures may become uncemented more often because tensile loads are transmitted to the cement seals every time the restoration is removed. Hence, the abutments for cements should be greater than 5 mm in height (Figure 29-97).

A passive superstructure, a reduced cost, and an easier bar impression technique are advantages of a cemented connecting bar for an overdenture. Reports in the literature document similar success rates for both options, and the choice may be up to the discretion of the restoring doctor. However, stronger cements and a reduction of the cantilever length should be considered for OD-4 and OD-5 treatment plans because of tensile forces on the anterior cement seals, which may break and cause complications.

Challenging Force Factors: Patient and Anatomical

The five treatment options proposed for mandibular implant-supported overdentures provide an organized approach to solving a patient's complaints or anatomical limitations. The prosthesis support and range of motion should be part of the initial diagnosis. The treatment options initially proposed are designed for completely edentulous patients with division A or B anterior bone in desire of an overdenture. These options are modified when the CHS is great (as when the anterior bone is division C–h) and eliminated for division D. The increase in crown-to-implant ratio and decrease in implant surface area mandate modification of these initial options. In addition, when the patient force factors are greater than usual (parafunction, masticatory dynamics, opposing arch is natural dentition) or the arch form is square (reduced A-P spread), these treatment options must be modified.

For example, under these adverse conditions, one more implant is added to each option, and OD-1 is eliminated completely. Therefore, OD-2 has three implants (A, C, and E positions), OD-3 has four implants (A, B, D, and E regions), OD-4 has five implants (A, B, C, D, and E areas), and OD-5 has six implants, with one positioned behind one of the mental foramen (when possible). If six implants cannot be placed because of inadequate posterior bone, the cantilever length is reduced, and a RP-5 restoration is fabricated.



FIGURE 29-97. The mandibular implant overdenture may use a cemented bar when the abutments for cement are greater than 5 mm in height.

Maxillary Implant Overdentures

Maxillary dentures usually are tolerated better by completely edentulous patients than their mandibular counterparts. As such, many treatment plans initially concentrate on the problems associated with the mandibular denture. However, when patients enjoy a stable, retentive, and perhaps fixed mandibular prosthesis, usually their attention is brought to the maxillary arch. When patients become aware of the anatomical and esthetic consequences of missing teeth, their desire for implant restorations increases. As a result, future restorations of the edentulous maxilla more often will include implant restoration.

The maxillary arch may be completely edentulous, opposing at least some teeth in the mandible. This condition occurs 35 times more often than the reverse situation. At age 45 years, 11% of the population has maxillary total edentulism opposing teeth, which increases to 15% by 55 years of age and then remains relatively constant.[2,3] Therefore, a total of approximately 12 million individuals in the United States have total edentulism only in the maxillary arch, representing 7% of the adult population overall.

Consequences of Edentulism

After a patient has a stable mandibular implant prosthesis, the maxillary arch should be addressed. The continued bone loss that becomes obvious in the mandible also occurs in the maxilla. The benefit of bone maintenance is especially noteworthy in the maxillary edentulous arch. However, the clinical consequences of this bone loss is not observed until the premaxilla becomes resorbed in height. Rather than using implants only in the edentulous mandibular arch, because the primary mechanical denture problems and complaints are in this arch, the maxillary arch should also be addressed. When implant prostheses are placed to support and retain the mandibular restoration, the bone in the maxillary region continues to be lost, and eventually the patient may complain of loss of retention and inability of the maxillary denture to function.

The patient is more likely to wear and accommodate to a maxillary complete denture compared with its mandibular counterpart. The greater retention, support, and stability compared with the lower restoration are also well documented. As such, the patient often is able to wear the device for longer periods of time before complications arise. By the time the patient notices problems of stability and retention caused by lack of premaxilla, the maxillary bone often has resorbed completely and is division D (Figure 29-98, *A*).

The loss of facial esthetics often occurs first in the maxillary arch, with the loss of vermilion border of the lip, increased length of the maxilla lip, and lack of facial bone support. However, patients may not realize these changes are related to

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FIGURE 29-98. **A,** The mandibular arch was treated with four anterior implants 25 years before this radiograph. The bone has been maintained in the anterior mandible during this time frame. The maxillary arch has continued to lose bone and now has severe atrophy. **B,** Facial esthetics are affected by the loss of bone in the jaw. The mandible still has a vermilion border of the lip, and the mentalis muscle remains attached. The maxillary lip has lost the vermilion border, and deep lines appear along with an increase in the columella–philtrum angle.

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the loss of teeth and bone. Implants should be used to treat the continued bone loss and prevent the later complications found in the maxillary arch (Figure 29-98, *B*). In addition, reports indicate that RP-5 mandibular IODs may cause a combination-like syndrome, with increased looseness, subjective loss of fit, and midline fracture of the upper denture.[80] Although not yet established as a cause-and-effect situation, the condition may be eliminated with a maxillary IOD.

The extended soft tissue coverage of a maxillary denture affects the taste of food and acts as an insulator to alter the temperature, which contribute to satisfaction. The soft tissue may become tender in the extended vestibular borders as the crest of the ridge resorbs. The palate of a maxillary prosthesis may cause gagging in some patients. Most of these negative issues may be eliminated in an implant-supported overdenture.

Reducing the bulk of the restoration, especially when the palate is eliminated from the overdenture, is more of a patient benefit than when the mandibular overdenture is reduced in bulk. Eliminating the palate reduces the gagging effect from some patients, improves the taste of food in some individuals, and has an oral sexual advantage to others. A few individuals have taste factors from the eleventh nerve that innervates taste buds in the palate. Although unusual, these patients benefit from the reduction of the palate of their overdenture.

When the premaxilla is resorbed, the maxillary denture begins to become unstable. The maxillary anterior teeth are positioned in front of the residual bone. As a result, the denture rotates up in the anterior, which means it rotates down in the posterior. The denture loses the valve seal as a consequence. Hence, in the maxillary arch, an implant prosthesis should be considered before bone is lost in the premaxilla. Initially, the mandibular height of bone is twice that of the maxilla; therefore, any bone loss in height in the maxillary arch is significant in long-term edentulous patients. The complete anterior ridge and even the nasal spine may be resorbed in the maxilla, causing pain and an increase in maxillary denture movement during function.[51,54,130]

Several factors affect the condition of the premaxilla and may result in a decrease in implant survival or an increase in prosthetic complications. The completely edentulous anterior bony ridge is often inadequate for endosteal implants. The facial cortical plate may be resorbed from periodontal disease or often is fractured during the extraction of teeth. In addition, the facial cortical plate resorbs during initial bone remodeling, and the anterior ridge loses 25% of its width within the first year after tooth loss and 40% to 60% over 3 years, mostly at the expense of the labial plate.[49] As a result, the maxillary denture migrates to a more palatal position.[49]

The doctor has the responsibility to inform the patient about the continued bone loss of the maxilla. Bone grafting is much more predictable for width gains rather than increases in height. Division B bone grafting often uses a synthetic bone component for the graft, and division C minus width (C–w) often requires autologous bone, often with the mandible as a donor. With edentulous maxillae requiring height augmentation (division C–h or D), the dentist often must resort to the iliac crest as a donor site for large volumes of bone.[131] As such, maxillary completely edentulous patients should understand that the surgical rehabilitation is much more complex and extensive because the volume of bone to reconstruct the arch becomes larger. Therefore, notifying patients of their continued bone loss is important rather than waiting until problems with their removable restorations develop.

Maxillary Overdenture versus a Fixed Prosthesis

Advantages

A maxillary overdenture has several advantages compared to a FP, and many are similar to a comparison of mandibular prostheses. However because a maxillary denture has more retention, support, and retention than a mandibular denture, a RP-5

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maxillary restoration has less benefit than a RP-5 mandibular restoration. The primary advantage of a RP-5 maxillary IOD is the reduced cost. The reduced fee is not only the reduced implant number (e.g., four vs. seven) but also the reduced need for sinus graft augmentation. Hence, the time for treatment is reduced, as is the surgical fee, and may be less than 50% of a RP-4 or fixed restoration.

The esthetic advantage of a maxillary overdenture compared with a fixed restoration is more evident in the maxilla compared with the mandible. The labial position of the maxillary lip for esthetics may require a labial flange, which makes it almost impossible for hygiene access when a fixed restoration is used. As such, when the teeth must be cantilevered off the premaxillary residual ridge more than 7 mm, an overdenture is strongly considered (Figure 29-99).

A clinical study by Heydecke et al. evaluated 13 patients who received both a RP-4 overdenture and a FP, both for 2 months each.[132] Psychometric evaluation of general satisfaction, comfort, ability to speak, stability, esthetics, ease of oral hygiene, and occlusion was performed for both restorations. The chewing ability with seven types of foods was also determined with both restorations. The general satisfaction rating was significantly higher for the RP-4 overdenture group. The ability to speak and ease of hygiene were better, but the masticatory dynamics were similar in both prostheses relative to stability, occlusion, and chewing ability. Nine of the 13 patients opted to have the RP-4 overdenture rather than the FP-3.

On the other hand, Brennan et al. also evaluated patient satisfaction and oral health–related quality of life outcomes of maxillary IODs and fixed complete prostheses.[133] Patients with maxillary overdentures reported significantly lower overall satisfaction, with lower scores for both with chewing capacity and esthetics. The advantages cited for the overdenture were reduced cost and the ability to perform oral hygiene procedures.

The patients who desire a fixed restoration are usually those who want the psychologic advantages of fixed teeth or patients who very recently lost their teeth, have not completely accommodated to a RP, and still have facial lip support. Apparently, long-term denture wearer do not perceive the advantage of a fixed restoration enough to compensate for the speech and hygiene benefits. Esthetics may also be the motivating factor for an overdenture when the maxillary lip needs additional support.

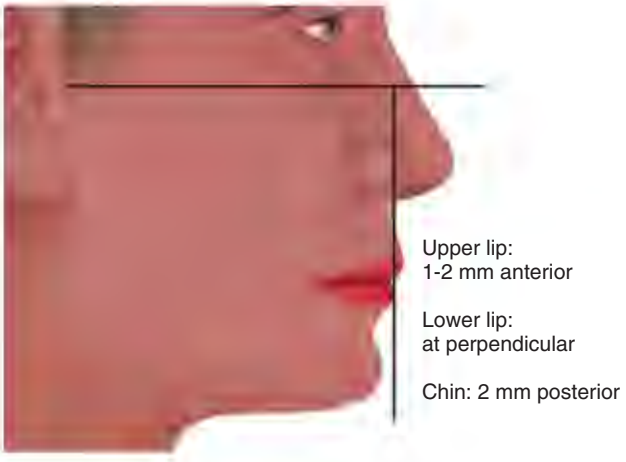


FIGURE 29-99. The horizontal position of the maxillary lip should be anterior to the lower lip by 1 to 2 mm. When the teeth are cantilevered more than 7 mm from the anterior residual ridge, a maxillary implant overdenture with a labial flange has an advantage over a fixed implant prosthesis.

Literature Review

Fewer reports have been published about maxillary overdentures than about edentulous mandibles.[133–154] Most maxillary overdentures in the literature are RP-5 restorations. Almost all reports indicate a greater implant failure and risk of prosthetic complications. For example, Engquist et al. report a 6% to 7% implant failure rate for mandibular implant-supported overdentures and a 19% to 35% failure rate for maxillary IODs.[134] In a follow-up study by Jemt of 70 patients with 336 implants, there was a 70% survival rate in resorbed bone and an 88% survival rate in the intermediate group with an 85% overall survival rate.[148] Smedberg et al. reported an 86% survival rate for 20 patients with 86 maxillary implants, and results showed a similar disparity of results based on bone volume quality.[135] In a 5-year prospective, multicenter study on 30 maxillae and 103 mandibles, Jemt and Lekholm reported that the survival rate of mandibular implants was 94.5% and 100% for mandibular prostheses. In the maxillae, the implant survival rate was 72.4%, and the prosthesis survival rate was 77.9%.[137]

Johns et al. reported on 133 patients with 117 implants in the maxilla for overdentures. A 28% implant failure rate was reported.[145] Widborn et al. evaluated 22 patients with 13 planned overdentures compared with FPs that ended up with an overdenture over a mean observation period of 5.7 years. The implant survival rate in the planned group was 77%, and rate in the unplanned group was 46%.[147] Palmqvist et al. also reported similar results.[136]

A prospective study by Johns et al. reported on maxillary overdentures over 5 years.[138] Sixteen patients were followed throughout the whole study with cumulative success rates of 78% and 72% for prostheses and implants, respectively. Jemt et al. reported an 84% survival rate for 430 maxillary implants on 92 consecutive patients at 1 year.[139] Chan et al. and Goodacre and Kan combined data from several reports and yielded an average 21% failure rate for implant-supporting maxillary overdentures, the highest failure rate of any prosthesis type.[140,141]

On the other hand, in 1991, Naert et al. reported on the 4-year performance of six maxillary overdentures with no implant lost.[142] Misch has followed 75 maxillary overdenture (RP-4) patients for 10 years with a 97% implant survival rate and a 100% prosthesis survival rate.[155] The primary differences in these treatment modalities have been implant number, position, and prosthetic movement guidelines that follow basic biomechanical concepts to reduce failure and decrease risks for maxillary overdentures.

Sanna et al. compared four to six implants connected with a bar with two unconnected implants over a 10-year period.[146] The splinted implants and bar had a 99.3% survival rate compared with an 85.7% survival rate for independent implants. There was also greater marginal bone loss on the independent implants. A review of the literature was performed by Slot et al. to compare maxillary overdentures over 1 year or more with six implants with a bar, four implants with a bar, and four implants with ball anchorage.[143] The highest survival rate was with six implants connected with a bar followed by four implants connected with a bar. The lowest survival rate occurred was when four independent ball attachments were used for the prosthesis. However, the range of implant survival rates was 95% to 98% for the 31 studies reviewed. Hence, the first-year implant survival rate was similar. The four-implant overdenture connected

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with a bar had a 5-year implant survival rate of 94.2% reported by Mericske-Stern et al.[144]

Treatment Planning Considerations

To increase implant and prosthesis survival rates, treatment for maxillary overdentures with division A bone is planned similarly to treatment for mandibles with C minus height (C–h) bone and greater factors of forces. In other words, four or more implants are inserted from first premolar to first premolar. In addition, subantral augmentation often is performed to place more distal implants and dramatically improve the A-P distance when the anterior and posterior implants are splinted with a bar. This treatment approach has proved successful in yielding success rates similar to those for mandibular overdentures.

From a biomechanical perspective, the implant-restored anterior maxilla is often the weakest section compared with other regions of the mouth. Compromised anatomical conditions and their consequences include the following.

In the majority of patients with available bone, the bone is less dense in the anterior maxilla than in the anterior mandible. In the mandible, a dense cortical layer is coupled with coarse trabecular bone strength and permits implants to be supported by a denser bone quality. The maxilla presents thin porous bone on the labial aspect, very thin porous cortical bone in the floor of the nasal region, and a more dense cortical bone on the palatal aspect.[156,156] The trabecular bone is usually fine and is also less dense than the anterior region of the mandible.[157]

In the premaxilla, esthetics and phonetics dictate that the replacement teeth be placed at or near their original position, often cantilevered off the residual ridge, which usually is resorbed palatally and superiorly. Crown height as a force magnifier is of paramount importance in the anterior maxilla, where the natural crown height is already greater than in any other region even under ideal conditions. The arc of closure is anterior to the residual ridge; as a consequence, the moment force is greatest against the maxillary anterior crowns supported by implants and directed against the thinner facial bone (Figure 29-100). All mandibular excursions place lateral forces on the maxillary anterior teeth, with resulting increased stress on the crestal bone, especially on the labial aspect of the implant.

As a consequence, many treatment plan aspects place the edentulous maxilla at a high risk of implant failure.

1. The narrow ridge of a premaxilla has parallel walls of bone so an osteoplasty to increase width is less effective. Therefore, the narrow ridges more often need narrower implants (resulting in increased stress concentrations in the implant and contiguous interfacial tissues, particularly at the crestal region).
2. The use of facial cantilevers (resulting in increased moment loads at the implant crest, often leading to localized crestal remodeling and implant or abutment fracture)
3. Oblique centric contacts (resulting in potentially harmful, off-axis load components)
4. Lateral forces in excursion (resulting in greater moment loads applied to the implant)
5. Reduced bone density (resulting in compromised bone strength and loss of implant support)
6. Absence of thick cortical plate at the crest (resulting in loss of high-strength implant support and less resistance to angled loads, which increase stress)
7. The accelerated bone volume loss in the incisor region, often resulting in the inability to place central and lateral incisor implants without substantial augmentation procedures (Box 29-15)[155,158]

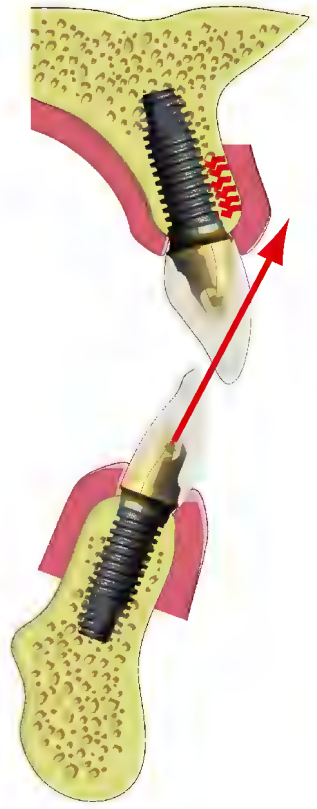


FIGURE 29-100. The arc of closure and the excursive movements of the mandible result in increased moment forces to the premaxilla.

BOX 29-15 Premaxilla: Compromised Anatomical Conditions

- Narrow ridge
- Less bone density
- Facial cantilevers
- Oblique centric contacts
- Lateral forces during mandibular excursions
- Absence of thick cortical plate
- Accelerated bone loss in incisor region

The maxillary arch may be divided into five segments, similar to an open pentagon (Figure 29-101). The central and lateral incisors represent one segment, each canine a separate segment, and the posterior premolars and molars individual segments. To splint mobile teeth to create a rigid prosthesis, three or more segments should be connected together. In other words, each segment is essentially a straight line, with little resistance to lateral forces. But because they are aligned along the arch, connecting at least three segments creates a tripod and provides an A-P spread with mechanical properties superior to a straight line and with greater resistance to lateral forces. The A-P spread for anterior (or posterior) cantilevers corresponds to the distance between the center of the most distal implant (in the splint) and the anterior aspect of the most anterior implant (Figure 29-102).

Three of the five segments described are part of the premaxilla: the canine, the incisors, and the opposite canine. Therefore,

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FIGURE 29-101. The maxillary arch may be considered a five-sided arch consisting of the incisors, the bilateral canines, and the posterior regions. Splinting three or more adjacent sides together results in a rigid structure.

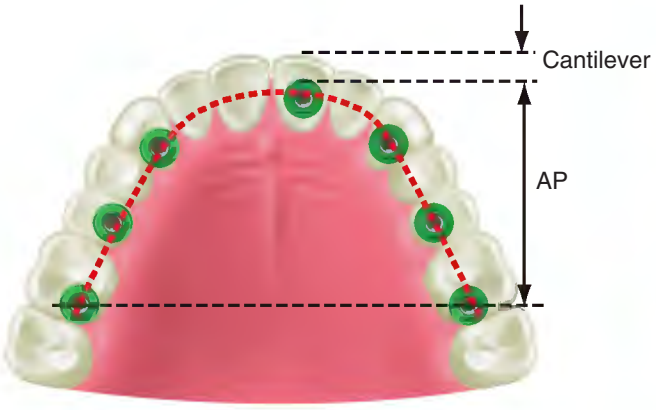


FIGURE 29-102. In the premaxilla the anteroposterior distance corresponds to the distance between the center of the most distal implant in the splint and the anterior aspect of the most anterior implant.

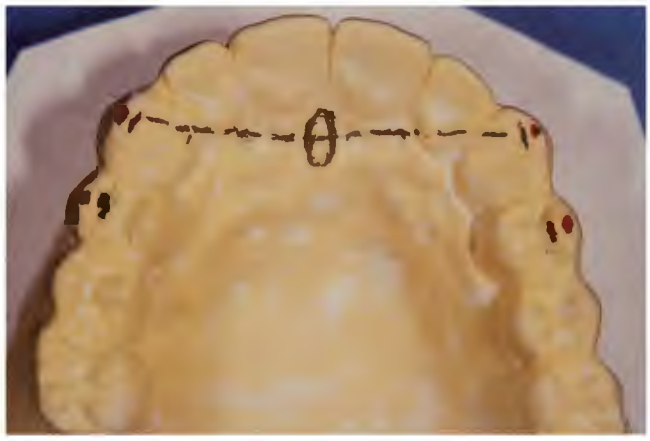


FIGURE 29-103. A square dentate arch form with a horizontal line drawn through the center of the incisive papilla and the tips of the canines.



FIGURE 29-104. A tapered dentate arch form with a horizontal line drawn through the center of the incisive papilla and the tips of the canines.

to achieve a sound biomechanical system able to sustain lateral forces during mandibular excursions and the angled forces of centric occlusion, at least one implant should be placed in each anterior section and then splinted together. Hence, at least three anterior implants usually are required: one in each canine position and at least one in one of the four incisor positions.

Previous studies have shown that the force distributed over three abutments results in less localized stress to the crestal bone than two abutments.[159] To resist mandibular excursions, implants should be splinted, and as a result in an edentulous premaxilla, implants usually should be placed in both canines and at least one additional incisor positioned in the anterior regions of the arch.[155,158]

Premaxilla Arch Form: Dentate and Residual Bone

The arch form of the maxilla influences the treatment plan of the maxillary overdenture. Three typical dental arch forms for the maxilla are square, ovoid, and tapering. The edentulous maxilla residual ridge of bone also may have three arch forms. Esthetic requirements may require a dental arch form different from the residual ridge form. The dental arch form of the patient is determined by the final teeth position in the premaxilla and not the shape resulting from the residual ridge. A residual ridge may appear square because of resorption or trauma. However, the final teeth position may need to be cantilevered to the facial with the final prosthesis. In other words, a dental ovoid arch form may be needed to restore a residual edentulous square arch form. The number and position of anterior implants are related to the arch form of the final dentition (restoration), not the existing edentulous arch form.

To determine the dentate arch form, one line is drawn through the incisive papilla to separate the right and left maxilla into two equal components. A second line is then drawn though the middle of the incisive foramen perpendicular to the first line. The second line will pass over the incisal tip position of the maxillary canine, whether the dentate arch is square, ovoid, or tapering (Figures 29-103 and 29-104).

A third line is then drawn parallel to the second line along the facial of the maxillary central incisors (Figure 29-105). When the distance between the second and third line is less than 8 mm, a square dentate arch form is present. When the distance between these lines is 8 to 12 mm, an ovoid dentate arch form exists. A distance of more than 12 mm indicates that a tapered dentate arch form is present.

In a dental square arch form, lateral and central incisors have minimum cantilever facially compared with the canine

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position. Mandibular excursions and occlusal forces may be reduced on the canine implants. As a result, implants in the canine position may suffice to replace the anterior six teeth for a RP-4 prosthesis because they are splinted to additional posterior implants (Figure 29-106). The four pontics between the canines create reduced forces because (1) the forces are lowest in the incisor region and (2) a square arch in the maxilla has less cantilevered occlusal forces to the canines.

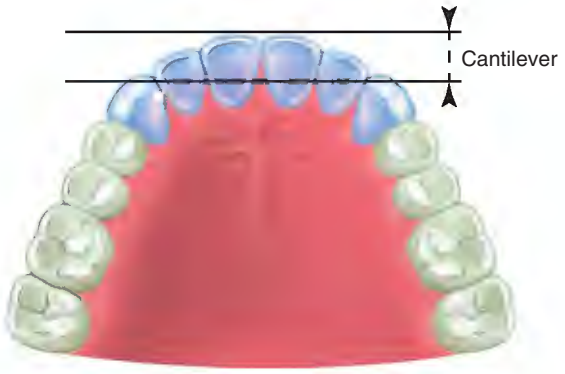


FIGURE 29-105. One horizontal line is drawn through the tips of the canines and through the incisive papilla, and a second parallel line is drawn along the facial of the maxillary incisors.

If the final teeth position is an ovoid arch form, three implants should be present in the premaxilla for an overdenture (Figure 29-107). This treatment plan may require bone augmentation before implant insertion. For the overdenture restoration of an ovoid dental arch form (which is the most common arch form), planning for implants in the canine positions and at least one additional implant, preferably in a central incisor position, is important. The additional implant resists the additional forces created in this arch form, enhances prosthesis retention, and reduces the risk of abutment screw loosening.

The overdenture restoration of a tapering dentate arch form places the greatest forces on anterior implants, especially when pontics replace the incisors. The anterior teeth are cantilevered facially from the canine position, with increased forces in centric occlusion and during mandibular excursions. As such, four implants should be considered to replace the six anterior teeth for a RP-4 prosthesis. The worse case scenario is a patient requiring a tapered dentate arch form to be restored on a square residual ridge form (Figure 29-108). As a result, bone grafting may be required to restore a more compatible residual ridge form. The bilateral canine and central incisor positions are biomechanically the best option. These positions are preferred when other force factors are greater, such as crown height, parafunction, and masticatory muscular dynamics.

When a tapered dentate arch form is restored on a square residual ridge form, implants are indicated in the posterior



FIGURE 29-106. **A,** In square dentate arch form, the incisors are not cantilevered from the canine position. Canine implants splinted to posterior regions are often sufficient to support a RP-4 prosthesis. **B,** A bar splints the anterior and posterior implants. **C,** The maxillary implant overdenture for a square dentate arch from may use two anterior implants in the canine position.

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FIGURE 29-107. The ovoid dentate arch form often requires three anterior implants (bilateral canine, and incisor) splinted to posterior implants for a RP-4 prosthesis.



FIGURE 29-108. One line is drawn from the most distal aspect of the implants. Another line is placed parallel to this line through the most anterior implant. The distance between these lines is the anteroposterior (A-P) distance and counters the forward cantilever of the prosthesis. The worst scenario is found with a tapering dentate arch form combined with a square edentulous arch form. This prosthesis, supported by five implants, will not be predictable for the long term because of the poor A-P distance of the implants and large anterior cantilever of the prosthesis.

regions. The most posterior implant is placed in the second molar position (along with a first molar implant) to increase the A-P distance and counter some of the anterior cantilever effect.

When one canine region cannot be used to place an implant in the edentulous maxilla, an implant in the first premolar and lateral incisor implant on each side of the missing canine are required to compensate for this vital position. A central incisor implant and canine position in the contralateral section can be splinted to these implants to act as abutments for the overdenture restoration.

In the presence of severe force factors, two implants most often are required to sustain the direction of force created during a mandibular excursion, which means a minimum of four implants are suggested to replace the anterior six teeth. In the presence of these severe forces (e.g., severe bruxism), larger-diameter implants should be used, especially in the canine position (which has increased angulation in excursions and higher bite forces). As such, in many instances, the completely edentulous anterior maxilla is restored with three or four implants splinted together to support the overdenture. In addition, posterior implants are usually required, especially for a RP-4 restoration.

Division C–h Incisive Foramen Implant

The premaxilla requires the most varied surgical approaches to improve success and is the most critical region for esthetics and phonetics. Options for division B and C–w bone more often require augmentation rather than osteoplasty as advocated in other intraoral regions. The opposing landmark is the floor of the nose, and this structure may be modified slightly to improve implant support in C–h ridges.

The dentist may use the incisive foramen region instead of a central incisor position to insert an endosteal implant when an overdenture is the intended final prosthesis.[151,155] The incisive canal ranges in length from 4 to 26 mm and is related to the height of bone in the premaxilla. The canal has an average axis of 20 degrees off the vertical (33 to 0.5 degrees).[152] This structure contains terminal branches of the nasopalatine nerve, the greater palatine artery, and a short mucosal canal (Stensen organ). The artery is often of minimal size, rarely is a surgical concern, and provides little to no blood supply to the anterior soft tissues. As the alveolus height is resorbed, the canal reduces in length. A vertical projection along the nasal floor is called the premaxillary wing. The nasal process of the premaxilla rises 2 to 3 mm above the nasal floor. As a result, when 8 to 10 mm of bone is present below the nasal floor, a large osteotome may create a greenstick fracture above the foramen and permit the placement of a 10- to 13-mm-long implant, usually 5 mm or more in diameter (Figure 29-109).

Posterior Implant Location

Several factors affect the strategic selection of implant size and position to restore a completely edentulous maxillary arch with an overdenture. Tarnow et al. have observed that the horizontal dimension of a crestal defect next to an implant measures almost 1.5 mm.[160] As such, if the implant is closer than this to an adjacent implant, a vertical angular defect may result in horizontal bone loss between the implants. This bone loss in turn may favor the proliferation of anaerobic bacteria in the sulcular environment. As a result, in general, two implant bodies should be 3 mm or more apart. In addition, when the implants are more than 5 mm apart and splinted with a bar, there is room for an overdenture attachment.

As previously presented, the maxilla may be compared to an open pentagon, with five different sections: the central and laterals, the bilateral canines, and the bilateral premolars and molars. Hence, posterior implants splinted to anterior implants are a particular advantage because four or five different planes of movement are connected together.

The number of implants most often used in an edentulous maxilla for a RP-4 overdenture should be in a range from seven to 10 implants. Many reports concur on the fact that maxillary bone tends to be of poorer quality and volume and presents few biomechanical advantages. To compensate for the poor local conditions, a greater number of implants can be planned to create a greater A-P spread, hence the need for sinus grafts or premaxilla reconstruction (or both). When force factors are moderate to severe or bone density is poor, more implants

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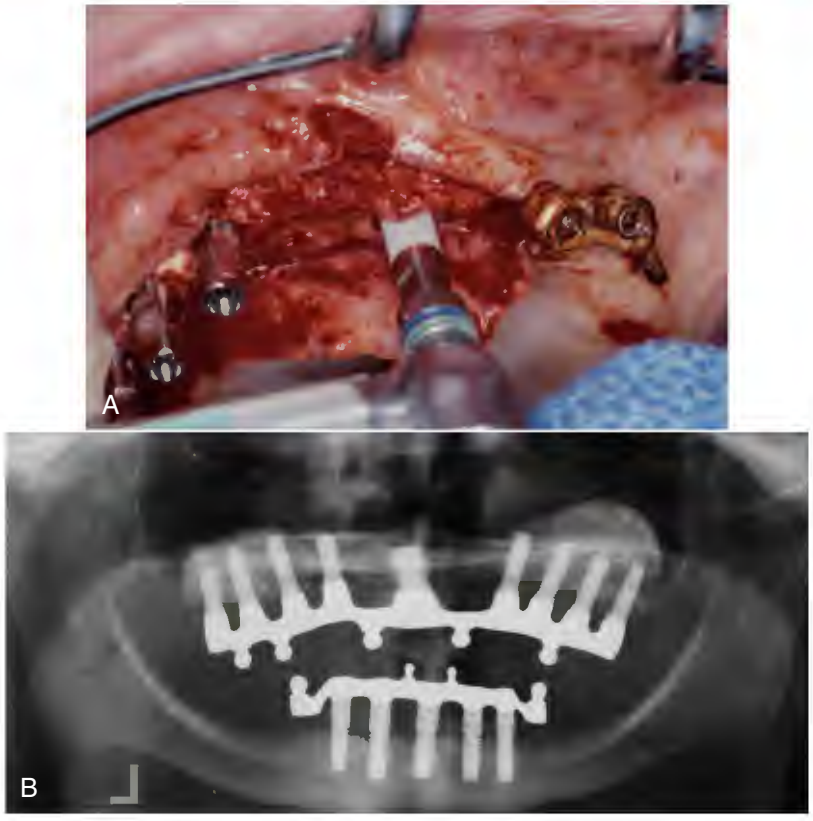


FIGURE 29-109. **A,** An implant may often be inserted in the incisive foramen when there is insufficient bone in the incisor regions. **B,** A panographic radiograph of maxillary and mandibular RP-4 implant overdenture. The maxilla has an incisor foramen implant and bilateral sinus grafts.

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should be inserted and in greater diameter to enhance the surface area. Likewise, the number of implants needed in an edentulous premaxilla is related to arch shape, as previously addressed.

With these concerns in mind, the minimum implant number and suggested locations for a completely edentulous maxillary RP-4 prosthesis are usually seven: at least one central incisor position (or incisive foramen), bilateral canine positions, bilateral second premolar sites, and bilateral distal half of the maxillary first molar sites (Figure 29-110). These seven implants should be splinted together to function as an arch. These implant positions create sufficient space between each implant to accommodate most any implant diameter and attachment type without concern for the adjacent site. The first molar implant sites in a completely edentulous maxilla almost always require sinus grafting because most edentulous maxillary posterior regions are inadequate in available bone height.

When force factors are moderate, the implant number should increase to eight or 10 implants. When eight implants are selected, the additional implant is usually placed in the premaxilla in a central incisor position. When 10 implants are used for patients with higher force factors or poor bone density, additional implants are planned in the distal half of the second molar position to improve the arch form, increase the A-P spread, and eliminate posterior cantilevers. This in an excellent biomechanical design to minimize stress. This design also may counter the effect of an incisal cantilever off the residual bone (tapered dentate arch form) for an esthetic tooth position and is also indicated for patients with parafunction such as chronic horizontal bruxism.

The first and second molar position is also a benefit when the premaxilla has higher force factors or is underengineered as to implant number or size. The increase in A-P distance between the canine and second molar site is a considerable benefit.

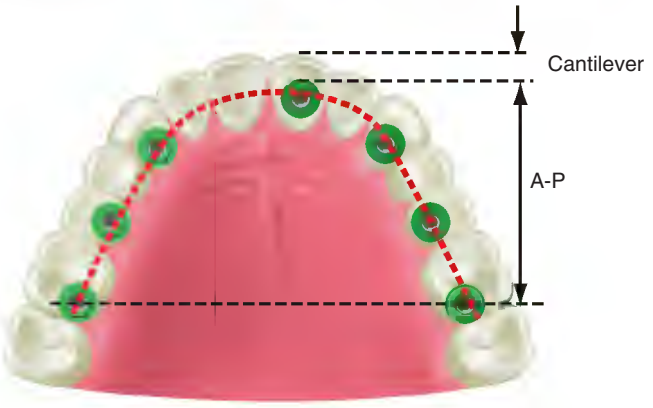


FIGURE 29-110. The ideal seven-implant positioning for a maxillary edentulous arch includes at least one central incisor position, bilateral canine positions, bilateral second premolar sites, and bilateral sites in the distal half of the first molars. In case of heavy stress factors, an additional anterior implant and bilateral second molar positions (to increase the anteroposterior [A-P] distance) may be of benefit.

Maxillary Implant Overdenture Treatment Options

Only two treatment options are available for the maxillary IODs, but five treatment options are available for the mandibular IODs. The difference is primarily because of the biomechanical disadvantages of the maxilla compared with the mandible,

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FIGURE 29-111. **A,** A panographic radiograph of a maxillary implant overdenture that was restored with individual implants. Five implants failed as a consequence of excessive force factors. **B,** The patient was restored with implants splinted together (after additional implants were added).



FIGURE 29-112. Inadequate crown height space for an implant overdenture is more often a problem in the maxilla than in the mandible.

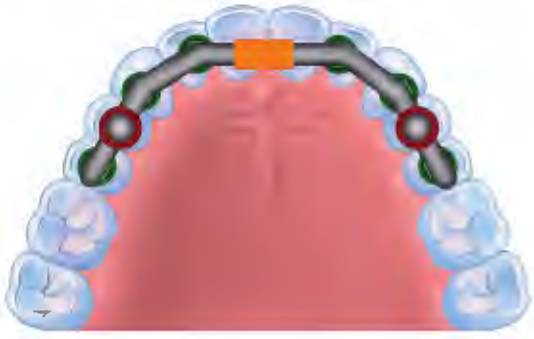


FIGURE 29-113. Four implants in the premaxilla usually are the minimum for a RP-5 maxillary overdenture.

including the fact the opposing arch is most always natural teeth or an implant prosthesis. Independent implants are not an option because bone quality and force direction are severely compromised (Figure 29-111). Cantilever bars usually are not recommended for the same reasons.[148,149] As such, the two treatment options provide a RP-5 restoration with some posterior soft tissue support or a RP-4 restoration, which is completely supported, retained, and stabilized by implants.

The CHS is important for maxillary overdentures, and more often a lack of space may compromise tooth position compared with the mandibular situation (Figure 29-112). At least 12 mm of posterior CHS is required and 15 mm of anterior space because the central incisor tooth is greater in height. Based on the poor success rates reported in the literature, specific biomechanical requirements, and poor bone quality, the fewest number of implants for a RP-5 maxillary overdenture should be four with as wide an A-P spread as possible.

Maxillary Implant Overdenture Option 1

The first treatment option for a completely edentulous maxilla has four to six implants, of which at least three are positioned in the premaxilla (Figure 29-113). Implant number and location are more important than implant size, but the implant should be at least 9 mm in length and 3.5 mm in body diameter. The key implants are positioned in the bilateral canine regions. When possible, at least one central incisor position is suggested. Other secondary implants may be placed in the first premolar region (Figure 29-114). When an implant cannot be placed in at least one central incisal position, the incisive foramen may be considered for implant insertion.[151] Another alternative is the use of bilateral lateral incisor implants. In this option, because of the reduced A-P spread, two implants are planned in the anterior region. In these conditions, the dentate arch form should be square to ovoid (Figure 29-115). When the lateral

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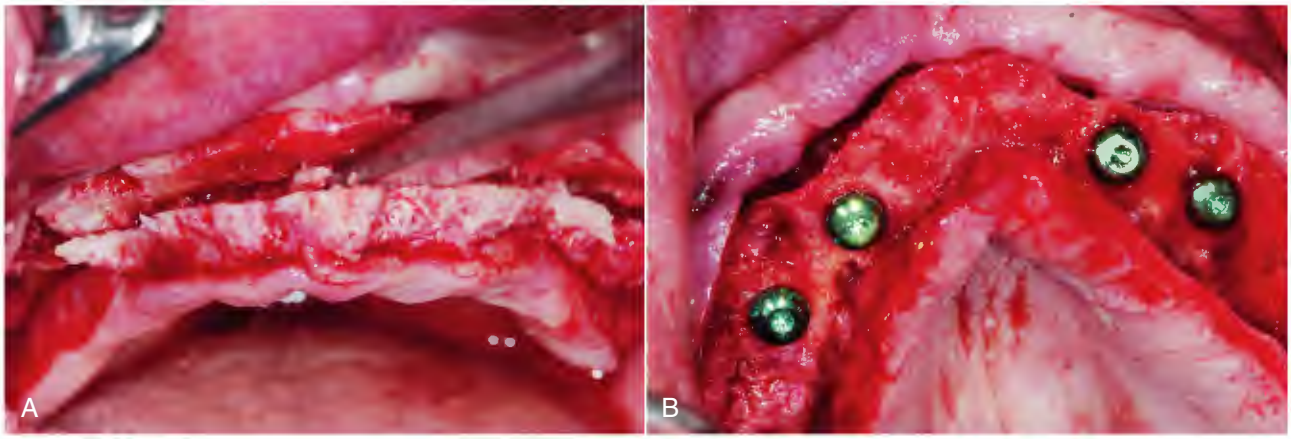


FIGURE 29-114. **A,** A RP-5 maxillary implant overdenture (IOD) should have at least 15 mm of crown height space in the anterior region. An osteoplasty may be required to gain sufficient space. **B,** A RP-5 maxillary IOD should have at least four implants. The canine positions are key positions. In this case, the patient's left lateral incisor region and right first premolar region was also used. When four implants are limited to the premaxilla for a RP-5 prosthesis, the dentate arch form should be square to ovoid.

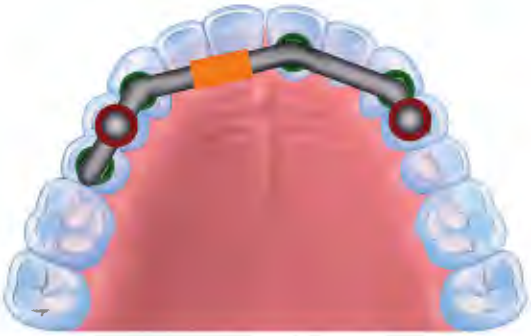


FIGURE 29-115. This maxillary implant overdenture has four implants to support a RP-5 restoration in the left lateral and canine position and the right canine and first premolar position.



FIGURE 29-116. When force factors are greater, five or six implants should be splinted together for a RP-5 implant overdenture. The first premolar positions increase the anteroposterior spread.

incisor is the anteriormost implant site and force factors are greater, the premolar position may also be used (along with the canine) to improve the A-P spread and increase the implant number. The first premolar site is usually anterior to the sinus and prevents the need for a sinus graft before implant placement (Figure 29-116).



FIGURE 29-117. A Hader clip can be used for a RP-5 restoration in the midline to gain posterior soft tissue support. When the clip is also positioned in the posterior regions, the restoration is more rigid, similar to a fixed restoration replacing 14 teeth.

The implants are splinted together with a rigid bar. The bar is not cantilevered distal and should follow the dentate arch form slightly lingual to the maxillary anterior teeth. The prosthesis should have at least two directions of movement. Hence, when a Hader clip is used, it is placed in the center of the arch and perpendicular to the midline. Relief is provided over the top of the implant distal to the bar to allow PM toward the tissue under posterior occlusal forces.

When O-rings are used to retain the restoration, they may be positioned more distal than a Hader clip, often immediately distal to the canine position. The restoration should be allowed to move slightly in the incisal region during function to rotate toward the posterior soft tissue around a fulcrum located in the canine or premolar position. The benefits are retention and stability, and support is obtained from the soft tissue. In addition, the anterior implants can halt the bone resorption process of the premaxilla.

The denture is designed exactly as a complete denture with fully extended palate and flanges. Multiple Hader clips should not be positioned around the arch. The pathway of rotation cannot rotate in three different directions. Hence, the prosthesis is too rigid (Figure 29-117).

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Maxillary Implant Overdenture Option 2

In the second option for a maxillary IOD, seven to 10 implants support a RP-4 restoration, which is rigid during function (Figure 29-118). This option is the most common treatment because it maintains greater bone volume and provides improved security and confidence to the patient. Many patients desire a fixed restoration in the maxilla. However, the loss of bone in the premaxilla requires a bone graft or a labial flange for lip support. Grafts for the entire premaxilla may require the iliac crest as a donor site because larger volumes of bone are required for the FP. Combined factors such as patient fear of treatment and lack of advanced training of the doctor are often the determining factors motivating the choice for a maxillary overdenture.

Unfortunately, many practitioners think the overdenture requires fewer implants and less attention to the biomechanics just because the restoration is removable. In the author's opinion, this is a primary cause of implant failure in maxillary IODs. The key implant positions for the RP-4 maxillary IOD are in the bilateral canines and distal half of the first molar positions. These molar positions usually require sinus grafting. Additional posterior implants are located bilaterally in the premolar position (preferably the second premolar). In addition, at least one anterior implant between the canines often is required. Therefore, seven is usually the minimum number of implants for this treatment option. When force factors are greater, the next most important sites are the second molar sites (bilaterally) to increase the A-P spread and improve the biomechanics of the system. The tenth implant would be placed in the premaxilla for a tapered arch form.

The implants are splinted together with a rigid bar. Four or more attachments are positioned around the arch. This provides a retentive, stable prosthesis (Figure 29-119). Usually, palatal coverage is maintained. The occlusal scheme for this RP-4 restoration is similar to a FP: centric occlusion around the arch and anterior contact only during mandibular excursion (unless opposing a mandibular denture) as described in implant protective occlusion (see Chapter 33).

The maxillary overdenture opposing a fixed restoration on natural teeth should be removed during sleep to prevent nocturnal parafunction. If the patient wears maxillary and mandibular overdentures, only the mandibular restoration needs to be removed.



FIGURE 29-118. A RP-4 maxillary implant overdenture should have seven key implant positions, similar to a maxillary fixed prosthesis.

Maxillary Overdenture Complications

The palatal aspect of most maxillary IODs should be similar to a denture. The extent of palatal coverage ranging from full to horseshoe shaped has been reported in the literature with varied degrees of success[134,136,148] (Figure 29-120). Many maxillary denture wearers accommodate easily to the acrylic palate, relative to speech and comfort, yet many restoring dentists routinely

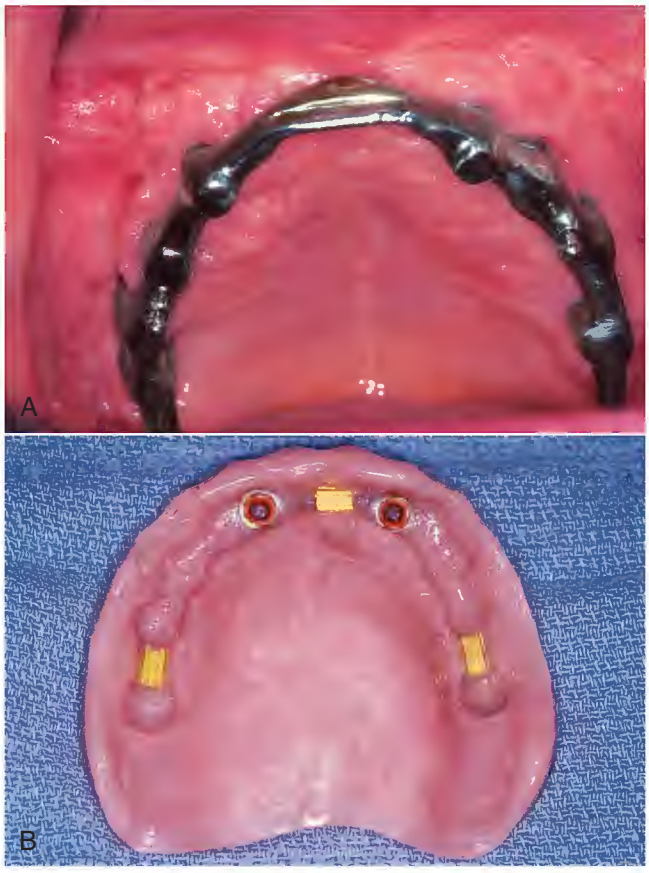


FIGURE 29-119. **A,** A maxillary RP-4 implant overdenture (IOD) usually has four to six attachments located around the arch. Hader clips are often used when the crown height space is limited. **B,** The maxillary IOD is designed with full palatal coverage and labial flange, similar to a complete denture.



FIGURE 29-120. Horseshoe-shaped overdentures have been described in the literature. However, an increase in prosthetic complications is often observed.

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eliminate the palate on maxillary IODs with prosthetic consequences. For example, food entrapment under the overdenture is a common complaint when the palate of the prosthesis is eliminated. The tongue often crushes food against the palate and pushes the food debris under the restoration. Impaired speech is also observed more often because air is forced under the palatal flange and over the labial flange of the denture.[25] The patient rarely complains of these two problems with a denture and as a result is unhappy with the final implant restorative result. Therefore, the palate of the prosthesis usually should be maintained with the maxillary IOD. In addition, the risk of fracture of the maxillary IOD is increased because acrylic receives its strength primarily through bulk.

Some patients express a primary desire to eliminate the palate of the maxillary complete denture. These patients include gaggers and patients uncomfortable with anything approaching the soft palate, patients with tori or exostoses, singers and actors because of a perceived change of voice caused by the change in volume of the prosthesis, food and wine consumers who use their palate to taste subtle differences in preparations, and new denture wearers unfamiliar with the palatal aspect of a maxillary denture. As a result, patient needs and desires may require the natural palate of the patient to be uncovered when wearing the maxillary overdenture.[158,159]

To reduce the complications of speech or food impaction, the following technique has been used with some success. The palate of the preexisting prosthesis is coated with a pressure-indicating paste or spray. The patient is asked to pronounce the linguoalveolar consonants "T" and "D." In dentate patients, when these sounds are produced, the tip of the tongue contacts the anterior alveolar ridge and the sides of the tongue are in tight contact with the maxillary teeth and palatal gingiva. The maxillary overdenture palate is not eliminated any farther than 5 mm posterior to the tongue contact area. This ensures that the tongue still will contact the acrylic on the palate and will prevent food and air from being forced under the denture.

The processing model for the prosthesis is scored 1 mm wide and 1 mm deep with a round bur on a line corresponding to the peripheral position of the prosthesis (Figure 29-121). The score line proceeds from the hamular notch in the posterior along the hard palate 5 mm medial to the alveolar ridge–palatal line angle (position of the greater palatine artery) to the anterior aspect 5 mm distal to the tongue position previously noted. The cast is not scored over the midpalatal suture because this soft tissue is very thin and cannot be depressed readily. When the denture is processed, a small lip of acrylic fills this score line, and when the overdenture is inserted, it will depress the tissue along this region gently and ensure intimate tissue contact (Figure 29-122). This further prevents food and air from being pushed under the overdenture. The "D" and "T" position of the tongue is several millimeters posterior to the position of the maxillary teeth. As a result, several millimeters of acrylic remain on the premaxilla. This also reduces the risk of fracture of the maxillary overdenture.

The anterior implants, connection bar, and attachments should be lingual to the position of the anterior teeth so as not to interfere with proper denture tooth position. However, this position may increase the height of the palatal slope in the region of the premaxilla compared with the original denture. A low-profile bar and attachment is often the design of choice to minimize the prosthesis bulk. Before designing the bar, a vacuum or press form is made of the contour of the preexisting denture and overdenture try-in prosthesis, similar to the one used for the surgical template. The design of the bar-attachment system is within the confines of the final prosthesis.

When the premaxillary support is underengineered relative to implant number, size, or position, a palatal strap may be used to help transfer force from one side of the arch to the other. Hence, the five-sided arch is converted to an anterior box (Figure 29-123, *A*). The maxillary overdenture covers the connecting palatal bar and often has a low-profile attachment (Figure 29-123, *B*). This same concept may be used for cleft palate patients or when implants cannot be inserted in the ideal arch positions (Figure 29-124). When force factors are low, the lack of implants in the premaxilla can be biomechanically improved with a posterior palatal strap (Figure 29-125).

Restorative Procedure

The restoration of the maxillary IOD is similar to the five-appointment step-by-step method described for mandibular overdentures (Figure 29-126). The position of the teeth and vertical dimension are similar to the medial-positioned

Text continued on p. 824



FIGURE 29-121. A score line in the processing cast is made 1 mm wide and deep from the hamular notch and along the palatal periphery of the denture except over the midpalatal suture.



FIGURE 29-122. The palate of a maxillary RP-4 implant overdenture with a horseshoe palate. A line may be seen on the palate that corresponds to the score line on the prosthesis.

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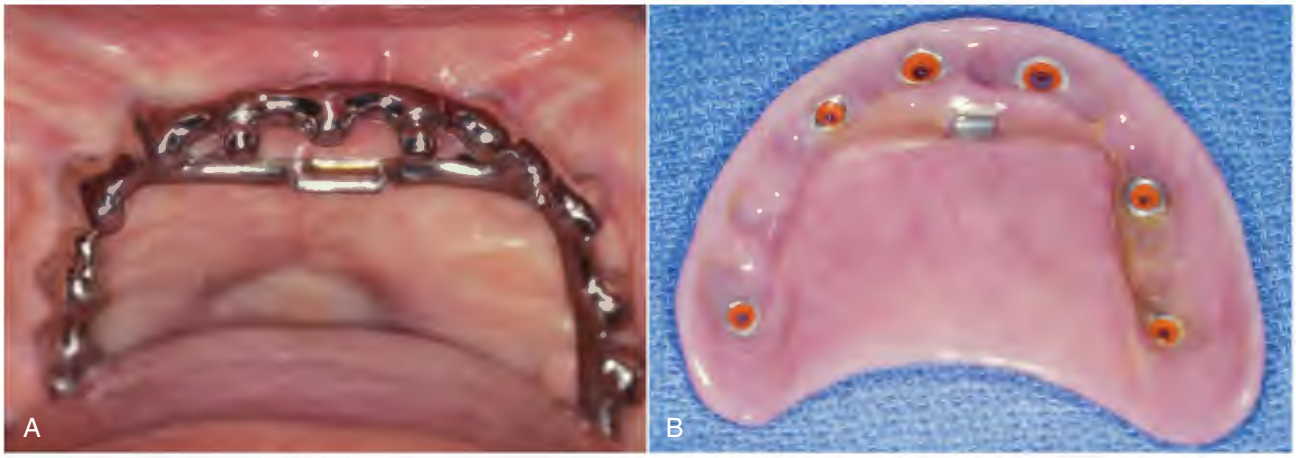


FIGURE 29-123. **A,** A palatal strap is used in the anterior region, which joins canine implants. A biomechanical box in the premaxilla is beneficial when implant support is inadequate or patient force factors are excessive. **B,** The maxillary RP-4 implant overdenture covers the palatal strap and often uses a Hader clip in this region.

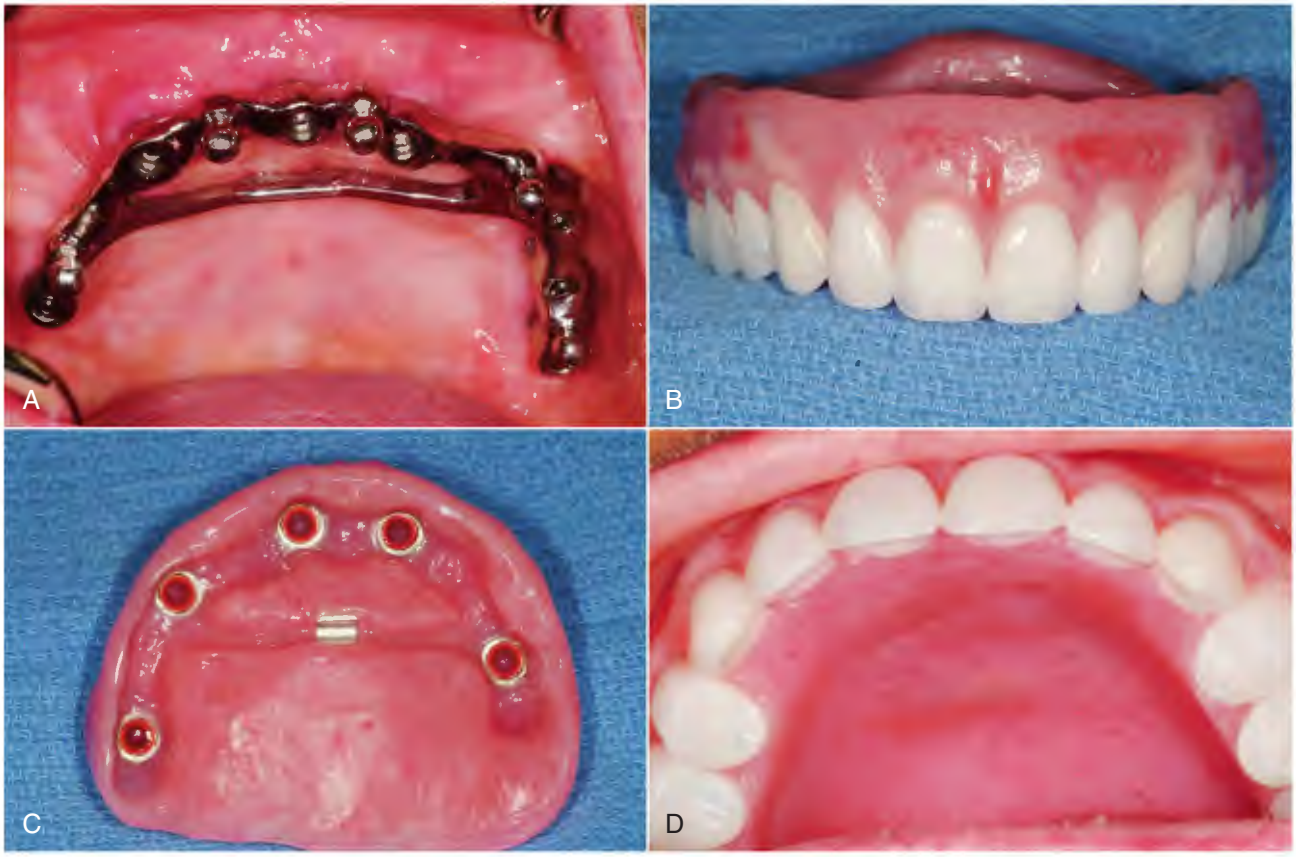


FIGURE 29-124. **A,** A maxillofacial cleft patient and implants were not inserted in the left canine or right premolar positions. A palatal strap connects one side of the arch to the other. **B,** The maxillary RP-4 implant overdenture (IOD) is fabricated similar in appearance to a complete denture. **C,** The attachments make a PM-0 restoration and include a Hader clip on the palatal strap. **D,** The palate of the maxillary IOD covers the palatal strap.

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FIGURE 29-125. The lack of implants between the canines can be improved by including a posterior palatal strap.



FIGURE 29-126. **A,** A maxillary arch with eight implants to serve as a foundation for a RP-4 implant overdenture. Abutments for screw retention 1 to 2 mm above the tissue have been torqued into position. **B,** Indirect impression transfers are threaded into the abutments for screw retention. **C,** A closed-tray alginate impression is made similar to a maxillary complete denture impression. **D,** Hygiene cover screws are threaded onto the abutments to protect them from calculus and food impaction. **E,** The indirect impression transfers are threaded on the abutment for screw analogs. **F,** The indirect impression transfers and abutment analogs are inserted into the maxillary preliminary impression.

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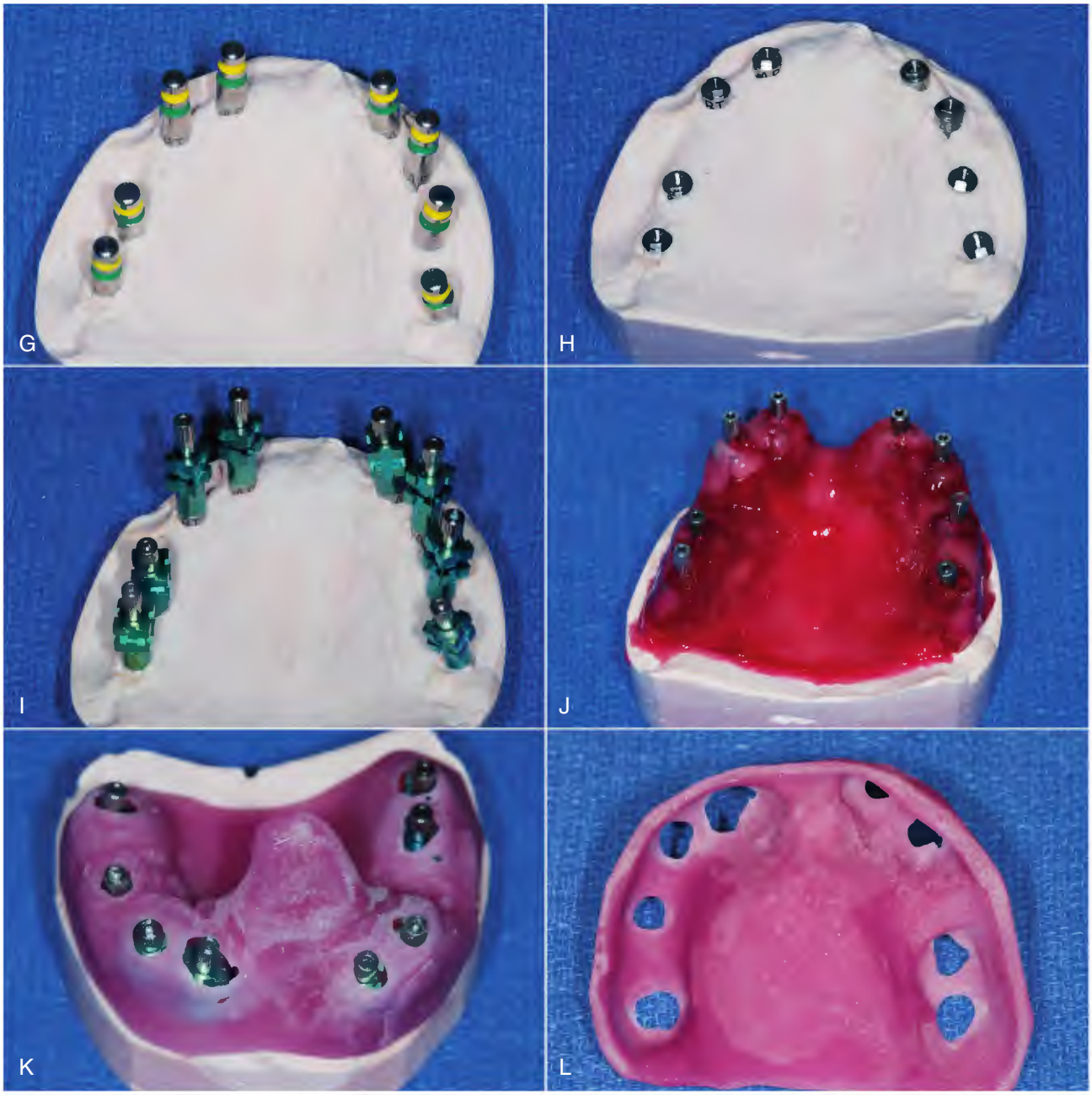


FIGURE 29-126, cont'd. **G,** The impression is poured with dental stone and separated after setting. **H,** The indirect impression transfers are removed from the cast. **I,** The direct impression transfers are threaded into the abutment analogs found within the cast. **J,** A 3-mm wax or clay spacer is placed around the direct impression transfers, and a 1-mm spacer is applied over the soft tissues. **K,** A custom modified open impression tray is made with light-cured acrylic. **L,** The tray is removed from the cast and modified as needed.

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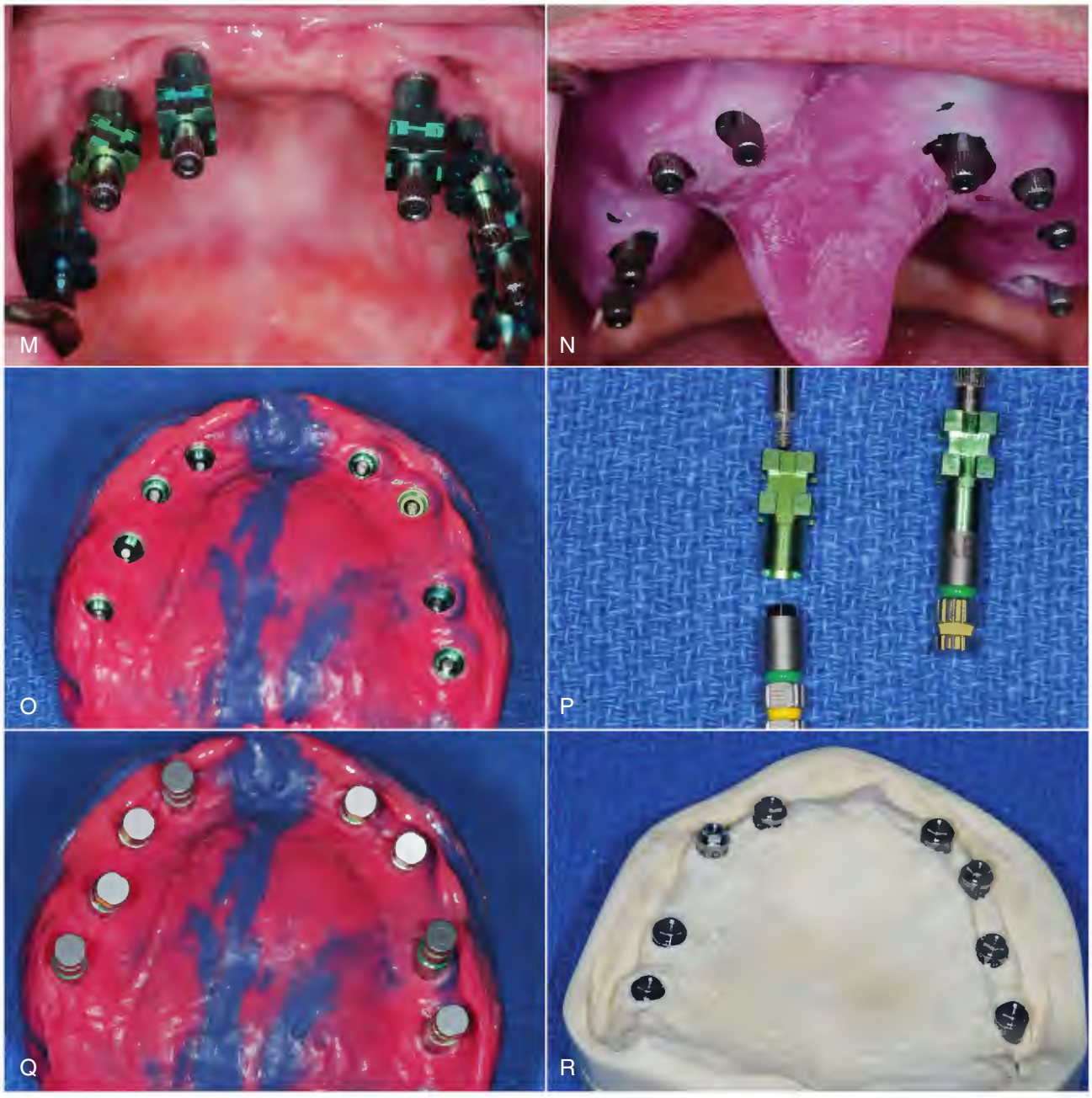


FIGURE 29-126, cont'd. **M,** The direct impression transfers are threaded into the abutment for screw retention in the mouth. **N,** The modified open custom tray is tried in over the direct impression transfers. **O,** A final impression of the maxilla is made. The direct impression transfer fixation screws are unthreaded and the impression evaluated. **P,** The direct impression transfers will be connected to the abutment for screw analogs in the impression. **Q,** The abutment for screw analogs are connected to the direct impression transfers captured in the impression. **R,** Dental stone is poured into the impression and allowed to set. The impression transfers are unthreaded, and the cast contains the abutment for screw analogs.

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FIGURE 29-126, cont'd. **S,** The direct impression analogs are threaded into the abutment analogs captured in the final cast. **T,** A baseplate is made that incorporates the direct impression transfers. **U,** A wax rim is added to the baseplate. Two long fixation screws in the canine position will fixate the device in the mouth. **V,** The baseplate and wax rim is made so the coping–abutment connection is visible, so the device is also a verification jig. **W,** After occlusal records are recorded, a wax try-in of the teeth confirms the correct tooth position. **X,** The bar and attachments are made within the contours of the restoration and cast in precious metal (or machined with CAD-CAM technology). At delivery, the bar is evaluated for a "passive" fit.

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FIGURE 29-126, cont'd. **Y,** The denture is processed, and the labial flange is made similar to a complete denture. **Z,** The occlusion and esthetics are evaluated.



FIGURE 29-127. **A,** A maxillary RP-4 implant overdenture in centric occlusion. **B,** In protrusive, the posterior teeth separate. **C,** Incisal guidance separates the posterior teeth in all excursions when a RP-4 prosthesis is opposing a fixed dentition.

lingualized occlusion discussed for a maxillary denture in Chapter 33. Whereas the occlusion for the RP-5 IOD is bilateral balance, the occlusal scheme for the RP-4 IOD is posterior disclusion and anterior guidance when opposing a RP-4 or fixed dentition in the mandible (Figure 29-127).

Summary

Mandibular and maxillary IODs borrow several principles from tooth-supported overdentures. The advantages of IODs relate to the ability to place rigid, healthy abutments in the positions of choice. The number, location, superstructure design, and prosthetic range of motion can be predetermined and based on a patient's expressed needs and desires and anatomical conditions. The same IOD treatment should not be provided to all edentulous patients. In the mandible, only two implants placed just anterior to the mental foramina rarely should be used. This treatment option has more prosthetic complications. The overdenture should be designed to predictably satisfy the patient's desires and anatomical limitations.

The most common overdenture option used by the profession is the two-implant overdenture with individual O-ring

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attachments. Yet the only benefits of this approach are improved retention and a reduced initial cost. The bone loss is accelerated in the posterior regions, and the maintenance of anterior bone is limited to the zone around each implant. In addition, more prosthetic complications occur, which is a negative for both the patient and doctor.

An ideal approach for the overall long-term health of the mandible and maxilla is a complete implant–supported prosthesis (RP-4 or fixed restoration). The bone volume is maintained in the anterior, and the posterior bone loss is significantly reduced or even improved. The occlusal load support is on the implants, not the soft tissues. The stability of the prosthesis is maximal because it does not move during function (mastication, speech). The retention is improved because it may have four to six overdenture attachments.

The patient initially may not be able to afford an OD-5 option (with a RP-4 or fixed prosthetic option). However, in the mandible, an OD-3 may be converted to an OD-4 after several years and eventually to an OD-5 after several more years. If the transition from one option to another is in a short time frame (1–2 years), the implants may be independent and use an O-ring system short term. This reduces the fee for the transitional prosthesis because no bar is fabricated, and a rebase may be used to modify the prosthesis. In the maxilla, independent implants are reported to have a higher failure rate. Therefore, a RP-5 with a splinted bar is a better option for the first stage of treatment.

A screw-retained prosthesis attaches to the implant abutment with significant compressive forces (10–30 N-cm torque). The coping screw should not place tension, compression, or shear forces on the superstructure. To accomplish the goal of a passive superstructure, the dentist scrutinizes all aspects of prosthesis reconstruction in an attempt to compensate for errors and variations during the process. Fabrication variables most important to the dentist include impression material shrinkage, permanent deformation, custom versus stock impression trays, variance among manufacturers in analog parts, stone and investment expansion, metal shrinkage, acrylic and porcelain shrinkage, soldering, and torque force applied to the coping screw. The step-by-step clinical protocol for screw-retained prostheses has been presented to produce the most passive castings as is technically possible and therefore minimize crestal bone loss and abutment screw loosening.

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CHAPTER 30

Maxillary Arch Fixed Implant Prostheses: Design and Fabrication

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Partially edentulous patients missing multiple maxillary anterior teeth are not unusual. Failed fixed partial dentures often result in additional tooth loss. Car accidents and other sources of trauma may also result in loss of multiple anterior teeth (Figure 30-1). Less often do the effects of periodontal disease affect only anterior teeth. Most partially edentulous patients prefer a fixed prosthesis (FP) to restore their dentition. There are many advantages to restoring multiple anterior missing teeth with a fixed implant restoration independent from the remaining natural teeth.

In addition to partially edentulous patients missing multiple anterior teeth, there are even more patients with completely edentulous maxillae. The average total edentulous rate around the world is 20% of the adult population by age 65 years, although there is wide disparity in the countries with the highest and lowest rates.[1] For example, from the 65- to 74-year-old age group, the total edentulous rate in Kenya and Nigeria is 4%, but Netherlands and Iceland have rates of 65.4% and 71.5%, respectively. The edentulous Canadian rate is 47% at age 65 to 69 years and 58% from ages 70 to 98 years (with Quebec at 67% for those older than age 65 years compared with Ontario with a rate of 41%).

A 1999 to 2002 survey found that total edentulism in the United States of both arches was present in almost 20 million people.[2] As expected, older persons are more likely to be missing all of their teeth. Total edentulism has been noted in 5% of employed adults ages 40 to 44 years, gradually increasing to 26% at age 65 years and to almost 44% in seniors older than age 75 years.[3] Gender was not found to be associated with tooth difference in retention or tooth loss after adjustments were made for age.

The maxillary arch may also be completely edentulous, opposing at least some teeth in the mandible. This condition occurs 35 times more often than the reverse situation. At age 45 years, 11% of the population has maxillary total edentulism opposing at least some teeth, which increases to 15% by 55 years of age and then remains relatively constant.[2,3]

The percentages of total edentulism of the maxillary arch translate into more than 30 million people or about 17% of the entire U.S. adult population.[4] To put these numbers in perspective, 30 million people represent approximately the entire U.S. African American population, the U.S. Hispanic population, the whole population of Canada, or the total population in the United States older than 65 years of age.

Maxillary dentures usually are tolerated better by completely edentulous patients than their mandibular counterparts. The greater retention, support, and stability compared with a lower restoration are well documented. As such, patients are often able to wear the devices for longer periods of time before complications arise. As such, many treatment plans for complete edentulous patients initially concentrate on the problems associated with the mandibular denture (Figure 30-2). However,



FIGURE 30-1. Multiple adjacent anterior teeth in partially edentulous patients may be lost from trauma and less often from periodontal disease.



FIGURE 30-2. Implant treatment plans for completely edentulous patients often address the mandible because it is the least stable unit. The maxilla is often restored with a traditional denture. This patient has a maxillary denture opposing a mandibular fixed implant-supported prosthesis.

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when patients enjoy a stable, retentive, and perhaps fixed mandibular prosthesis, often their attention is brought to the maxillary arch. When patients become aware of the anatomical and esthetic consequences of missing teeth, their desires increase for maxillary implant restorations. As a result, future restorations of the edentulous maxilla more often include implant restoration.

Consequences of Anterior Maxillary Edentulism

Several factors affect the condition of the premaxilla and may result in a decrease in implant survival or an increase in prosthetic complications. A completely edentulous anterior bony ridge is often inadequate for endosteal implants. The facial cortical plate is very thin over the maxillary anterior teeth and may be resorbed from periodontal disease or often is fractured during the extraction of teeth (Figure 30-3). In addition, the facial cortical plate resorbs during initial bone remodeling, and the anterior ridge loses 25% of its width within the first year after tooth loss and 40% to 60% over 3 years, mostly at the expense of the labial plate.[5,6] As a result, the maxillary denture migrates to a more palatal position in the anterior maxilla.

By the time the patient notices problems of stability and retention caused by lack of premaxilla, the maxillary bone often has resorbed in height and is a division C-h to D (Figure 30-4). When the premaxilla resorbs, the maxillary denture begins to become unstable. The maxillary anterior teeth are positioned in front of the residual bone. As a result, the denture rotates up in the anterior, which means it rotates down in the posterior. The denture loses the valve seal as a consequence. The complete anterior ridge and even the nasal spine may be resorbed in the maxilla, also causing pain and a further increase in maxillary denture movement during function.[7,8] Hence, an implant prosthesis should be considered for the maxillary arch before bone is lost in the premaxilla.

The doctor has the responsibility to inform the patient about the continued bone loss of the maxilla. Bone grafting is much more predictable for width gains than increases in height. Division B bone grafting often may use a synthetic bone component for the graft. Division C minus width (C–w) often requires at least some autologous bone, often with the mandible as a donor. With edentulous maxillae requiring height augmentation (division C–h or D), the dentist may have to resort to the iliac crest as a donor site for large volumes of bone.[9] As such, the maxillary completely edentulous patient should understand that the surgical rehabilitation is much more complex and extensive because the volume of bone to reconstruct the arch becomes larger. Rather than waiting until the bone is resorbed or the patient complains of problems with the prosthesis, the dental professional should educate the patient about the bone loss process after tooth loss (Box 30-1). The patient should be made aware that the future bone loss can be arrested by a dental implant.

Chapter 25 presents the fixed treatment plan options for edentulous and partially edentulous premaxillae, including the key implant positions and the number and size of the implants. This chapter presents unique conditions of the maxilla that relate to implant number. In addition, this chapter addresses the sequence of treatment to restore the maxillary arch within the esthetic zone.

Advantages of a Maxillary Implant Prosthesis

The use of dental implants to provide support for an implant overdenture (IOD) offers many advantages compared with the use of removable soft tissue–borne restorations. A primary reason to consider dental implants to replace missing teeth is the maintenance of alveolar bone. For example, after the implants are inserted, the bone loss may resorb as little as

BOX 30-1 Consequences of Maxillary Edentulism

1. Rapid bone loss in width
   a. Extraction process
   b. Resorption of labial bone
2. Bone loss in height
   a. Denture instability
   b. Esthetic consequences
3. Advanced bone grafting procedures required to remedy the bone loss



FIGURE 30-3. The bone in the edentulous anterior maxilla often is narrow because the labial plate is thin over the roots and often fractures during extractions or resorbs soon after tooth loss.



FIGURE 30-4. When the premaxilla bone height is lost, the maxillary denture has a dramatic decrease of retention and stability.

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0.6 mm vertically over 5 years, and long-term resorption may remain at less than 0.05 mm per year.[10]

When a maxillary denture is used opposing mandibular teeth or an implant-supported restoration, the maxillary bone loss may be accelerated.[11] An endosteal implant can maintain bone width and height as long as the implant remains healthy. As with a tooth, periimplant bone loss may be measured in tenths of a millimeter and may represent a more than 20-fold decrease in lost bone structure compared with the resorption that occurs with RPs.

The features of the inferior third of the face are closely related to the supporting skeleton[7] (Figure 30-5). When vertical bone is lost, the dentures only act as "oral wigs" to improve the contours of the face. The dentures become bulkier as the bone resorbs, making it more difficult to control function, stability, and retention. With implant-supported prostheses, the vertical dimension may be restored, similar to natural teeth. In addition, the implant-supported prosthesis allows a cantilever of anterior teeth for ideal soft tissue and lip contour and improved appearance in all facial planes. This happens without the instability that usually occurs when an anterior cantilever is incorporated in a traditional maxillary denture. The facial profile may be enhanced for the long term with implants rather than deteriorating over the years, as can occur with traditional dentures.

Facial esthetics are affected as a consequence of the maxillary arch with bone loss, with the loss of vermilion border of the lip, increased length of the maxillary lip, and lack of facial bone support. However, patients may not realize these changes are related to the loss of teeth and bone (Figure 30-6).

From a bone volume conservation standpoint in the jaws, completely edentulous patients should be treated with enough implants to completely support a prosthesis whether the patient is partially or completely edentulous. The continued bone loss after tooth loss and associated compromises in esthetics, function, and health make all edentulous patients implant candidates. As a result, complete implant-supported restorations should be the restoration of choice.

The complete denture often moves during mandibular jaw movements during function and speech. The maxillary teeth are often positioned for lower denture stability rather than where natural teeth usually reside. With implants, the maxillary teeth



FIGURE 30-5. The bone of the maxillary jaw helps support the face and is related to facial esthetics.



FIGURE 30-6. **A,** A panoramic radiograph of a 70-year-old woman with severe maxillary bone atrophy. The anterior mandible had implants to support an overdenture 30 years ago. The bone has been maintained in the anterior mandible. **B,** The facial esthetics of the maxilla and maxillary lip are completely different than those of the anterior mandible (which has maintained muscle attachments and the vermilion border of the lower lip).

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may be positioned to enhance esthetics and phonetics rather than in the neutral zones dictated by traditional denture techniques to improve the stability of a lower prosthesis.

Occlusion is difficult to establish and stabilize with a completely soft tissue–supported prosthesis. Proper occlusal contacts often occur by chance, not by design.[12] An implant-supported restoration is stable. The patient can more consistently return to centric relation occlusion rather than adopt variable positions dictated by the prosthesis' instability.

Proprioception is awareness of a structure in time and place. The receptors in the periodontal membrane of a natural tooth help determine its occlusal position. Although endosteal implants do not have a periodontal membrane, they provide greater occlusal awareness than complete dentures. Implant patients can determine 50-micron differences with rigid implant bridges compared with 100 microns in those with complete dentures (either one or two).[13] As a result of improved occlusal awareness, the patient functions in a more consistent range of occlusion.

With an implant-supported prosthesis, the direction of the occlusal loads is controlled by the restoring dentist. Horizontal forces on RPs accelerate bone loss, decrease prosthesis stability, and increase soft tissue abrasions. Therefore, the decrease in horizontal forces that are applied to implant restorations improves the local parameters and helps preserve the underlying soft and hard tissues.

The maximum occlusal force of a traditional denture wearer ranges from 5 to 50 lb. Patients with an implant-supported FP may increase their maximum bite force by 85% within 2 months after the completion of treatment. After 3 years, the mean force may reach more than 300% compared with pretreatment values.[14] As a result, an implant prosthesis wearer may demonstrate a force similar to that of a patient with a fixed restoration supported by natural teeth.

Chewing efficiency with an implant-supported prosthesis is greatly improved compared with that of a soft tissue–borne restoration. The masticatory performance of dentures, overdentures, and natural dentition was evaluated by Rissin et al., and the traditional denture showed a 30% decrease in chewing efficiency.[15] The tooth-supported overdenture loses only 10% of chewing efficiency compared with natural teeth. An implant-supported prosthesis may function the same as natural teeth.

Retention of an implant-supported prosthesis is a great improvement over soft tissue–borne dentures. Mechanical means of rigid implant retention are far superior to the soft tissue retention provided by dentures or adhesives and cause fewer associated problems.

Patients treated with implant-supported prostheses judge their overall psychological health as improved by 80% compared with their previous state while wearing traditional, removable prosthodontic devices.[10] They perceive the implant-supported prosthesis as an integral part of their body.

A FP has less bulk of acrylic compared with a denture or IOD, reducing the bulk of the restoration, especially when the palate is eliminated. A few individuals have taste buds in the palate that are innervated from the eleventh nerve. Although unusual, these patients benefit from the elimination of the palate of their prosthesis. Therefore, eliminating the palate reduces the gagging effect for some patients, improves the taste of food in some individuals, and has an oral sexual advantage to others.

The success rate of implant prostheses varies, depending on a host of factors that change for each patient. However, compared with traditional methods of tooth replacement, a fixed implant prosthesis offers increased longevity, improved function, bone preservation, and better psychological results (Box 30-2).

Fixed Prosthesis versus Overdenture

The maxillary overdenture has several advantages compared with a traditional denture. However, because a maxillary denture has more retention, support, and retention than the mandibular denture, a RP-5 maxillary restoration has less benefit than the RP-5 mandibular restoration. The primary advantage of the RP-5 maxillary IOD is the reduced cost. The reduced fee is not only the reduced implant number (e.g., 4 vs. 7) but usually reduces the need for sinus graft augmentation. Hence, the time for treatment is reduced, as is the surgical fee, and may be less than 50% of the RP-4 or fixed restoration.

A survey by Carlsson et al. in 10 countries indicated a wide range of fixed versus removable options to treat edentulous patients.[16] The proportion of IOD selection versus fixed implant dentures was highest in the Netherlands (93%) and lowest in Sweden and Greece (12%). Cost was cited as the number one determining factor in the choice. However, with such a wide range of prosthesis type selection from one country to another, the influence of the doctor presenting the treatment options must be a major factor.

The esthetic advantage of a maxillary overdenture compared with a fixed restoration may be more evident in the maxilla compared with the mandible. The labial position of the maxillary lip for esthetics may require a labial flange, which makes it almost impossible for hygiene access when a fixed restoration is used. As such, when the teeth must be cantilevered off the premaxillary residual ridge more than 7 mm, an overdenture is strongly considered (Figure 30-7).

The IOD may be removed at night to reduce the noxious effects of nocturnal parafunction. These cyclic forces increase the risk of biomechanical problems, not only of the implants but also of the entire implant system, including the prosthesis occlusal material, the screws and cements that retain the prosthesis, the abutment screws, the crestal marginal bone, the complete bone–implant interface, and fracture of any of the prosthetic components or even the implants themselves.

A clinical study by Heydecke et al. evaluated 13 patients who received both a RP-4 overdenture and a FP, both for 2 months

BOX 30-2 Advantages of Maxillary Implant Prosthesis

1. Maintenance of bone
2. Esthetic advantages
   a. Occlusal vertical dimension maintained
   b. Muscle tone of lip
3. Improved function
   a. Mastication
   b. Speech
4. Improved occlusion
5. Improved proprioception
6. Improved occlusal force
7. Improved chewing efficiency
8. Improved retention
9. Improved psychologic health
10. Less bulk of restoration

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FIGURE 30-7. **A** to **C,** When the labial position of the teeth needed to support the upper lip is more than 7 mm anterior to the residual ridge, a bone graft or hydroxyapatite graft on the facial of the residual ridge is required to support the upper lip for a fixed prosthesis. Another method to support the maxillary lip is an implant overdenture with a labial flange.

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each.[17] Psychometric evaluation of general satisfaction, comfort, ability to speak, stability, esthetics, ease of oral hygiene, and occlusion was performed for both restorations. The chewing ability with seven types of foods was also determined with both restorations. The general satisfaction rating was significantly higher for the RP-4 overdenture group. The ability to speak and ease of hygiene were better, and the masticatory dynamics were similar in either prosthesis relative to stability, occlusion, and chewing ability. Nine of the 13 patients opted to have the RP-4 overdenture rather than the FP-3 at the conclusion of the study.

On the other hand, Brennan et al. also evaluated patient satisfaction and oral health–related quality of life outcomes of maxillary IODs (RP-5 and RP-4) and fixed complete prostheses.[18] Patients with maxillary overdentures reported significantly lower overall satisfaction, with lower scores for both chewing capacity and esthetics. The advantages cited for the overdenture were reduced cost and the ability to perform oral hygiene procedures.

Implant fixed restorations have a psychologic advantage compared with overdenture prostheses. Whereas an overdenture is a prosthesis, a fixed restoration is considered a body part. Patients with an IOD respond, "These are much better than my denture." When patients have a fixed restoration, they often state, "These are better than my teeth."

In the author's experience, patients who desire a fixed restoration are usually those that want the psychologic advantages of fixed teeth or patients who very recently lost their teeth and have not completely accommodated to a removable prosthesis (RP). These patients also most often have anterior bone and do not need the labial support of a denture flange to support the maxillary lip. On the other hand, long-term denture wearers do not perceive the advantages of a fixed restoration enough to compensate for the hygiene benefits. Esthetics may also be the motivating factor for an overdenture when the maxillary lip needs additional support.

A greater crown height space (CHS) is required for an overdenture. Hence, when abundant bone is present and implants are already inserted, a FP will have fewer issues of prosthesis fracture or positioning teeth over a bar.

More prosthetic maintenance is required for an overdenture. Attachments wear and need to be replaced, relines are necessary for RP-5 restorations, and denture teeth wear more rapidly on an IOD than a denture. As a result, a new IOD may need to be fabricated every 7 years.

A side effect of an IOD is food impaction under the prosthesis. The denture is border molded, so the muscles are in their contracted position. Otherwise, because the prosthesis is more rigid than a denture, sore spots develop during function. In the relaxed muscle state, food goes beyond the denture border. When the patient swallows, the food is pushed under the denture. A FP does not extend to peripheral borders and traps less food in comparison.

The advantage of developing a treatment plan for long-term health, rather than short-term gain, is beneficial to the patient. As such, if finances are not an issue, the dentist should design a prosthesis that is completely supported, retained, and

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stabilized by implants. If cost is a factor, a transitional implant-retained restoration with fewer implants greatly improves the performance of a denture and arrests the bone loss in the premaxilla. Then the dentist may establish a strategy for the next one or two steps to obtain the final complete implant-supported restoration.

Fewer reports have been published for maxillary implant prostheses than for the edentulous mandible.[19] The most often reported literature for the edentulous maxilla is similar to the original articles published by Branemark et al.[20] In this approach, four to six implants were positioned anterior to the maxillary sinuses, and a cantilever FP was fabricated. Approximately a 10% higher failure rate was observed in the maxilla compared with the mandible.[21]

Most all reports agree that a greater implant failure and risk of prosthetic complications exists in the maxilla compared with the mandible for full-arch restorations. In addition, maxillary overdentures have a higher failure rate than full-arch fixed restorations. For example, Engquist et al. report a 6% to 7% implant failure for mandibular implant–supported overdentures and a 19% to 35% failure for maxillary IODs.[22] Smedberg et al. reported an 86% survival rate for 20 patients with 86 maxillary implants, and results showed a similar disparity of results based on bone volume quality.[23] Palmqvist et al. also reported similar results.[24] A prospective study by Johns et al. reported on maxillary overdentures over 5 years.[25] Sixteen patients were followed throughout the whole study with a cumulative success rate of 78% and 72% for prostheses and implants, respectively. Widborn et al. evaluated 22 patients with 13 planned overdentures compared with FPs that ended up with an overdenture over a mean observation period of 5.7 years.[26] The implant survival rate in the planned overdenture group was 77%, and survival rate in the unplanned group was 46%.

Jemt et al. reported an 84% survival rate for 430 maxillary implants on 92 consecutive patients at 1 year.[27] In a follow-up study by Jemt of 70 edentulous maxillary patients with 336 implants, there was a 70% survival rate in resorbed bone and 88% in the intermediate group with an 85% implant overall survival rate.[28] In a 5-year prospective, multicenter study on 30 maxillae and 103 mandibles, Jemt and Lekholm reported that the survival rates of mandibular implants were 94.5% and 100% for mandibular prostheses.[29] In the maxillae, the implant survival rate was 72.4%, and the prosthesis survival rate was 77.9%.

Goodacre et al. performed a literature review from 1981 to 2003.[30] The implant prosthesis type with the lowest implant survival was a maxillary overdenture with a 21% failure rate followed by a full-arch maxillary FP with a 10% failure rate. A similar implant survival was reported by Chan et al.[31] They combined data from several reports and yielded an average 21% failure rate for implant-supporting maxillary overdentures, the highest failure rate of any prosthesis type. The primary causes of failure were implant overload as a result of decreased bone density, reduced implant size, and reduced implant number.

On the other hand, Sanna et al. reported on splinted implants for maxillary overdentures compared with full dental FPs with no implant failure.[32] The author has followed 75 maxillary overdenture (RP-4) patients and 110 full-arch FPs for 10 years with splinted implants and found 97% implant survival and 100% prosthesis survival rates.[33] Hence, no difference may be observed between these modalities when enough implants support the prosthesis. The primary differences in these treatment modalities have been implant number, position, and prosthetic guidelines that follow basic biomechanical concepts to reduce failure and decrease risks for maxillary full arch prostheses. In other words, an implant foundation specific for implant position and number.

BOX 30-3 Advantages of a Fixed Full-Arch Maxillary Prosthesis

1. Recent edentulous patients prefer fixed teeth
2. Psychologic advantage of "permanent teeth"
3. Less crown height space required for restoration
4. Less prosthetic maintenance
5. Less food impaction
6. Higher implant survival rates

In conclusion, if an edentulous patient desires a RP, an IOD is often the treatment of choice. If cost is a problem for a patient who desires a fixed restoration, the overdenture may serve as a transitional device until additional implants may be inserted and restored. However, when the patient desires a fixed restoration and the anterior bone is sufficient to support the maxillary lip, a fixed restoration has many advantages (Box 30-3).

Treatment Planning Considerations

An independent, fixed implant-supported restoration has become the treatment of choice for most patients with complete or partial edentulism. A FP presents several advantages over a removable partial denture or an overdenture for a maxillary edentulous patient. However, several criteria should be evaluated, and the treatment sequence should be noted.

The bone available for implant insertion in esthetic regions should be evaluated because the bone will influence greatly the labial lip support, the soft tissue drape, the implant size, the implant insertion (angulation and depth), and hence the final prosthetic result. Bone loss after maxillary anterior tooth loss is rapid and has considerable consequences. Thereafter, almost all multiple maxillary anterior edentulous sites require at least some bone and soft tissue augmentation before, along with, or at implant uncovery. Even when the bone is restored, the soft tissue drape is usually compromised. The maxillary anterior region with multiple adjacent teeth missing most often is restored with an overdenture or a fixed restoration that replaces teeth and the soft tissue drape (FP-3 prosthesis) (Figure 30-8).

In the majority of patients with available bone, the bone is less dense in the anterior maxilla than in the anterior mandible.[34] In the mandible, a dense cortical layer is coupled with coarse trabecular bone strength and permits implants to be supported by a denser bone quality. The maxilla presents thin porous bone on the labial aspect, very thin porous cortical bone in the floor of the nasal region, and a more dense cortical bone on the palatal aspect. The trabecular bone is usually fine and is also less dense than the anterior region of the mandible.

In the premaxilla, esthetics and phonetics dictate that the replacement teeth be placed at or near their original position, often cantilevered off the residual ridge, which usually is resorbed palatally and superiorly (Figure 30-9). The arc of closure is anterior to the residual ridge; as a consequence, the moment force is greatest against the maxillary anterior crowns supported by implants and directed against the thinner facial bone[33] (Figure 30-10). All mandibular excursions place lateral forces on the maxillary anterior teeth, with resulting increased

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FIGURE 30-8. **A** and **B,** A fixed prosthesis to replace multiple adjacent maxillary anterior teeth most often also replaces the soft tissue drape with the restoration (a FP-3 prosthesis).

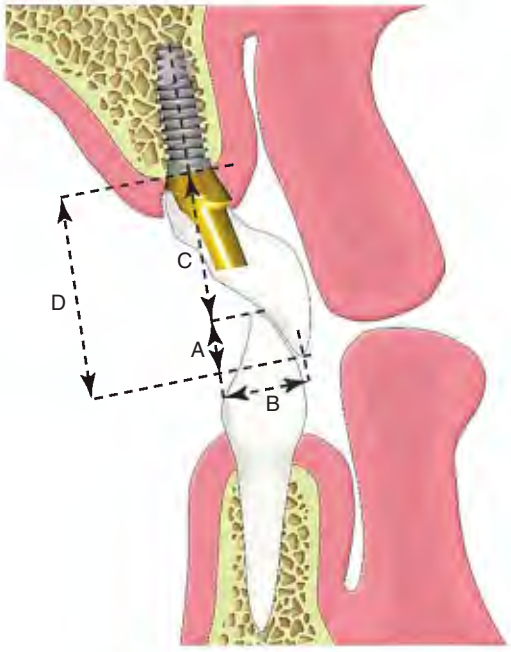


FIGURE 30-9. There are often facial cantilevers on anterior implants (*points A* to *B*). The crown height is also larger than the natural tooth (*C* in centric occlusion and *D* in protrusive).

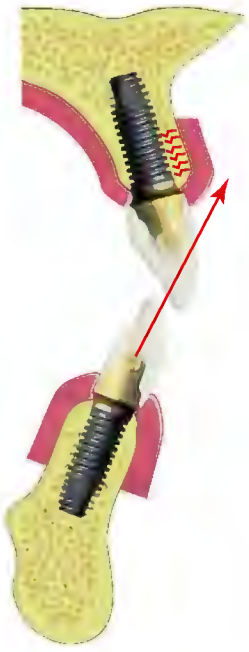


FIGURE 30-10. The arc of mandibular closure is anterior to the maxillary ridge; as a result, increased forces of the maxilla are applied to the thinner facial cortical plate.

stress on the crestal bone, especially on the labial aspect of the implant.

As a consequence, many treatment plan aspects place the edentulous maxilla at a high risk of implant failure:

1. The narrow ridge of a premaxilla has parallel walls of bone, so an osteoplasty to increase width is less effective (Figure 30-11). Therefore, the narrow ridges more often need narrower implants (resulting in increased stress concentrations in the implant and contiguous interfacial tissues, particularly at the crestal region).
2. This region is the most difficult to insert implants parallel to each other and within the contours of the restoration (Figure 30-12). The use of facial cantilevers results in increased moment loads at the implant crest, often leading to localized crestal remodeling and implant or abutment fracture.
3. Oblique centric contacts, resulting in potentially harmful, off-axis load components



FIGURE 30-11. The anatomy of the edentulous premaxilla is often not conducive to osteoplasty procedures to gain ridge width because the opposing plates of bone are often parallel to each other.

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FIGURE 30-12. Ideal implant placement in the premaxilla is often more difficult than other regions of the mouth because the bone is often narrower than in most other regions of the mouth.



FIGURE 30-13. Mandibular excursions place lateral forces on maxillary anterior implants, which increase the resultant stresses.

4. Lateral forces in excursion, resulting in greater moment loads applied to the implant (Figure 30-13)
5. Reduced bone density, resulting in compromised bone strength and loss of implant support)
6. Absence of thick cortical plate at the crest, resulting in loss of high-strength implant support and less resistance to angled loads
7. The accelerated bone volume loss in the incisor region, often resulting in the inability to place central and lateral incisor implants without substantial augmentation procedures
8. Anterior cantilevered crowns from maxillary anterior implants often require additional implants splinted together and an increase in the anteroposterior (A-P) distance, between the most distal to most anterior implant positions to compensate for the increased lateral loads and moment forces to the premaxillary implants, especially during mandibular excursions
9. The opposing arch for a maxillary implant prosthesis almost always has natural dentition or an implant prosthesis. A mandibular restoration often opposes a maxillary denture. Hence, the bite forces are often greater against a maxillary implant prosthesis.

To increase implant and prosthesis survival rates, treatment for maxillary FPs with division A bone are planned similarly to



FIGURE 30-14. The maxillary arch may be treated as an open pentagon, with five straight-line segments. When teeth are missing in multiple segments, at least one implant is required in each section.

that for mandibles with C minus height (C–h) bone and greater factors of forces. In other words, more implants are typically used in the maxillary arch compared with the mandibular situation. For example, four or more implants are inserted from first premolar to first premolar to replace the anterior eight teeth. In addition, subantral augmentation often is performed to place more distal implants and dramatically improve the A-P distance when the anterior and posterior implants are splinted together. This treatment approach has proved successful in yielding success rates in the maxilla similar to those of mandibular restorations.

Premaxilla Arch Form: Dentate and Residual Bone

The maxillary arch may be divided into five segments similar to an open pentagon[33] (Figure 30-14). The central and lateral incisors represent one segment, each canine a separate segment, and the posterior premolars and molars represent individual segments. Each segment is essentially a straight line, with little resistance to lateral forces. But because they are aligned along the arch, connecting at least three segments creates a tripod and provides an A-P distance (A-P spread) with mechanical properties superior to a straight line and with greater resistance to lateral forces. The A-P spread for anterior (or posterior) cantilevers corresponds to the distance between the center of the most distal implant (in the splint) and the anterior aspect of the most anterior implant.

Three of the five maxillary arch segments described are part of the premaxilla: the canine, the incisors, and the opposite canine. Therefore, to achieve a sound biomechanical system able to sustain lateral forces during mandibular excursions and the angled forces of centric occlusion, at least one implant should be placed in each anterior section and then splinted together. Previous studies have shown that the force distributed over three abutments results in less localized stress to the crestal bone than two abutments.[35] Hence, at least three anterior implants usually are required: one in each canine position and at least one in one of the four incisor positions.[33,36]

Implant Number and Premaxilla Arch Form

In Chapter 12, a discussion of key implant positions for implant prostheses is presented. The rules to determine the key implant positions are no cantilever, no posterior three adjacent pontics, the canine site, and the first molar site. In the premaxilla, the dentate arch form may also affect the implant number (Box 30-4).

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The type of arch form of the maxilla influences the treatment plan of the maxillary prostheses. Three typical dentate arch forms for the maxilla are square, ovoid, and tapering. The edentulous maxilla residual ridge of bone also may have three arch forms. Esthetic requirements may require a dentate arch form different from the residual ridge form. The dentate arch form of the patient is determined by the final teeth position in the premaxilla and not the shape resulting from the residual ridge. A residual ridge may appear square because of resorption or trauma. However, the final teeth position may need to be cantilevered to the facial with the final prosthesis. In other words, an ovoid dentate arch form may be needed to restore a residual edentulous square arch form. The number and position of anterior implants are related to the arch form of the final dentition (restoration), not the existing edentulous arch form.

To determine the dentate arch form one line is drawn through the incisive papilla to separate the right and left maxilla into two equal components. A second line is then drawn through the middle of the incisive foramen perpendicular to the first line (Figure 30-15). The second line will pass over the incisal tip position of the maxillary canines, whether the dentate arch is square, ovoid, or tapering[37] (Figure 30-16).

A third line is then drawn parallel to the second line along the facial of the maxillary central incisors[33] (Figure 30-17). When the distance between the second and third line is less than 8 mm, a square dentate arch form is present. When the distance between these lines is 8 to 12 mm, an ovoid dentate arch form exists. A distance of more than 12 mm indicates that a tapered dentate arch form is present (Box 30-5).

In a square dentate arch form, lateral and central incisors have minimum cantilever facially compared with the canine position. Mandibular excursions and occlusal forces may be reduced on the canine implants. As a result, implants in the canine position may suffice to replace the anterior six teeth for a full-arch FP because they are splinted to additional posterior implants (Figure 30-18). The four pontics between the canines create reduced forces because (1) the forces are lowest in the incisor region and (2) a square arch in the maxilla has less cantilevered occlusal forces to the canines (Figure 30-19).

If the final teeth position is an ovoid arch form, three implants should be positioned in the premaxilla for a FP[33] (Figure 30-20). For the fixed restoration of an ovoid dentate arch form (which is the most common arch form), planning for implants in the canine positions and at least one additional implant, preferably in a central incisor position, is important. The additional implant resists the additional forces created in this arch form, enhances prosthesis retention, and reduces the risk of abutment screw loosening (Figure 30-21).

BOX 30-4 Key Implant Positions and Number for Edentulous Maxillae

1. No cantilever
2. No posterior three adjacent pontics
3. Canine site
4. First molar site
5. Dentate arch form

BOX 30-5 Premaxilla Dentate Arch Form

1. Distance from facial of central incisors to mid incisive papilla
   a. <8 mm = square dentate arch form
   b. 8–12 mm = ovoid dentate arch form
   c. >12 mm = tapered dentate arch form

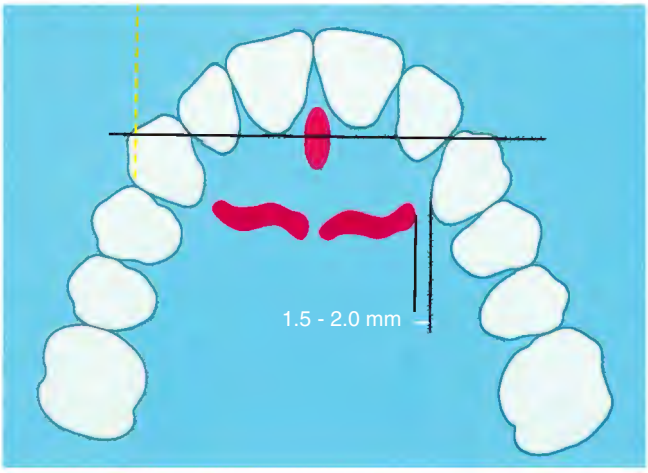


FIGURE 30-15. A line drawn through the center of the incisive papilla passes through the incisal tip of the maxillary canines.

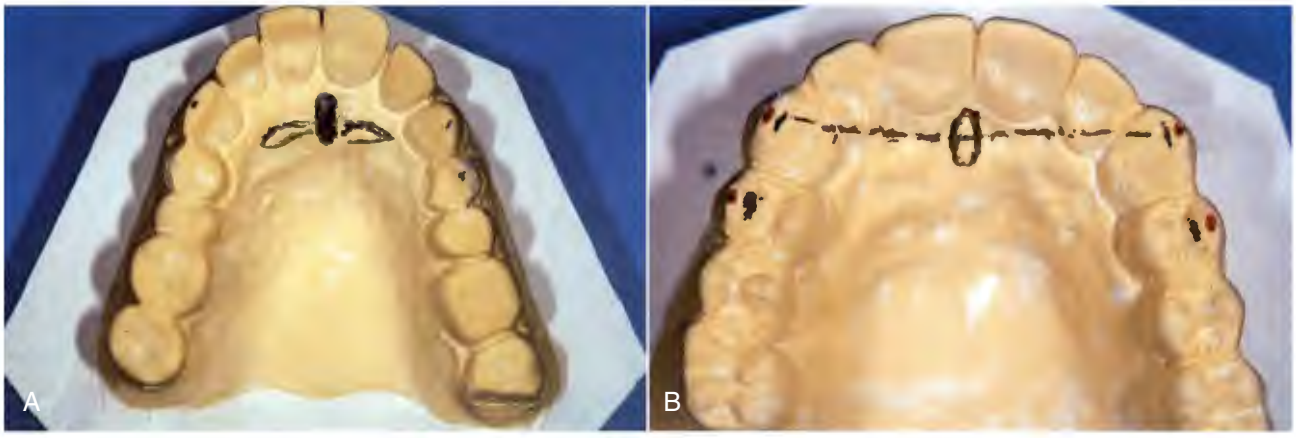


FIGURE 30-16. **A,** A tapered dentate arch form has the facial of the maxillary teeth 12 mm or more from the canine-to-canine plane. **B,** An ovoid dentate arch form has the facial of the maxillary incisor 8 to 12 mm from the canine plane.

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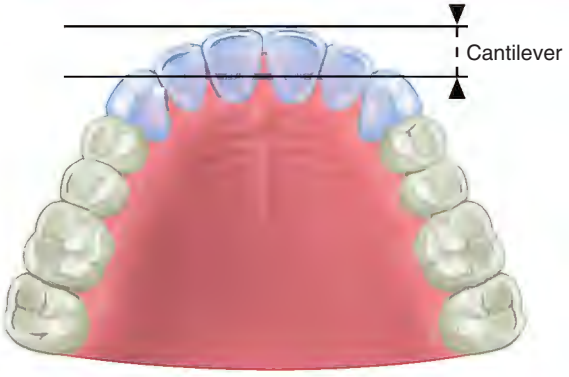


FIGURE 30-17. Two horizontal lines are drawn. The first line bisects the incisive papilla and connects the tips of the canines. The second line is parallel and along the facial position of the central incisor. The distance between these lines determines whether the dentate arch form is square, ovoid, or tapering.

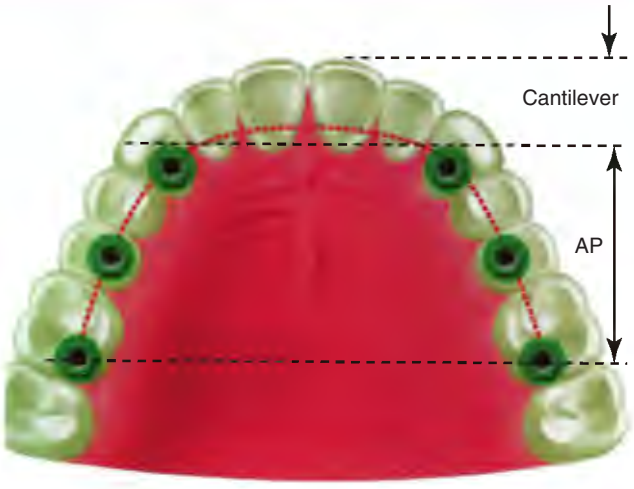


FIGURE 30-18. A square dentate arch form has the maxillary incisors less than 8 mm from the canine plane. When force factors are low, a square dentate arch form may use two implants in the canine positions when additional implants are used in the posterior regions. A total of six implants for a fixed or RP-4 prosthesis may be used in an edentulous square dentate maxilla. *A-P,* Anteroposterior distance.

The fixed restoration of a tapering dentate arch form places the greatest forces on anterior implants, especially when pontics replace the incisors (Figure 30-22). The anterior teeth are cantilevered facially from the canine position, with increased forces in centric occlusion and during mandibular excursions. As such, four implants should be considered to replace the six anterior teeth for a FP[33] (Figure 30-23 and Table 30-1).

The worse-case scenario is a patient requiring a tapered dentate arch form to be restored on a square residual ridge form (Figure 30-24). As a result, in these cases, a bone graft may be required to restore a more compatible residual ridge form. The bilateral canine and central incisor positions are biomechanically the best option for a tapered premaxilla. These positions are preferred when other force factors are greater, such as crown height, parafunction, and masticatory muscular dynamics.

When a dentate tapered arch form is restored on a square residual ridge form, implants are especially indicated in the posterior regions. The most posterior implants are placed in the second molar position (along with a first molar implant) to increase the A-P distance and counter some of the anterior cantilever effect[33] (Figure 30-25).

When one canine region cannot be used to place an implant in the edentulous maxilla, an implant in the first premolar and lateral incisor implant on each side of the missing canine are suggested to compensate for this vital position (Figure 30-26). A central incisor implant and canine position in the contralateral section can be splinted to these implants to act as abutments for the fixed restoration.

In the presence of severe force factors, two implants most often are required to sustain the direction of force created during a mandibular excursion, which means a minimum of four implants is suggested to replace the anterior six teeth. In the presence of these severe forces (e.g., severe bruxism), larger-diameter implants should be used, especially in the canine position (which has increased angulation in excursions and higher bite forces). As such, in many instances, the completely edentulous anterior maxilla is restored with three or four implants splinted together to support the FP. In addition, posterior implants are usually required, especially for a full-arch fixed restoration.

Precise implant position in a mesiodistal aspect is not mandatory in a FP-3 prosthesis (Figure 30-27). The pink restoration materials that replace the soft tissue drape hide the implant position and do not affect the mesiodistal width of the overlaying teeth.

TABLE 30-1
Treatment Plan for Edentulous Premaxilla

Arch Form	Anterior Cantilever (mm)	Number of Implants	Implant Position
Square	<8	2	Canines
Ovoid	8-12	3	Two canines and one incisor
Tapering	>12	4	Two canines and two incisors

Posterior Implant Number

As previously presented, the maxilla may be compared to an open pentagon, with five different sections: the central and laterals, the bilateral canines, and the bilateral premolars and molars. Hence, posterior implants splinted to anterior implants are a particular advantage because four or five different planes of movement are connected together.

The number of implants most often used in an edentulous maxilla for a FP should be in a range from seven to 10 implants.[33] Many reports concur on the fact that maxillary bone tends to be of poorer quality and volume and presents few biomechanical advantages. To compensate for the poor local conditions, a greater number of implants can be planned to create a greater A-P spread, hence the need for sinus grafts or premaxilla reconstruction. When force factors are moderate to severe or bone density is poor, more implants should be inserted and in greater diameter to enhance the surface area. Likewise, the number of implants needed in an edentulous premaxilla is related to arch shape, as previously addressed.

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FIGURE 30-19. **A,** A maxillary full-arch fixed prosthesis with a square dentate arch form. **B,** The maxillary anterior teeth are less than 8 mm from the canine-to-canine position. **C,** Two canine implants are used to restore the anterior six teeth. Additional implants are positioned in the posterior regions to increase the anteroposterior distance. **D,** The FP-3 full-arch maxillary prosthesis with a square dentate arch form. **E,** The FP-3 maxillary restoration is opposing a fixed FP-3 mandibular prosthesis.

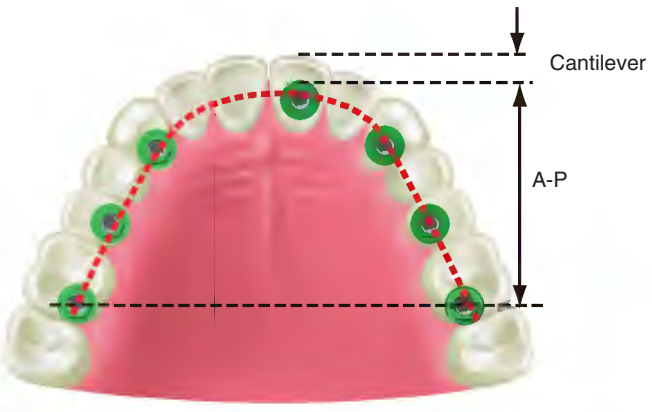


FIGURE 30-20. In an ovoid dentate arch form, three implants should be planned in the premaxilla: one in each canine position and one additional anterior implant. In addition, at least four posterior implants should be splinted to form an arch in an edentulous maxilla. *A-P,* Anteroposterior distance.

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FIGURE 30-21. **A,** A full-arch maxillary FP-3 prosthesis for an ovoid dentate arch form. Three implants are used in the premaxilla and connected to additional posterior implants. **B,** A FP-3 fixed full-arch maxillary prosthesis in an ovoid dentate arch form. **C,** A full-arch FP-3 maxillary restoration opposing natural dentition in a female.

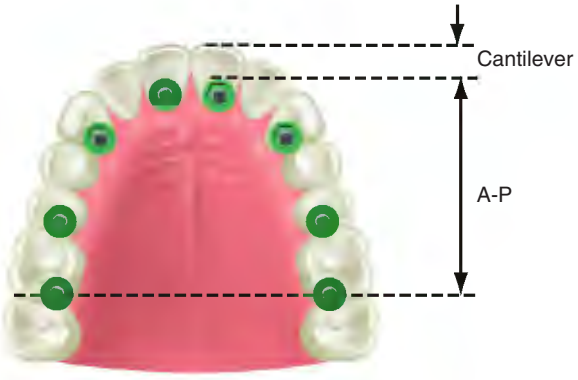


FIGURE 30-22. In a tapered arch form, the anterior cantilever from the canines is greater and should be supported by more implants in the premaxilla. At least four posterior implants should also be added to restore the completely edentulous arch. *A-P,* Anteroposterior distance.

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FIGURE 30-23. **A,** A full-arch maxillary FP-3 prosthesis in a man with a tapered dentate arch form. **B,** The maxillary FP-3 prosthesis in situ. **C,** The occlusal view of the FP-3 tapered dentate arch form. **D,** The maxillary FP-3 prosthesis opposes a mandibular FP-3 implant prosthesis.



FIGURE 30-24. The residual ridge form is square, and the dentate arch form is tapered. As a result, the anterior teeth are cantilevered from the implants. Because posterior implants were not used to replace the posterior teeth, they are also cantilevered in the restoration. The reduced anteroposterior distance makes this restoration more at risk of biomechanical complications.

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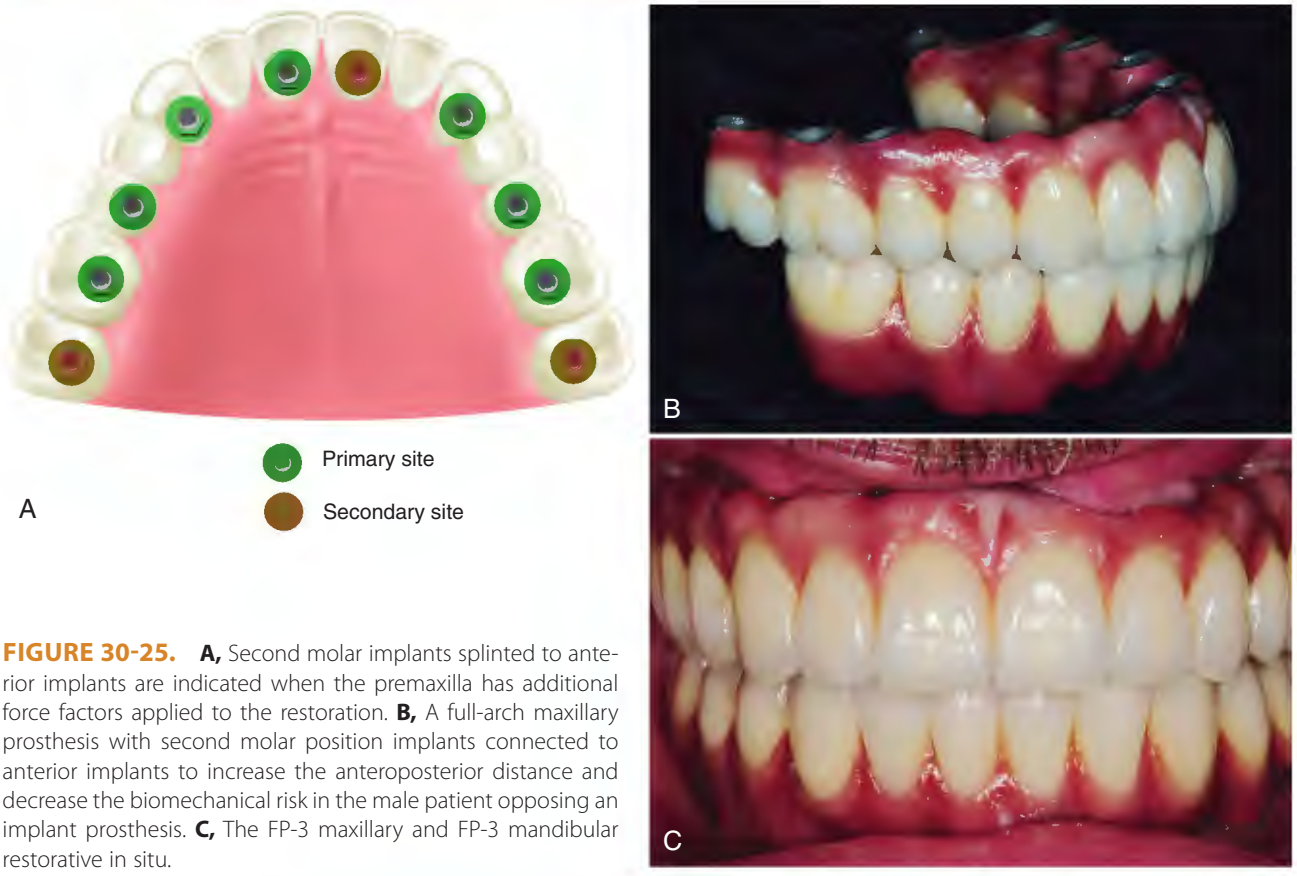


FIGURE 30-25. **A,** Second molar implants splinted to anterior implants are indicated when the premaxilla has additional force factors applied to the restoration. **B,** A full-arch maxillary prosthesis with second molar position implants connected to anterior implants to increase the anteroposterior distance and decrease the biomechanical risk in the male patient opposing an implant prosthesis. **C,** The FP-3 maxillary and FP-3 mandibular restorative in situ.

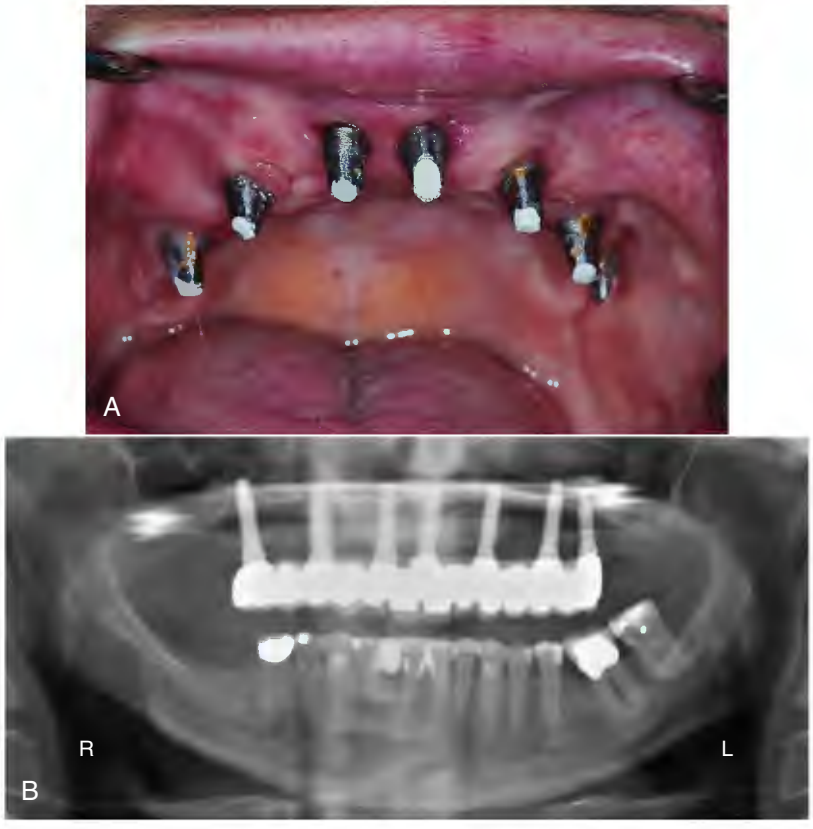


FIGURE 30-26. **A** and **B,** When an implant is not inserted into the canine position, implants should be positioned in the lateral and first premolar positions and splinted to additional implants.

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With these concerns in mind, the minimum implant number and suggested locations for a completely edentulous maxillary FP is usually seven: at least one incisor position, bilateral canine positions, bilateral second premolar sites, and bilateral distal half of the maxillary first molar sites (Figure 30-28). These seven implants should be splinted together to function as an arch. These implant positions create sufficient space between each implant to accommodate most any implant diameter. The first molar implant sites in a completely edentulous maxilla almost always require sinus grafting because most edentulous maxillary posterior regions are inadequate in available bone height.



FIGURE 30-27. Implant positions in the mesiodistal locations are less specific in FP-3 restorations compared with FP-1 prostheses.

When force factors are moderate to severe, the implant number should increase to eight or 10 implants.[33] When eight implants are selected, the additional implant is usually placed in the premaxilla in a central incisor position. When 10 implants are used for patients with higher force factors or poor bone density, additional implants are planned in the distal half of the second molar position to improve the arch form, increase the A-P spread, and eliminate posterior cantilevers. This is an excellent biomechanical design to minimize stress. This foundation design also may counter the effect of a facial cantilever off the residual bone (tapered dentate arch form) for an esthetic tooth position and is also indicated for patients with severe parafunction such as chronic bruxism.

The first and second molar position is also a benefit when the premaxilla has higher force factors, is underengineered as to implant number or size, or is a tapered dentate arch form on a square to ovoid residual available bone. The increase in A-P distance between the canine and second molar site is a considerable benefit.

Sequence of Treatment Planning

The maxillary anterior horizontal and vertical tooth positions are evaluated before any other segment of the arches. No other region of the mouth should be restored until this position is determined because it negatively influences the proper position of every other segment (e.g., occlusal vertical dimension (OVD), mandibular anterior tooth position, and posterior planes of

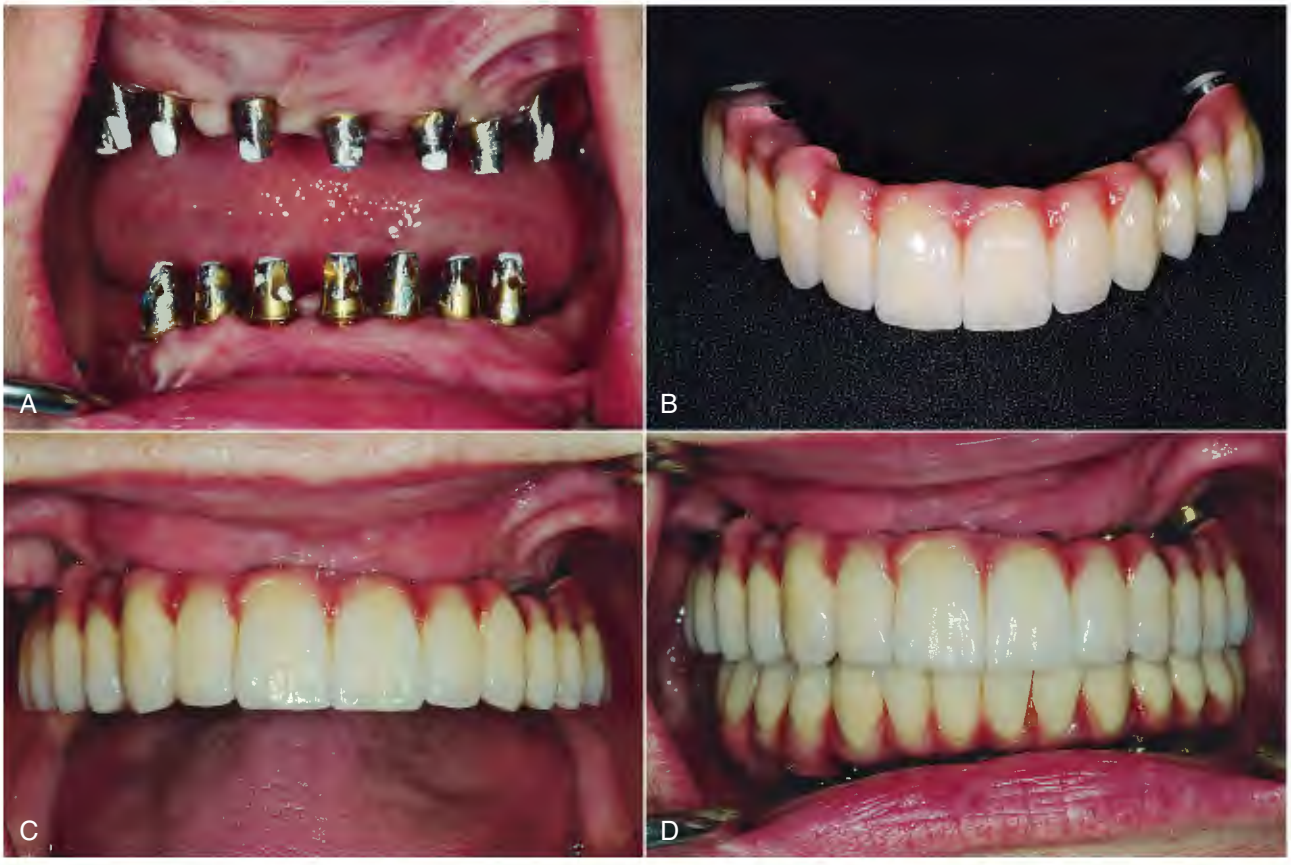


FIGURE 30-28. **A,** Full-arch maxillary and mandibular implant foundations for fixed restorations. Cantilevers are used less often in the maxilla compared with the mandible. **B,** The maxillary FP-3 prosthesis. **C,** The maxillary restoration in situ. **D,** The maxillary FP-3 restoration opposing a mandibular fixed implant prosthesis.

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occlusion). If the patient is wearing a maxillary complete denture, the maxillary anterior tooth position is often incorrect. As a result of resorption of the premaxilla, the denture shifts apically and posteriorly following the bone loss pattern.

After the position of the maxillary anterior teeth is acceptable, the next prosthetic step is either the evaluation of the OVD or maxillary occlusal plane. The posterior teeth positions are then determined, primarily using the mandibular teeth for occlusal force direction and the maxillary teeth when in the esthetic zone (Box 30-6).

Maxillary Labial Lip Position

The farther forward the maxillary anterior teeth are positioned from the implants, the more leverage on the bone interface, abutment screws, and implants. Yet many dentists attempt to do plastic surgery with plastic, hoping to eliminate vertical lines in the lip by bulking up the labial flange of an overdenture or positioning the teeth farther forward. Patients desiring to eliminate wrinkles from bone loss should have surgery and augmentation, not plastic added to a prosthesis. This is especially important when the patient desires a FP. Bone and soft tissue augmentation may be required to restore the natural appearance of the face without the help of a labial denture flange that may not exist at the end of treatment when a fixed restoration is planned. Hence, the facial position of the lip relative to esthetics is an important criterion to evaluate before the placement of the implants. This criterion alone may indicate an overdenture rather than a FP.

Whether a denture, an overdenture, or a FP is being fabricated, a full-arch or anterior edentulous maxillary reconstruction begins with the determination of the facial position of the maxillary incisal edge. Its modification at a later step may alter all other determinants of a reconstruction.

A baseplate and wax rim (or the patient's existing denture) may determine the facial support necessary for the labial contour of the maxillary lip. Most often the facial surfaces of the central incisors are 12.5 mm from the most posterior aspect of the incisive papilla.[37,38] The wax rim is initially positioned with this in mind. The farther forward the labial flange and teeth position, the higher the resting position of the lip and the greater the incisal edge exposure. This is why the labial position of the teeth is the first determined.

The labial position of the maxillary anterior teeth is first determined with the lip in repose. This is primarily evaluated by overall support of the maxillary lip and its relationship to the balance of the face, especially in relation to the nose and presence or absence of a philtrum in the midline.[39] When the baseplate and wax rim are in position, the philtrum of the lip should have a visible depression in the midline under the nose. If the philtrum is too flat, the lip is extended too far, and wax should be removed from the labial aspect of the wax rim. In addition, the maxillary lip should be anterior to the lower lip when the face is at rest with the lips together.

BOX 30-6 Sequence of Restorative Treatment

1. Labial position of anterior teeth
2. Incisal position of anterior teeth
3. Occlusal vertical dimension
4. Mandibular incisal edge position
5. Posterior planes of occlusion
6. Posterior tooth position

The labial position of the maxillary lip also is determined by the position of the lower lip and chin with the face at the proper vertical dimension. A horizontal line, represented by the Frankfort plane, may be drawn from the highest point of the auditory meatus (top of the tragus) to the lowest point on the margin of the orbit, with the patient's head in a vertical position. On average, a vertical perpendicular line drawn from the Frankfort plane to the lower lip should have the maxillary lip anterior to this landmark 1 to 2 mm and the chin 2 mm posterior to this line.[39] (Figure 30-29).

In a study by D'lessio and Misch, the position of the maxillary lip to Frankfort plane to the vertical line at the lower lip was evaluated for 94 beauty contestants age 18 to 24 years[33] (Figure 30-30). All women had the maxillary lip 2 mm or more anterior to the lower lip. Hence, the female patient's lip is positioned farther forward than the average 1 to 2 mm position.

When the teeth are positioned more labial, the vertical position of the lip is elevated. Likewise, a more palatal position of the maxillary anterior teeth results in a more inferior or extended position of the lip. An alternative to increasing the length of the anterior teeth so more teeth are visible with the lip in repose

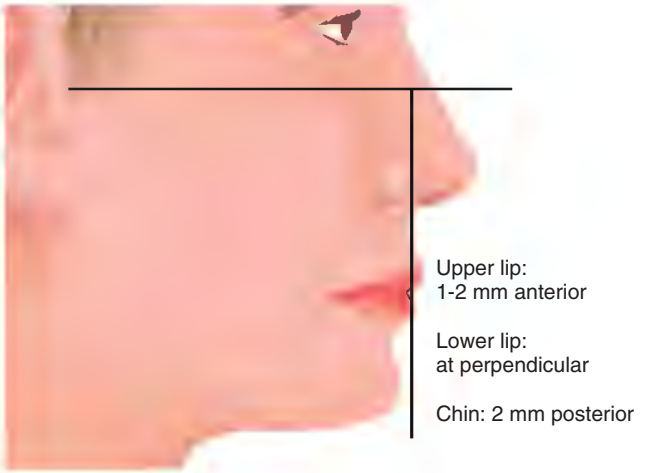


FIGURE 30-29. A horizontal line is drawn from the tragus to the lowest portion of the orbit. A vertical perpendicular line at the lower lip position should have the maxillary lip 2 mm anterior and the chin 2 mm posterior when the OVD is in the proper position.

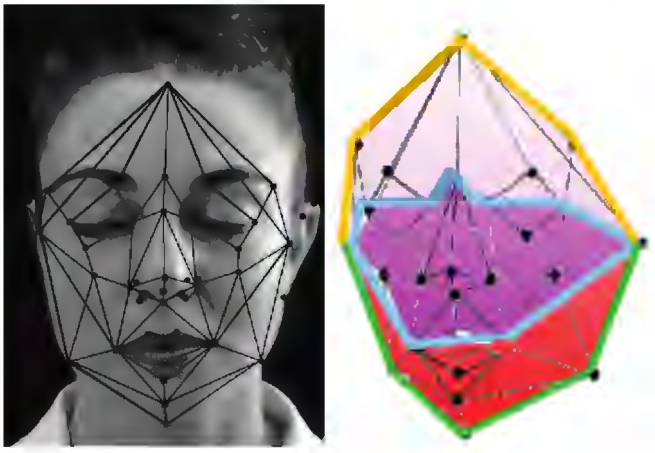


FIGURE 30-30. A study by D'lessio and Misch compared beauty contestants' faces versus facial averages in the literature with the 50 points described by Leonardo da Vinci.[55]

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may be to increase the thickness of the premaxillary alveolar ridge. This extra alveolar ridge thickness brings out the lip and raises the vermilion border. As a result, the teeth are not longer, but the border of the lip is higher. In addition, if the added width to the ridge is with autologous bone, replacing teeth with implants rather than pontics, further helps to maintain the situation. A fuller maxillary lip may also look younger because vertical age lines may also be reduced.

In a completely edentulous patient, the labial flange of the patient's existing denture may be removed and the lip position evaluated before the completed treatment plan for a fixed restoration. When the lip needs the support of the labial flange for esthetics yet a fixed restoration is planned, onlay grafts with hydroxyapatite (HA), connective tissue, autograft, or allograft may be indicated to increase labial tissue thickness for proper lip support.

The labial position of the lip in relationship to the premaxillary bone is the primary criterion to determine whether a fixed restoration, a bone graft and fixed restoration, or a maxillary overdenture is indicated. When the labial position of the wax rim (teeth) is forward of the residual ridge more than 7 mm, a bone graft before implants or a HA graft on the labial plate is required to support the lip for a fixed restoration, or a maxillary overdenture with a labial flange is considered (Figure 30-31).

Maxillary Incisal Edge Position

The next step in the evaluation process (when the labial position is acceptable) is the vertical position of the maxillary anterior teeth related to the lip in repose.[40] The position of the maxillary incisal edge primarily reflects esthetic and phonetic requirements. When the maxillary lip is at rest, the incisal edges of the teeth usually are visible. A general guideline was suggested by Rufenacht, who observed that the length from the base of the vestibule to the incisal edge of the maxillary central incisor is 22 mm on average.[41]

The average lip length from the base of the nose to the inferior border of the maxillary lip is 20 to 22 mm in young women and 22 to 24 mm in men. If the patient has a maxillary lip discrepancy, the lip position is highly variable. Typically, when the upper lip is shorter than 20 mm, a greater portion of the incisal edge will show with the lip in repose. Likewise, when the lip is longer than 22 mm, less incisal edge is shown in repose.

A significant decrease of maxillary central incisor tooth length exposure is relative to age, especially between ages 30 and 40 years. According to Vig and Brundo, a 30-year-old patient exposes more than 3 mm of the maxillary central incisor when the maxillary lip is at rest or repose.[40] A 40-year-old patient shows 1.5 mm of the maxillary central incisor; a

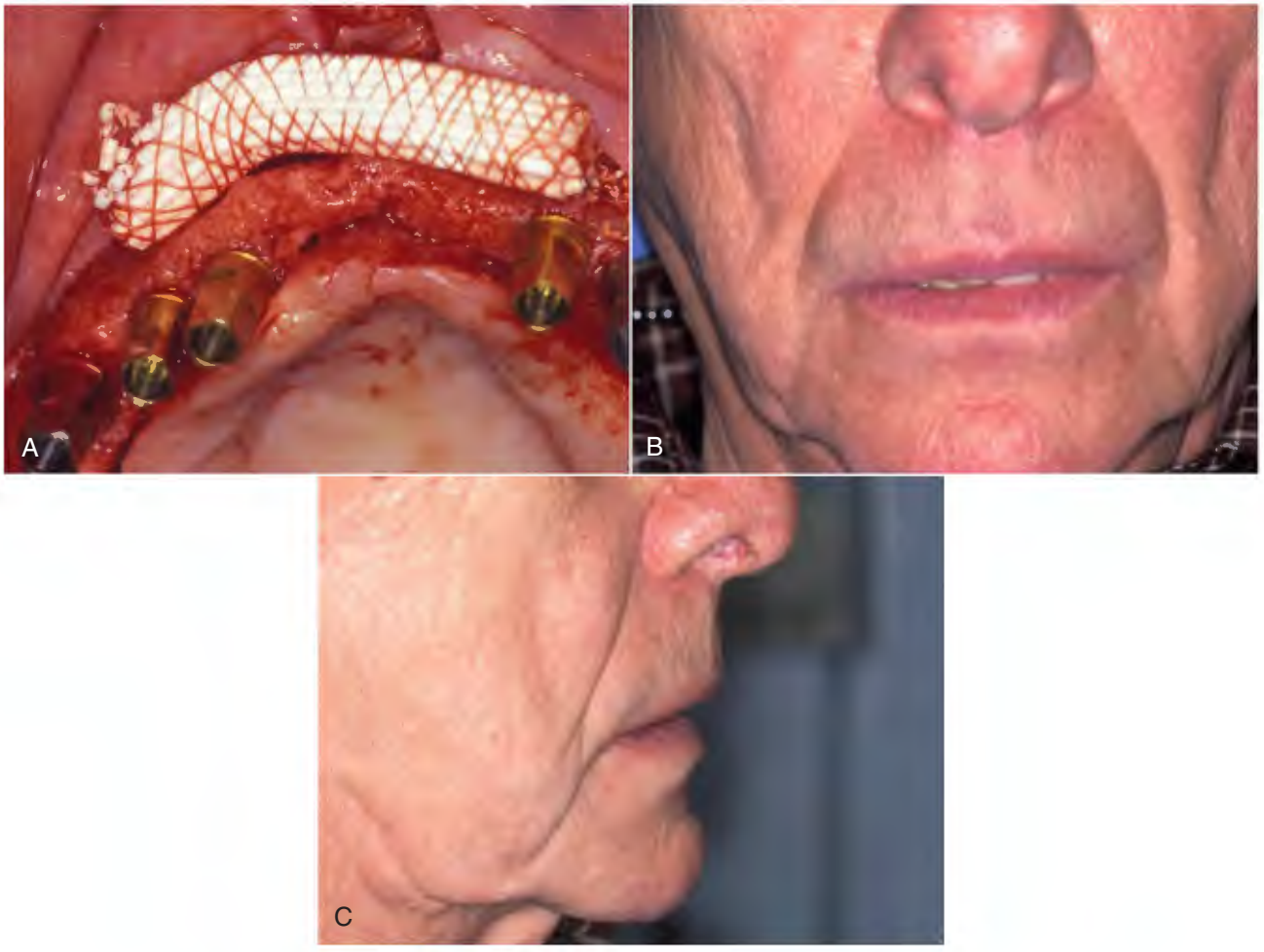


FIGURE 30-31. **A,** A hydroxyapatite graft was added to the facial of the residual ridge at stage 2 uncovery of the implants. **B,** The synthetic graft helps support the maxillary lip (frontal view). **C,** Sagittal view. A fixed restoration may be fabricated even though the bone was deficient to support the labial position of the lip.

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50-year-old, about 1 mm; and a 60-year-old, 0.5 mm. With an 80-year-old, the lip is observed level with the teeth. These positions are averages, and patients 65 years of age wearing a denture often have natural teeth shorter than the relaxed maxillary lip because of loss of facial muscle tonicity and loss of premaxillary bone height. Yet even 80-year-old edentulous patients often desire to have maxillary central incisors below the lip at rest.

In a study by the author, the position of the maxillary central incisor, in relation to the maxillary lip and the age of the patient (a range of 8 mm) is much more variable than the position of the canine, which has a range of 3 mm.[42] The lip bow in the center of the upper lip rises several millimeters on some women and is barely obvious on others. The higher the lip bow, the more central incisor surface is seen on the patient regardless of age. In addition, a short upper lip (less than 20 mm) will result in more central incisor exposure. Men rarely exhibit an exaggerated lip bow and therefore have a more consistent incisor edge to lip position. The canine position is closer to the corner of the lip and is not affected by the lip bow effect in the midline or the length of the maxillary lip. As such, it is a more consistent position and usually corresponds to the length of the resting lip position from 30 to 60 years of age in both men and women.

In other words, the maxillary canine is the key for the anterior vertical tooth position. The author has suggested the canine tip be located ±1 mm with the lip in repose regardless of the age or sex of the patient (Figure 30-32). A horizontal line drawn from one canine tip to the other should be level to the horizon. The central incisors are 1 to 2 mm longer than the horizontal plane of the canines.

The anterior incisal width of the wax rim is made similar to that of the final teeth to evaluate phonetics. When the patient says "F," the maxillary incisal edges should lightly touch the wet–dry border of the lower lip, similar to lower lip position during a broad smile position.[43] When the patient says "E," 50% to 70% of the space between the maxillary and mandibular lips should be occupied by the maxillary central incisors. If less than 50% of the space is occupied, the teeth usually can be lengthened, but if more than 70% of the space is occupied by maxillary central incisors, lengthening the teeth usually is not indicated. The patient should not have a reverse smile, where more space is below the maxillary incisal edges compared with the lateral incisors. A slight uniform space is acceptable.



FIGURE 30-32. The incisal edge of the maxillary anterior teeth (using the canine position). The canine vertical position is determined by the resting lip line (in the canine region). The central incisors are 1 to 2 mm longer in the horizontal plane of the canines. (This is the same patient as in Figure 30-23.)

Occlusal Vertical Dimension

To determine the anterior position of the mandibular teeth and the CHS of the maxilla and mandible, the overall issue of OVD must be addressed. The patient's existing OVD should be evaluated early in an implant prosthetic treatment plan because any modification will significantly modify the overall treatment. Because the OVD affects the CHS, it may influence the number, size, position, and angulation requirements of the implants.

The OVD is defined as the distance measured between two points when the occluding members are in contact.[44] It is usually established with a maxillary and mandibular baseplate and wax rim, at least initially. The determination of the OVD is not a precise process because a range of dimensions is possible without clinical symptoms. At one time, it was believed that OVD was very specific and remained stable throughout a patient's life. However, this position is not necessarily stable when the teeth are present or after the teeth are lost. Long-term studies have shown that this is not a constant dimension and often decreases over time without clinical consequence in dentate, partially edentulous, or completely edentulous patients. A completely edentulous patient often wears the same denture for more than 10 years, during which time the OVD is reduced 10 mm or more without symptoms or even patient awareness.[45]

The OVD may most often be altered without the symptoms of pain or dysfunction, especially when the condylar disc assembly is healthy. However, this is not to say that altering the OVD has no consequence. A change in OVD affects the esthetics of the chin-to-face position. Any change in the OVD will modify the horizontal dimensional relationship of the maxilla to the mandible. Therefore, a change in OVD will modify the anterior guidance, range of function, and facial esthetics.

The most important effect of OVD on tooth (implant) loading may be the effect on the biomechanics of anterior guidance and esthetics. The more closed the OVD, the farther forward the mandible rotates and the more skeletal class III the chin appears. In completely edentulous patients restored with fixed implant prosthodontics, a change in OVD in either direction affects biomechanics. Opening the OVD and decreasing the incisal guidance with a resulting bilaterally balanced occlusion may increase forces placed on posterior implants during mandibular excursion. Closing the OVD may increase the forces to anterior implants during any excursion.

The OVD is almost never naturally too large, and unless some manufactured interference has been created, it is within clinical guidelines or collapsed. Therefore, the restoring dentist most often should determine whether the OVD needs to be increased. In other words, the existing OVD in a patient without symptoms of the temporomandibular joint is a position to start the evaluation, not one that necessarily must be maintained.

According to Kois and Phillips, three situations primarily mandate the modification of the OVD: (1) esthetics, (2) function, and (3) structural needs of the dentition.[46] Esthetics are related to OVD for incisal edge positions, facial balance, and position of the chin and the occlusal plane. Function is related to the canine positions, incisal guidance, and angle of load to teeth or implants. Structural requirements are related to dimensions of teeth for restoration while maintaining a biological width or the CHS, which may modify biomechanical force.

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Methods to Evaluate Occlusal Vertical Dimension

In traditional prosthodontics, a range of techniques has been described to establish the OVD. Whereas objective methods use facial dimension measurements, subjective methods rely on esthetics, resting arch position, and closest speaking space. There is no consensus on the ideal method to obtain the OVD. Therefore, this dimension is part art form and part science. And yet it is critical enough that a final treatment should not be rendered until a determination has been made relative to this dimension.

The most common subjective methods to determine OVD include the use of resting interocclusal distance and speech-based techniques using sibilant sounds. Niswonger proposed the use of the interocclusal distance ("freeway space"), which assumes that the patient relaxes the mandible into the same constant physiologic rest position.[47] The practitioner then subtracts 3 mm from the measurement to determine the OVD.

Two observations conflict with the "freeway space" approach to determine OVD. First, the amount of freeway space is highly variable in the same patient, depending on factors such as head posture, emotional state, presence or absence of teeth, parafunction, and time of recording (greater in the morning). Second, interocclusal distance at rest varies 3 to 10 mm from one patient to another. As a result, the distance to subtract from the freeway space is unknown for a specific patient. Therefore, the physiologic rest position should not be the primary method to evaluate OVD. However, it should be evaluated after the OVD is established to ensure a freeway space exists when the mandible is at rest.

Silverman stated that approximately 1 mm should exist between the teeth when making an "S" sound.[48] Pound further developed this concept for the establishment of centric and vertical jaw relationship records for complete dentures.[43,49] Although this concept is widely used by the profession, it does not correlate to the original OVD of the patient. Denture patients often wear the same prosthesis for more than 14 years and during this time lose 10 mm or more of their original OVD. Yet all of these patients are able to say "Mississippi" with their existing prosthesis. If speech were related to the original OVD, these patients would not be able to pronounce the "S" sound because their teeth would be more than 11 mm apart. To say the letter "S" with the correct sound, the teeth must be approximately 1 mm apart. Therefore, the speaking space should not be used as the only method to establish OVD.

After the OVD has been determined, the speaking space should be observed, and the teeth should not touch during sibilant sounds. On occasion, a short adjustment period of a few weeks may be required to establish this criterion. Therefore, on occasion, a transitional prosthesis should be used to evaluate this position in case it must be modified before the final restoration.

After the position of the maxillary incisor edge is determined, the OVD influences esthetics of the face in general. Facial dimensions are objective (because they are measured) and directly related to the ideal facial esthetics of an individual. They can be easily assessed regardless of the clinician's experience.[50,51] This objective evaluation is usually the method of choice to initially evaluate the existing OVD or establish a different OVD during prosthetic reconstruction. In addition, it may be performed without the need for additional diagnostic tests.

Facial measurements can be traced back to antiquity, when sculptors and mathematicians followed the *golden ratio* for body and facial proportions as described by Plato and Pythagorus. The golden ratio relates to the length and widths of objects in nature as 1 to 0.618.[52] It was observed that biologic features follow this ratio. Architectural proportions often follow the golden ratio because it is considered the most esthetically appealing to the human eye.[53,54] Leonardo da Vinci later contributed several observations and drawings on facial proportions, which he called *divine proportions*.[55] He observed the distance between the chin and the bottom of the nose (i.e., OVD) was a similar dimension as (1) the hairline to the eyebrows, (2) the height of the ear, and (3) the eyebrows to the bottom of the nose—and each of these dimensions equaled one third of the face.

Many professionals, including plastic surgeons, oral surgeons, artists, orthodontists, and morticians, use facial measurements to determine OVD. The author reviewed the literature and found that many different sources reveal many correlations of features that correspond to the OVD[50,51,56]:

1. The horizontal distance between the pupils
2. The horizontal distance from the outer canthus of one eye to the inner canthus of the other eye
3. Twice the horizontal length of one eye
4. Twice the horizontal distance from the inner canthus of one eye to the inner canthus of the other eye
5. The horizontal distance from the outer canthus of the eye to the ear
6. The horizontal distance from one corner of the lip to the other following the curvature of the mouth (cheilion to cheilion)
7. The vertical distance from the external corner of the eye (outer canthus) to the corner of the mouth
8. The vertical height of the eyebrow to the ala of the nose
9. The vertical length of the nose at the midline (from the nasal spine [subnasion] to the glabella point)
10. The vertical distance from the hairline to the eyebrow line
11. The vertical height of the ear
12. The distance between the tip of the thumb and the tip of the index finger when the hand lies flat with the fingers next to each other

All of these measurements do not correspond exactly to each other but usually do not vary by more than a few millimeters (with the exception of the vertical height of the ear) when facial features appear in balance. An average of several of these measurements may be used to assess the existing OVD. In a clinical study by the author, the OVD was often slightly larger than the facial measurements listed (more in men than women) but was rarely a smaller dimension.[51] The subjective criteria of pleasing esthetics may then be considered after the facial dimensions are within balance to each other.

Esthetics are influenced by OVD because of the relationship to the maxillomandibular positions.[57] The smaller the OVD, the more skeletal class III the jaw relationship becomes; the greater the OVD, the more skeletal class II the relationship becomes. The maxillary anterior tooth position is determined first and is most important for the esthetic criteria of the reconstruction. Alteration of the OVD for esthetics rarely includes the maxillary tooth position. For example, the OVD position may be influenced by the need to soften the chin for a patient with a large mental protuberance, by increasing the OVD.

Radiographic methods to determine an objective OVD are also documented in the literature. Tracings on a cephalometric radiograph are suggested when gross jaw excess or deficiency is noted. Such conditions may stem from vertical maxillary excess;

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vertical maxillary deficiency; vertical mandibular excess (long chin); vertical mandibular deficiency (short chin); or apertognathia or skeletal class II, division 2 (deep bite) situations. Orthodontic treatment planning of a dentate patient often includes a lateral cephalogram and may be used to evaluate OVD (glabella–subnasale, subnasale–menton). The same measurements may be performed on an edentulous patient.[58,59]

After the OVD satisfies the esthetic requirement of the prosthetic reconstruction, it may still be slightly refined. For example, the OVD may be modified to improve the direction of force on the anterior implants. In addition, anterior mandibular implants on occasion are too facial to the incisal edge position, and increasing the OVD makes them much easier to restore. Therefore, because the OVD is not an exact measurement, the ability to alter this dimension within limits may often be beneficial.

Mandibular Incisor Edge Position

Tooth Position: Anterior

Vig and Brundo observed that the amount of lower teeth observed with the lips slightly parted was variable related to age.[40] Approximately 0.5 mm of the lower teeth is displayed for a 20-year-old person, 1 mm for a 40-year-old person, 2 mm for a 50-year-old person, 2.5 mm for a 60-year-old person, and 3 mm for an 80-year-old person. However, this is not explicit enough to determine the vertical position of the lower anterior teeth.

After the OVD has been determined, the position of the mandibular anterior teeth may be determined. The goal is to restore a patient with a full-arch fixed maxillary prosthesis with mutually protected occlusion. In other words, in centric occlusion, the posterior teeth have occlusal contacts from the canine to the last molar. In right and left mandibular excursions, the canine or canine and lateral incisor discludes the posterior teeth.

The incisal guidance is defined as the influence of contacting surfaces of the mandibular and maxillary anterior teeth on mandibular movements.[44] The incisal guide angle is formed by the intersection of the plane of occlusion and a line within the sagittal plane determined by the incisal edge of the maxillary and mandibular central incisors in maximal intercuspation. It is responsible for the amount of posterior tooth separation during mandibular excursions; to do so, it should be steeper than the condylar disc assembly (Christensen's phenomenon). The amount of incisal guidance determines the steepness of the curve of Spee.

Any planned maxillary prosthesis and associated compensating curves should be developed within these confines. If not, the maxillomandibular arch position may be improper (i.e., in skeletal class II, division I patients), and the posterior teeth may exhibit lateral contacts during mandibular excursions. Under these conditions, the masseter and temporalis muscles do not reduce their contraction force during these jaw movements (as they do when only anterior teeth occlude in excursions), and the strong muscles of mastication continue to contract and place an increased force on the entire stomatognathic system.

A steep incisal guidance helps in avoiding posterior interferences in protrusive or lateral movement. However, the steeper the incisal guide angle, the greater force applied to anterior teeth or crowns. This may present a significant problem for a full-arch maxillary FP. On the other hand, if the incisal guidance is too shallow, posterior contacts exist in excursions.

When natural teeth are present or when a FP supported by natural teeth is planned in the anterior region, the mandibular teeth incisal edge should contact the lingual aspect of the maxillary anterior natural teeth at the desired OVD position.[60,61] Anterior centric stops usually prevent the continued extrusion of mandibular anterior natural teeth. However, in a full-arch maxillary implant prosthesis, no anterior contact in centric relation occlusion is designed, especially when opposing an implant prosthesis.[62] A vertical overbite with natural maxillary anterior teeth is usually in the range of 5 mm. When an implant prosthesis is planned in both anterior jaw regions, a reduced 2- to 4-mm vertical overbite is beneficial.[63]

Maxillary anterior prosthetic teeth almost always are positioned forward of the anterior residual ridge to satisfy phonetic and esthetic requirements. Moment forces result from the contact with the natural mandibular anterior teeth. Implants do not extrude or exfoliate in the absence of occlusal contacts. Therefore, when the mandibular arch is an implant restoration, anterior centric occlusal stops should be eliminated on the maxillary implant prosthesis, similar to a maxillary anterior denture occlusion. Most often, the horizontal overjet usually is increased about 1 to 2 mm, with no centric stops. This helps protect the premaxilla from excess forces in centric occlusion relation and initial excursions of the mandible because the premaxilla is vulnerable to these external stresses. A vertical overbite of 2 to 4 mm is usually created, which is slightly less than ideal with natural teeth but still provides incisal guidance. The more shallow anterior guidance separates the posterior teeth but does not further increase forces on the anterior implants compared with the forces generated with a steep incisal guidance.

The tips of the maxillary canines are in a plane related to the middle of the incisive papilla in 92% of cases,[37] which usually positions them closer to the residual ridge compared with the maxillary anterior incisors. Therefore, anterior centric occlusion contacts may be placed on the mesial aspects of the canines, with reduced anterior moment force. The six maxillary anterior teeth are positioned for esthetics and phonetics first. Accordingly, the implant-supported mandibular anterior incisors are set primarily for phonetics and incisal guidance.

Existing Occlusal Planes (Posterior Maxillary and Mandibular Planes of Occlusion)

After the maxillary anterior teeth are set on the wax rims or the metal try-in with white wax to duplicate their positions, the posterior tooth position can be determined. The plane of occlusion is an important consideration for any maxillary prosthesis. The occlusal plane is defined in three dimensions: occlusal gingival, A-P, and buccolingual. The maxillary anterior occlusal gingival position is obtained from the incisal edge position relative to esthetics and phonetics. This dimension also determines the position of the teeth in relation to the residual crest of the anterior ridge. The buccolingual dimension is parallel to a line drawn through the pupils of the eyes (but follows a compensating curve). The A-P dimension is established by the anterior incisal edge and the position of the posterior occlusal plane.

After the maxillary anterior teeth position, OVD, and mandibular anterior teeth position are deemed acceptable, the horizontal occlusal planes are determined in the posterior regions of the mouth. The maxillary occlusal plane may also be determined immediately after the maxillary incisal edge position is correct when both the maxilla and mandible are being restored at the same time.

The occlusal surface of one side of the dental arch should be parallel to the other. When it is not, one ramus may be longer

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than the other or one side may have extruded (exfoliated) from the lack of opposing dentition. Their position related to the curves of Wilson (mediolateral) and Spee (A-P) and to each other should allow harmonious occlusion with maximum occlusal interdigitation and canine or mutually protected occlusion in excursions.

In the occlusal-gingival position of the posterior occlusal plane, guidelines range from keeping the occlusal plane closer to the mandibular arch,[64,65] setting it midway between the two arches[66] using anatomical landmarks to position it in its natural location,[67,68] or terminating it posteriorly at the distal half of the retromolar.[69] The anatomical landmark approach has fueled further controversy because several planes and lines have been suggested.

A review of the literature highlights the controversy within the profession for the position of the posterior occlusal plane. Lundquist and Luther studied the mandibular occlusal plane in young class I jaw relationship dentate patients by joining the tips of mandibular cuspids to the distolingual cusp of the last molar.[70] This line corresponded 75% of the time to the lower half of the retromolar pad and 25% with a point in the upper half of the retromolar pad. Ismail and Bowman recommended the use of the upper third of the retromolar pad and the incisal edge when fabricating mandibular dentures.[71] Other authors suggested using the junction between the middle and superior third of the retromolar pad as a guideline.[72] Another common recommendation was to orient the occlusal plane parallel to Camper's line,[73] although confusion exists as to the actual position of this structure. A consistent landmark is the inferior alar process of the nose, but the posterior landmark varies from the superior to the middle point of the tragus.

One reason for this controversy is that most authors use the posterior occlusal plane position for full denture fabrication. When the occlusal plane is oriented lower than the one observed with natural teeth, the stability of a lower denture is improved. The lowered plane of occlusion helps decrease moments of force on the lower denture, and the tongue rest position is above the posterior teeth, which helps stabilize the mandibular denture. However, when maxillary implant-supported prostheses are fabricated, the opposing arch is most always natural dentition or implant supported (or both). When the maxillary or mandibular restoration is implant supported, the lower occlusal plane position is not indicated because it places the posterior maxillary teeth lower than the original tooth position, affecting esthetics (especially in the premolar area during smiling), and increases the crown height of the maxillary prosthesis.

The author evaluated the existing maxillary occlusal plane from the maxillary canine to the first molar in 50 patients with natural maxillary teeth.[74] The anterior reference point was the inferior alar process position. In half of the patients, the parallel posterior reference point was located in the upper third of the tragus; in 46%, it was parallel to the midtragus; and in 4%, it was below the midtragus. The tragus position was different on the contralateral side in almost 25% of the patients. The results suggest that the posterior plane of occlusion with natural teeth varies in the middle to superior third of the tragus position for 96% of patients. Therefore, the dentist can modify the orientation of the occlusal plane within this extended range to improve maxillary implant reconstructions relative to esthetics and forces on the implant abutments.

Transversal arch relationships include the existence of posterior crossbites, which occur frequently in implant dentistry, especially when they are out of the high lip line esthetic zone. Edentulous maxillary posterior arches resorb palatally and medially after tooth loss. Sinus grafts can restore available bone height, but the ridge still remains medial to the opposing mandibular tooth central fossa. This is especially pronounced when opposing a Misch-Judy division C–h or moderate atrophic mandible because the mandible widens after the residual alveolar ridge resorbs. For example, when mandibular implants are used in C–h bone volume for implant support opposing a maxillary implant prosthesis, the posterior teeth may be set in crossbite (especially when out of an esthetic zone) to decrease the moment forces developing on the maxillary posterior teeth.

Tooth Position: Posterior

Controversy exists as to where the teeth should be located, especially in the posterior regions of the mouth. Two approaches usually are given that propose different solutions: (1) the application of biomechanics or (2) the duplication of the natural architecture.

Most denture posterior tooth positions relate to the placement of a denture tooth over the residual posterior ridge. This allows the denture to be more stable. Perhaps the most known posterior denture tooth position was made popular by Pound.[75,76] The Pound triangle was created by drawing two lines from the mesial of the canine to each side of the retromolar pad. The lingual aspect of the posterior teeth is positioned between these lines. However, in a study by the author, the natural dentition is most always lingual to the lingual aspect of Pound's triangle.[74]

The author compared the position of the lingual cusps of mandibular molars in 30 patients with proper jaw relationship and occlusion with the lingual cusp position referred to by Pound (Figure 30-33). In all patients, the position of the posterior lingual cusps extended medial to a line drawn from the canine to the medial aspect of the retromolar pad. In the majority of patients, the lingual cusps extended 2 mm beyond the line; in about 10%, they extended to 3 mm; and another one third were 1 mm beyond the line.[74] The author has suggested that for mandibular implant prostheses, posterior teeth may be set medial to the retromolar pad in a position similar to natural teeth.

The posterior tooth position originally suggested by Pound helps stabilize a mandibular denture. However, an implant-supported mandibular overdenture does not require such a tooth position to enhance stability. In addition, the more medial the posterior denture teeth, the more vertical the

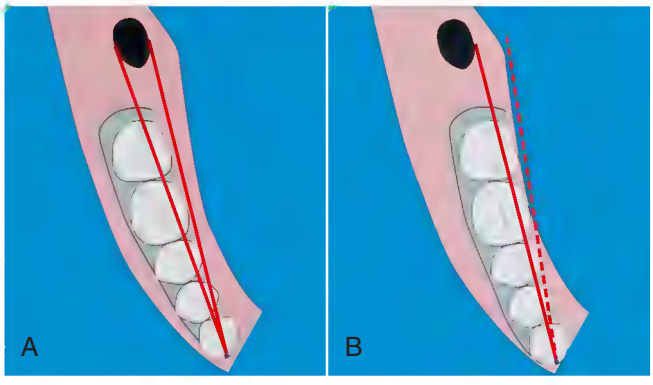


FIGURE 30-33. Pound's triangle for posterior teeth (**A**) places the lingual cusps of the posterior teeth facial to a line drawn from the canine to the lingual of the retromolar pad. The author prefers to position the central fossa of the posterior teeth on this landmark (**B**).

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occlusal forces generated over the maxillary bone. Therefore, the central fossa of the mandibular posterior teeth is suggested to be positioned on a line drawn from the tip of the mandibular canine to the lingual aspect of the retromolar pad. The mandibular posterior teeth are placed so that the central fossa is over this line and the lingual cusps extend medial to the line.

Although this position suggested by the author places the posterior tooth more medial than previous denture tooth position techniques, the lingual cusps are in similar location to that of the original teeth. This permits the maxillary teeth to be positioned more naturally in the buccal corridor and requires less facial position of the maxillary teeth for reduced ridge laps and improves force direction on the maxillary implants. The occlusal centric contacts follow the guidelines of implant-protected occlusion described by Misch and Bidez.[63]

Fixed Prosthesis Design

The average maxillary central incisor is 10.5 mm in height.[41] The height of the maxillary teeth should not be more than 12 mm. Soft tissue replacement with acrylic or pink porcelain should be considered when longer teeth are indicated, especially when the patient's high lip line exposes the interdental papillae of the central incisors.

Full-arch maxillary FPs most often do not have the natural soft tissues fill the interproximinal regions between the crowns. Instead, the prostheses are most often FP-3, with pink porcelain or acrylic replacing the soft tissue drape. When the teeth are not in the esthetic zone, a full-arch porcelain–metal or zirconium restoration may not attempt to replace the soft tissue drape, and the restoration may be FP-2. The active lip lines are determined to evaluate the necessity of replacing the soft tissue drape in the prosthesis. In addition, the active lip line determines the height of each tooth restored.

Active Lip Lines

After the horizontal and vertical positions of the anterior teeth are determined, the active lip positions are then evaluated. The maxillary high lip line during smiling and mandibular low lip line during speech are observed in relation to the teeth and the surrounding soft tissue (the soft tissue drape). The lip line positions are especially noted when teeth within the "esthetic zone" are replaced or restored.

Number of Teeth

The number of teeth displayed in the horizontal dimension in a broad smile is first assessed and is variable.[77] Approximately 7% of patients only show the anterior six teeth in the maxilla or mandible when smiling or during speech. The first premolar is more often seen in the maxilla during smiling and represents 48.6% of the population, the largest group of patients. The second premolar to second premolar can be seen 40.6%. The first molar to first molar can be seen in 3% of the patients and is the smallest group. When the teeth are in the esthetic zone, the facial contours of the teeth should not be compromised. Bone augmentation may be necessary to insert the implants in a more ideal position, so facial ridge laps or cantilevers are not necessary. However, it is not unusual in full-arch maxillary implant restorations to have facial ridge laps to restore the dentition.

Maxillary High Lip Line

The active lip positions in the vertical position are also highly variable but in general are related to the patient's age and sex. In general, older patients show fewer maxillary teeth during smiling but demonstrate more mandibular teeth during sibilant sounds.[77] Women show more maxillary teeth during smiling, and younger patients show more teeth than older patients. Men show more mandibular teeth during speech. A man shows fewer teeth than a woman of the same age.

The full-arch fixed maxillary prosthesis in implant dentistry attempts to reproduce a normal crown contour. However, with a high lip position during smiling, this goal must also make sure the natural soft tissue drape appears ideal around the crown. As a consequence, the esthetic requirements are much more demanding and often mandate additional surgical steps to enhance the soft and hard tissues before the crown restoration. Rarely when multiple anterior teeth are missing is a FP-1 prosthesis used to restore the arch.

The selection of a FP-2 and a FP-3 prosthesis is often based solely on the evaluation of the high lip line. A FP-2 prosthesis is easier to fabricate when a porcelain–metal prosthesis is fabricated because it does not require gingival-colored restorative materials in the prosthesis. However, these restorations can only be used when no soft tissue is exposed during smiling or speech.

The vertical translation of the maxillary lip during smiling is variable. The maxillary high lip line is determined while the patient displays a natural, broad smile. There are three vertical categories of maxillary high lip lines: low, average (ideal), and high ("gummy"). The low active lip line displays no soft tissue around the teeth (interdental papilla or gingiva above the teeth) during smiling. The active high lip line demonstrates all of the interdental papilla and any of the soft tissue above the cervices of the teeth. This is slightly different than the high lip position described in "esthetic dentistry," which most often used a 2-mm cervical soft tissue guideline.[77] This modification is necessary with implant prostheses because the cervical soft tissue will need to be replaced or the teeth will often appear too long.

The clinical characteristics of the average or ideal esthetic smile include maximum crown exposure, the exposure of the interdental papilla, and no gingival exposure over the cervicals of the teeth (maxillary lip at the free gingival margin of the centrals and canines during smiling) (Figure 30-34).

Approximately 70% of the adult population has a smile line within a few millimeters of the free gingival margin, and approximately 60% of the population shows interdental papilla but no cervical tissue.[77] In implant restorations, if any of the soft tissue (e.g., interdental papilla or cervical tissue) is displayed, the implant surgery, bone graft, or restoration must also replace soft tissue.

Almost 30% of men and 12% of women older than the age of 35 years have a low lip line and do not show the interdental papilla when smiling (average of 20%).[77] The author has observed that this percentage increases to 40% behind the maxillary canine and 70% behind the first premolar. In these patients, the soft tissue drape does not require a primary focus in the posterior regions and can often be compromised with a FP-2 restoration when the patient is notified before treatment. However, an average to high lip position during smiling contraindicates this restoration type because of poor cervical esthetics. A gummy or high smile line occurs in 14% of the young female patients and 7% of young male patients and is less for older patients.[77]

If the patient's active high lip line is greater than 12 mm from the incisal edge position of the teeth, the height of the clinical crowns are evaluated relative to their width. The normal

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FIGURE 30-34. **A,** A FP-3 maxillary full-arch implant prosthesis opposing a FP-2 mandibular fixed full-arch restoration. **B,** The maxillary high lip line exposes the maxillary crowns and interdental papilla but not the cervical aspect of the soft tissue drape.



FIGURE 30-35. **A,** The resting lip line determines the vertical position of the canine. The central incisors are 1.5 to 2 mm longer in the horizontal plane. **B,** The high smile line is measured to determine the height of the maxillary central incisor (between 9 and 12 mm). **C,** The laboratory prescription relates the height and width of each anterior tooth. **D,** The high smile position with the prostheses in position. (This is the same patient as in Figure 30-28.)

clinical crown height is 10 mm for the central incisor, 9 mm for the lateral incisor, and 10 mm for the canine. The height-to-width ratio is 0.86 for the central incisor, 0.76 to 0.79 for the lateral incisor, and 0.77 to 0.81 for the canine.

In patients with a high lip line during smiling who are missing all of their anterior teeth, the prosthetic teeth can be made longer (up to 12 mm) instead of the average 10-mm height to reduce the gingival display and result in a more esthetic restoration. Therefore, the height of the maxillary anterior teeth is determined by first establishing the incisal edge of the canine by the lip in repose. Second, the high smile line determines the height of the tooth (from 9 to 12 mm).[33] When the high lip line is 9 mm to the incisal edge, the tooth is made 9 mm high. If the high lip line is at 11 mm, the tooth is made 11 mm high. Third, the width of the anterior teeth is determined by the height-to-width ratios (Box 30-7 and Figures 30-35 and 30-36).

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BOX 30-7 Clinical Crown Size

Central Incisors Ratio: 0.85

HIGH	WIDE
9 mm	7.7 mm
10 mm	8.5 mm
11 mm	9.4 mm
12 mm	10.1 mm

Lateral Incisors Ratio: 0.77

HIGH	WIDE
8 mm	6.2 mm
9 mm	6.9 mm
10 mm	7.7 mm
11 mm	8.5 mm

Canine Incisors Ratio: 0.79

HIGH	WIDE
9 mm	7.1 mm
10 mm	7.9 mm
11 mm	8.7 mm
12 mm	9.5 mm

Several reports refer to the golden proportions for teeth width: 1.6 to 1.0 to 0.6. This ratio cannot be easily used by the technicians because the ratio is the appearance of the teeth in the premaxillary arch, which is on a curve. The canine in this ratio is 0.6 of a lateral incisor, but the canine is larger than a lateral incisor. The average lateral incisor is 6.5 mm wide, and the average canine is 7.5 mm wide. In addition, the most variable tooth width in the maxilla is the lateral incisor with a range from 4.5 mm (peg) to as large as 8 mm. It does not make sense to apply the 1.0 golden ratio to the tooth with the greatest range of width. Instead, the height-to-width ratios of 0.85, 0.77, and 0.79 are more appropriate for the central, lateral, and canine.

The cervical third of the maxillary premolars is also observed during a high smile line. It is not unusual to reveal the cervical third and gingiva of the interdental papilla of the premolar with a high lip line. These teeth should not appear too short (or long) and unnatural in height. Bone resorption may cause the implants to be inserted more palatally in this area. The position of these crowns may then be too palatal and therefore affect the esthetic result. Bone and soft tissue grafts are the primary methods to eliminate the need for ridge laps or the addition of pink porcelain at the gingiva. They are also indicated to reduce crown height. However, it is not unusual to overcontour the teeth in the esthetic zone and use pink restorative materials to replace the soft tissue drape.

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FIGURE 30-36. **A,** A full-arch maxillary fixed implant restoration opposing mandibular anterior teeth. **B,** The resting lip line determines the maxillary canine vertical position. **C,** The high lip line translates 14 mm from the incisal edge. Therefore, the teeth are made 12 mm in height.

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For multiple tooth replacement in the posterior regions, when the high lip line exposes the interdental papilla region but not the cervical gingival region, pink restorative materials may be used in the interimplant space to replace the papillae. When the high lip line exposes the cervical areas, the interdental and cervical aspects of the region should be addressed with surgery (e.g., grafting) or prosthetics (e.g., FP-3 restorations).

A high lip position of the edentulous maxilla restored with a FP-3 prosthesis that displays the patient's own soft tissue in the edentulous site is more difficult to restore than when the CHS is greater than usual but no natural soft tissues are shown during smiling in the edentulous site. When the patient's soft tissue is seen, the prosthetic gingival replacement must match the color and texture of the patient's tissue. When the patient's soft tissue is not visible, the restoration materials do not need to match the existing color, and it is easier to obtain an esthetic result.

The ideal CHS for a FP is between 8 and 12 mm, accounting for an ideal 3 mm of soft tissue, 2 mm of occlusal material thickness, and a 5 mm or greater abutment height. A CHS greater than 12 mm is not unusual for maxillary fixed restorations. The replacement teeth often require the addition of gingival-tone materials in esthetic regions. The greater impact force on implants compared with teeth, combined with the increased crown height, creates increased moment forces on implants and risks of uncemented or unretained prostheses and component or material fracture. These problems are especially noted when associated with less favorable biomechanics on cantilevered sections of fixed restorations.

A CHS greater than 15 mm means a large amount of metal must be used in the substructure of a traditional fixed restoration to keep porcelain to its ideal 2-mm thickness (Figure 30-37). Fine-tuning techniques for traditional fixed restorations are required under these conditions.[78,79] Controlling surface porosities of metal substructures after casting as their different parts cool at different rates becomes increasingly difficult.[80] Furthermore, when the casting is reinserted into the oven to bake the porcelain, the heat is maintained within the casting at different rates, so the porcelain cools in different regions at different rates.[81] If not controlled properly, both of these factors increase the risk of porcelain fracture after loading.[82]

For excessive CHS, considerable weight of the prosthesis (approaching 3 oz of alloy) may affect maxillary trial placement appointments because the restoration does not remain in place without the use of adhesive. Noble metals must be used to control alloy's heat expansion or corrosion; therefore, the costs of such implant restorations have dramatically increased. Proposed methods to produce hollow frames to alleviate these problems, including the use of special custom trays to achieve a passive fit, may double or triple the labor costs.



FIGURE 30-37. **A,** A fixed porcelain–metal restoration of an arch with a CHS greater than 15 mm must use a large amount of metal to ensure that the porcelain is only 2 mm thick in any direction. **B,** The porcelain on a FP-3 prosthesis should be no more than 2 mm thick to reduce the risk of fracture. Heating and cooling of large metal castings are more difficult to control in order to reduce complications. **C,** The maxillary restoration in situ.

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An alternative method of fabricating FPs in situations of CHS of 15 mm or greater is the fixed complete denture or hybrid prosthesis, with a smaller metal framework, denture teeth, and acrylic resin to join these elements together. The reduced metal framework compared with a porcelain-to-metal FP exhibits fewer dimensional changes and may more accurately fit the abutments, which is especially important for a screw-retained restoration. It is less expensive to fabricate than a porcelain-to-metal FP, is highly esthetic (premade denture teeth), easily replaces teeth and soft tissue in appearance, and is easier to repair if fracture occurs.

Because acrylic resin acts as an intermediary between the porcelain denture teeth and metal substructure, the impact force during dynamic occlusal loading may be reduced compared with a porcelain–metal restoration. As a general rule, fixed hybrid prostheses (FP-3) are used for situations with CHS of 15 mm or greater (Figure 30-38). When the CHS is less than 15 mm, the decrease in bulk of acrylic increases the risk of fracture and complications. Therefore, a porcelain–metal restoration is suggested.

The framework of the hybrid restoration is fabricated to reduce fracture of the prosthesis. Acrylic has strength in bulk, so larger connection rings are placed in the metal substructure rather than only small retentive beads (Figure 30-39). The framework is designed in an "I" beam to reduce the risk of metal fatigue and fracture (Figure 30-40). Whereas round castings flex to the power of four, an "I" beam flexes to the power of three. A pink masking material is painted on the substructure to reduce the amount of metal color bleed through the acrylic (Figure 30-41). The cervical aspect of the "I" beam substructure is polished to reduce plaque adhesion and is not covered in acrylic, so acrylic is not in contact with the tissue (Figure 30-42). This permits compressive forces on the acrylic holding the teeth to the framework during function and resists acrylic fracture. The denture teeth in these prostheses should not be acrylic or composite owing to a high fracture and wear rate. Instead, porcelain denture teeth are suggested (Figure 30-43).

On occasion, undercontoured interproximal areas are designed in such restorations to assist oral hygiene and have been referred to as "high water" restorations. This is an excellent method in the mandible; however, it results in food entrapment, affects air flow patterns, and may contribute to speech problems in the anterior maxilla. Instead, the restoration should block all movement during speech and often butts up against the tissue. However, hygiene considerations are still incorporated into the interproximal design next to each implant.

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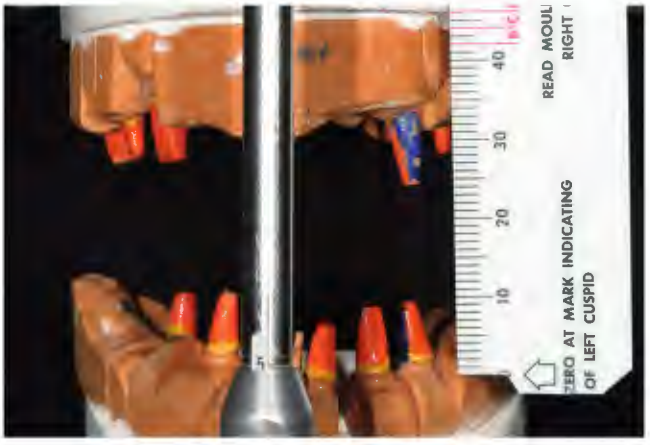


FIGURE 30-38. Hybrid fixed prostheses of denture teeth and acrylic and metal substructures are often used when the crown height space is 15 mm or greater.



FIGURE 30-39. Large connecting rings are placed in the metal substructure to connect the acrylic base to the framework.



FIGURE 30-40. **A** and **B,** The metal substructure is fabricated in the design of an "I" beam to decrease the risk of fracture.

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FIGURE 30-41. A pink masking material is applied to the framework to reduce metal color bleed through the acrylic.



FIGURE 30-42. The cervical aspect of the casting is polished, and no acrylic covers the tissue surface of the casting.



FIGURE 30-43. **A,** A large crown height space may be restored with a hybrid prosthesis of a metal framework, porcelain denture teeth, and acrylic. The denture teeth in these prostheses should not be acrylic or composite owing to a high fracture and wear rate. Instead, porcelain denture teeth are suggested. **B,** Panoramic radiograph of a FP-3 hybrid maxillary prosthesis, with a metal framework, porcelain denture teeth, and acrylic. **C,** The hybrid fixed maxillary prosthesis in situ. It may be made esthetic, has reduced laboratory costs, is lightweight, and may be repaired more easily than a traditional ceramic-to-metal restoration.

The CHS is a considerable force magnifier; therefore, the greater the crown height, the shorter the prosthetic cantilever that should extend from the implant support system. When the CHS is greater than 15 mm, no cantilever should be considered unless all other force factors are minimal. The occlusal contact intensity should be reduced on any offset load from the implant support system. Occlusal contacts in centric relation occlusion may even be eliminated on the most posterior aspect (or offset region) of a cantilever. In this way, a parafunction load may be reduced because the most cantilevered portion of the prosthesis is only loaded during functional activity (e.g., chewing).

Most recently, a full zirconium framework has been used to restore the complete edentulous arch. These CAD-CAM prostheses have several advantages over either the porcelain–metal or

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porcelain denture teeth acrylic–metal restoration. However, zirconium frameworks with porcelain veneers have a higher risk of fracture. Therefore, full zirconium may be used but is less esthetic. Another alternative is to have porcelain veneers only in nonfunctional regions, as the facial of the anterior teeth, with all occlusal contacts on zirconium, including all excursions.

Papillae Height

The height of the papillae in a FP-3 prosthesis is determined by the shape of the tooth. An anterior square teeth form has a papillae height of 2 to 3 mm. An ovoid anterior tooth form has a 4- to 5-mm-high papilla. A tapered teeth form has 6- to 7-mm-high papillae between the teeth. Hence, the doctor first determines the tooth form and then determines the papilla height between the anterior teeth.

It has been suggested the height of the papilla is more incisal between the central incisors and progressively is less in height proceeding toward the canine. The author has observed that this is rarely the situation. Instead, the papilla height is similar for the anterior six teeth from the mesial of the canine to the mesial of canine. The papilla is less on the distal of the canine.

Step-by-Step Fabrication of Fixed Full-Arch Maxillary Prostheses

Case 1: Direct Method with CAD-CAM Technology

Appointment 1: Abutment Selection, Preparation, Impression, Occlusal Vertical Dimension, Centric Bite Registration, and Transitional Restoration

1. The straight abutments for cement retention are threaded into the implant bodies (Figure 30-44).
2. A vacuum form of the maxillary denture is used to evaluate the abutment positions (Figure 30-45).
3. The abutments are prepared in the mouth for parallelism with a high-speed handpiece and carbide drills (Figure 30-46).
4. A large photographic mirror is used to evaluate the abutment parallelism (Figure 30-47).
5. The abutment screw holes are obturated with a light-cured material (e.g., Fermit) (Figure 30-48).
6. A Misch occlusal analyzer is used to evaluate the opposing arch curves of Wilson and Spee (Figure 30-49).
7. A vacuum form of the denture with unset addition silicone putty in the palate (Figure 30-50).
8. The vacuum form is positioned relative for the occlusion and incisal edge position. The addition silicone putty is allowed to set against the palate and helps position the vacuum form (Figure 30-51).



FIGURE 30-45.



FIGURE 30-46.

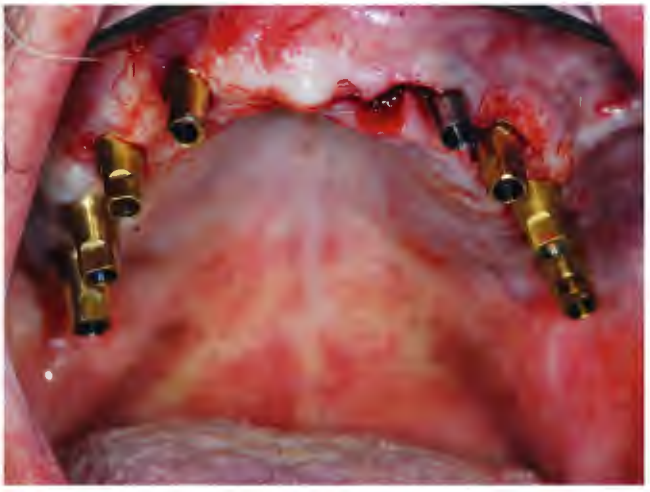


FIGURE 30-44.



FIGURE 30-47.

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FIGURE 30-48.



FIGURE 30-51.



FIGURE 30-49.



FIGURE 30-52.

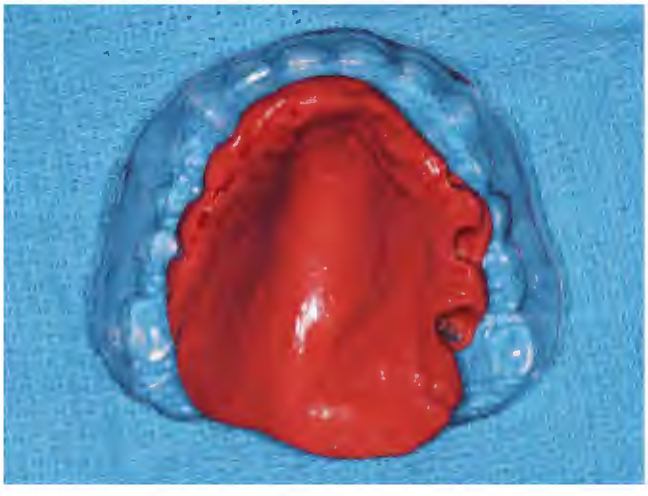


FIGURE 30-50.



FIGURE 30-53.

9. The vacuum form with set addition silicone on the palate positioned for occlusion and esthetics (Figure 30-52).
10. An impression is made with the vacuum form as a customized impression tray along with a bite registration (Figure 30-53).
11. The impression within the customized impression tray (vacuum form) allows the laboratory to pour and mount the arch at the DVD of the patient (Figure 30-54).
12. A bite registration on the vacuum form permits the laboratory to mount the cast to the mandible (Figure 30-55).

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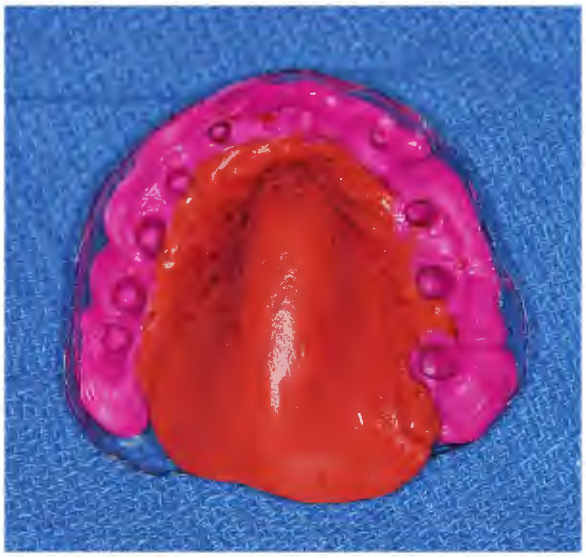


FIGURE 30-54.



FIGURE 30-55.

13. A Boley gauge confirms that adequate room above the abutments exist for the occlusal materials (Figure 30-56).
14. A second custom tray–vacuum form with putty in the palate to maintain the occlusal remisal dimension (Figure 30-57).
15. Acrylic is placed in the vacuum form and positioned over the abutments (Figure 30-58).
16. The vacuum form is positioned for occlusion and incisal edge position with acrylic (Figure 30-59).
17. The acrylic sets and is modified in the laboratory (Figure 30-60).
18. The teeth are defined with a sandpaper disc (Figure 30-61).
19. A picture of the initially trimmed acrylic transitional restoration (Figure 30-62).
20. The occlusion is evaluated on the transitional restoration. The occlusion follows the implant-protective occlusion philosophy of the author (Figure 30-63).
21. A final impression is made of the abutments using light body polyether (Figure 30-64).
22. The stock tray with regular body polyether is seated over the abutments (Figure 30-65).
23. The final impression is evaluated (Figure 30-66).
24. An alginate impression is made of the abutments and poured in quick-set stone (Figure 30-67).

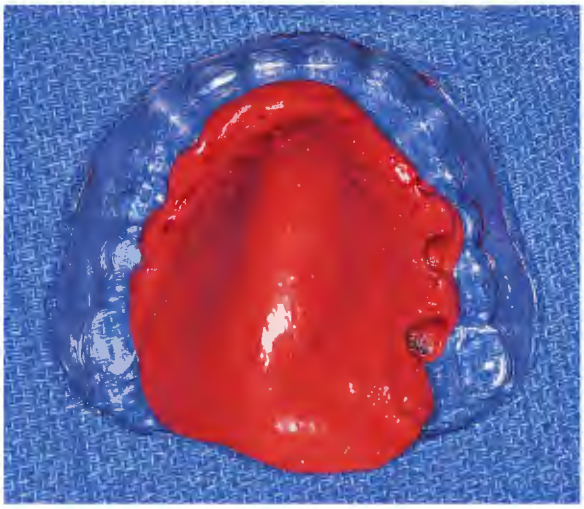


FIGURE 30-57.



FIGURE 30-56.



FIGURE 30-58.

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FIGURE 30-59.



FIGURE 30-60.

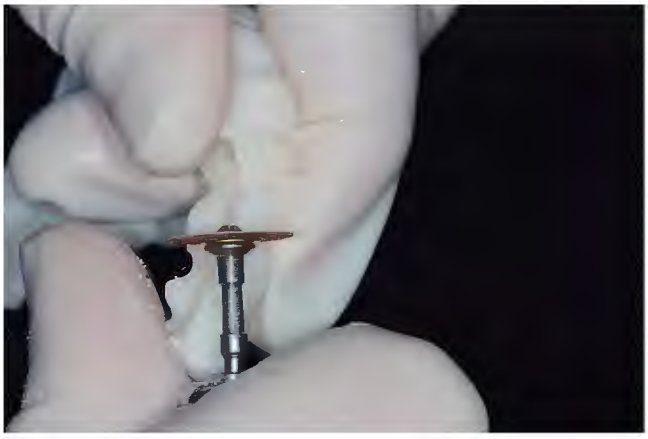


FIGURE 30-61.



FIGURE 30-62.



FIGURE 30-63.



FIGURE 30-64.

25. The stone model is used to make a light-cured baseplate (Figure 30-68).
26. The baseplate engages only the top of each abutment (Figure 30-69).
27. Sticky wax is applied to the baseplate (Figure 30-70).
28. A wax rim is added to the baseplate (Figure 30-71).
29. The baseplate and wax rim are placed in the mouth (Figure 30-72).
30. The wax rim is modified in relation to the labial lip support (Figure 30-73).
31. The incisal edge of the maxillary anterior teeth (using the canine positions) is determined with the wax rim (Figure 30-74).
32. The completed wax rim for the anterior teeth and OVD (Figure 30-75).
33. The midline of the restoration is determined using dental floss to evaluate the midline of the face (Figure 30-76).

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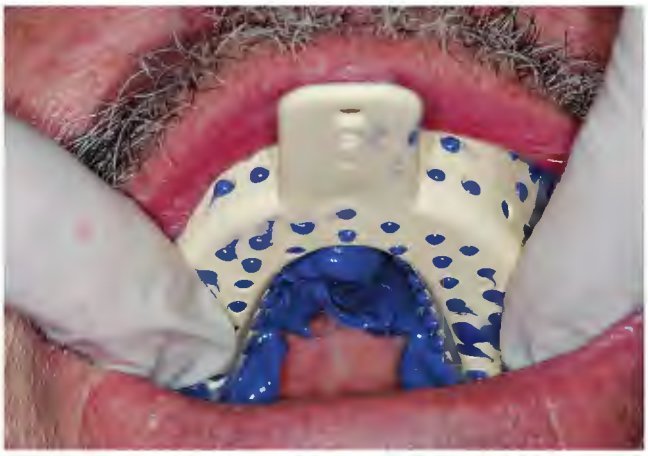


FIGURE 30-65.



FIGURE 30-66.

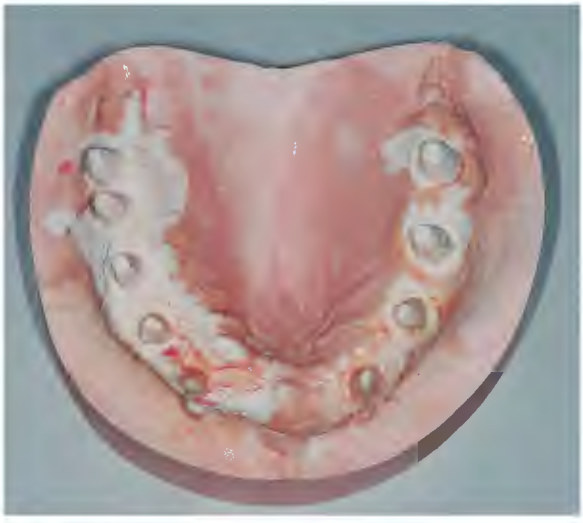


FIGURE 30-67.

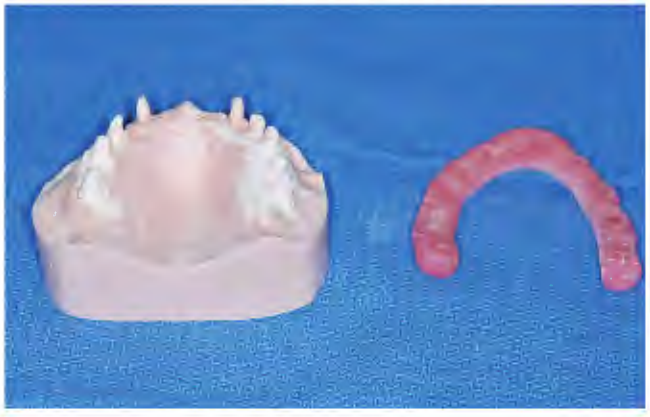


FIGURE 30-68.



FIGURE 30-69.



FIGURE 30-70.

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FIGURE 30-71.



FIGURE 30-74.



FIGURE 30-72.



FIGURE 30-75.



FIGURE 30-73.



FIGURE 30-76.

34. The high lip line during smiling is determined. The height of the lip translation corresponds to the height of the tooth, which determines the width of the tooth (Figure 30-77).
35. The alar width of the nose often corresponds to the mid-canine position (Figure 30-78).
36. Bite registration material is placed on the intaglio aspect of the baseplate after adhesive is painted over the abutment locations (Figure 30-79).
37. Bite registration material is placed over the wax rim (Figure 30-80).
38. The OVD and centric bite are recorded on the baseplate and wax rim (Figure 30-81).
39. A shade of the soft tissue drape is made along with the shade for the teeth. The shape of the teeth is also selected (Figure 30-82).

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FIGURE 30-77.



FIGURE 30-80.



FIGURE 30-78.



FIGURE 30-81.



FIGURE 30-79.

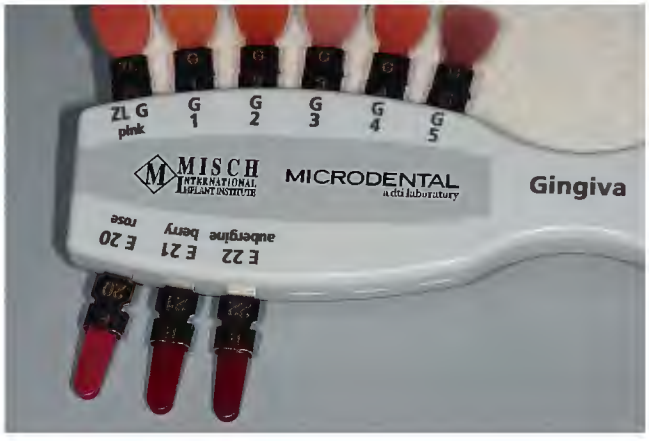


FIGURE 30-82.

40. After a face-bow registration of the maxillary arch is made, the transitional registration is cemented with non-eugenol temporary cement (Figure 30-83).

Laboratory Phase 1: Casting Fabrication (or Acrylic Temporary)

41. The final impression and the opposing dentition and bite registration are scanned and digitized in the laboratory (Figure 30-84).
42. The teeth are developed with the computer using the appropriate software (Figure 30-85).
43. The occlusion of the restoration is determined with the software (Figure 30-86).
44. CAD-CAM technology cuts an acrylic block to the descriptions of the computer (Figure 30-87).

Appointment 2: Metal Try-In (or Acrylic Try-In)

45. The patient returns for an acrylic teeth try-in appointment. The transitional restoration is removed (Figure 30-88).

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FIGURE 30-83.

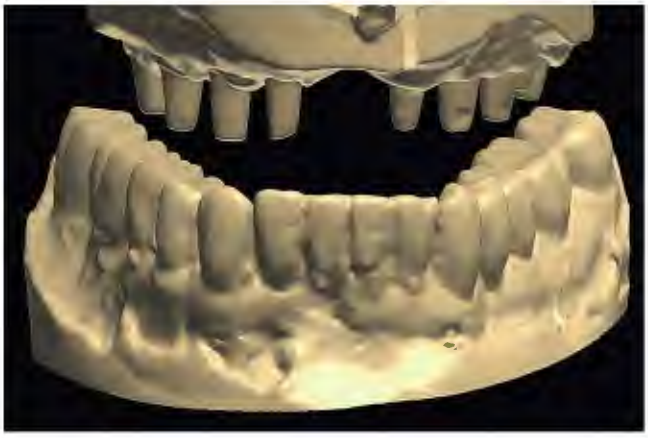


FIGURE 30-84.

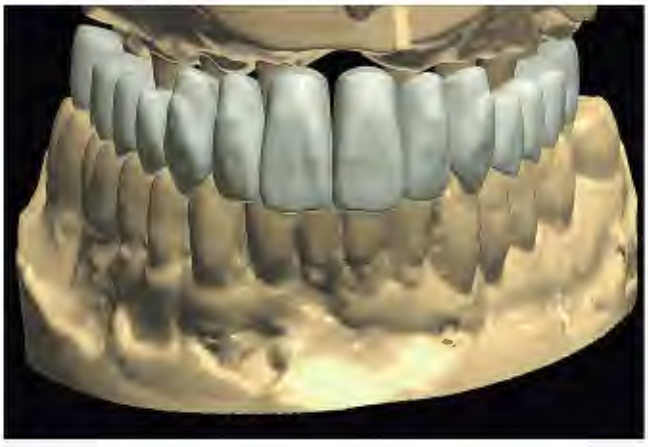


FIGURE 30-85.

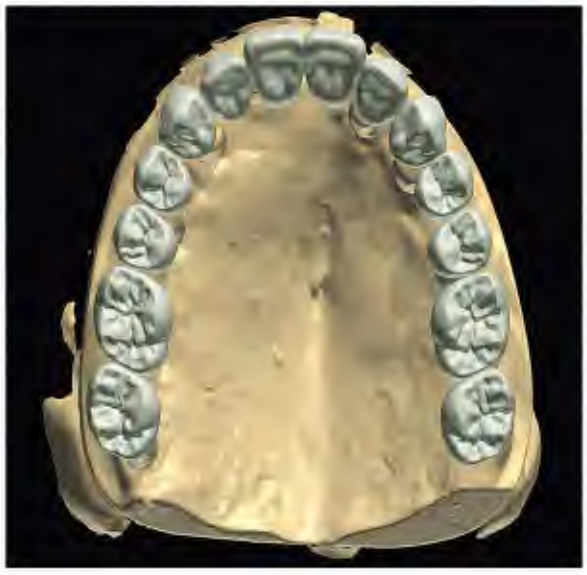


FIGURE 30-86.

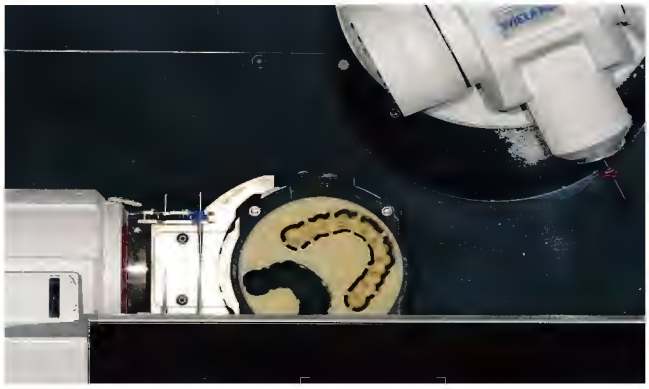


FIGURE 30-87.



FIGURE 30-88.

46. A try-in of acrylic that is made according to CAD-CAM technology is evaluated. Any modification is noted for the final restoration. A new bite registration is made when indicated. A metal try-in is made when a traditional porcelain–metal restoration is fabricated (Figure 30-89).

Laboratory Phase 2: Final Restoration

47. The final restoration is made with CAD-CAM technology (Figure 30-90).
48. The final restoration is made. This CAD-CAM zirconium prosthesis has porcelain on nonocclusing surfaces and zirconium on all functional aspects of the restoration (Figure 30-91).
49. The esthetic areas are modified by staining where necessary (Figure 30-92).
50. All functional areas are made of zirconium (Figure 30-93).

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FIGURE 30-89.



FIGURE 30-90.



FIGURE 30-91.



FIGURE 30-92.



FIGURE 30-93.



FIGURE 30-94.

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Appointment 3: Final Delivery

51. The transitional restoration is removed and the abutments cleaned (Figure 30-94).
52. The final CAD-CAM zirconium FP-3 prosthesis is cemented after the occlusion has been confirmed (Figure 30-95).
53. A high smile with the FP-3 in situ. The height of the papilla is noticeable because it was determined in relation to the tooth form (Figure 30-96).

Case 2: Indirect Method (Courtesy of Dr. Ray Hazen, Rochester, Indiana.)

Appointment 1: Implant Body Impression

Sequence of Treatment

1. The full-arch maxilla is shown with 10 implants and per-mucosal extensions (PMEs) (Figure 30-97).
2. The PMEs are removed (Figure 30-98).
3. The vacuum form over the denture is inserted into the mouth, and a bite registration is made (Figure 30-99).
4. A picture of the vacuum form and bite registration after the denture is removed (Figure 30-100).
5. Abutments are inserted into the implant bodies (Figure 30-101).
6. The abutments positioned in the mouth after insertion (Figure 30-102).
7. A radiograph confirms that the abutments are completely seated (Figure 30-103).
8. The template is inserted over the abutments (Figure 30-104).
9. An impression is made of the abutments using the vacuum form as a customized tray (Figure 30-105).
10. The impression is removed and evaluated (Figure 30-106).

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FIGURE 30-95.



FIGURE 30-96.



FIGURE 30-97.



FIGURE 30-98.



FIGURE 30-99.



FIGURE 30-100.

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FIGURE 30-101.



FIGURE 30-102.

FIGURE 30-103.





FIGURE 30-104.



FIGURE 30-105.

11. The custom impression tray transfers the approximate incisal edge position, OVD, and centric bite (Figure 30-107).

Laboratory Phase 1: Abutment Selection and Temporary Fabrication

12. Implant body analogs are added to the abutments (Figure 30-108).
13. The abutments and implant body analogs are reinserted into the impression (Figure 30-109).
14. The models are poured and mounted in the laboratory (Figure 30-110).
15. The abutments are modified in the laboratory (Figure 30-111.
16. A transitional restoration is fabricated in the laboratory (Figure 30-112).
17. The transitional restoration is made following the guidelines of the vacuum form (Figure 30-113).

Appointment 2: Final Impression, Reassess Occlusal Vertical Dimension, Delivery of Temporary Prosthesis

18. The modified abutments are inserted into the maxillary implants (Figure 30-114).
19. The abutment screw holes are obturated after the screws are tightened to 35 Ncm (Figure 30-115).
20. A final impression is made of the abutments (Figure 30-116).

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FIGURE 30-106.



FIGURE 30-107.



FIGURE 30-108.



FIGURE 30-109.



FIGURE 30-110.



FIGURE 30-111.

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FIGURE 30-112.



FIGURE 30-113.



FIGURE 30-114.



FIGURE 30-115.

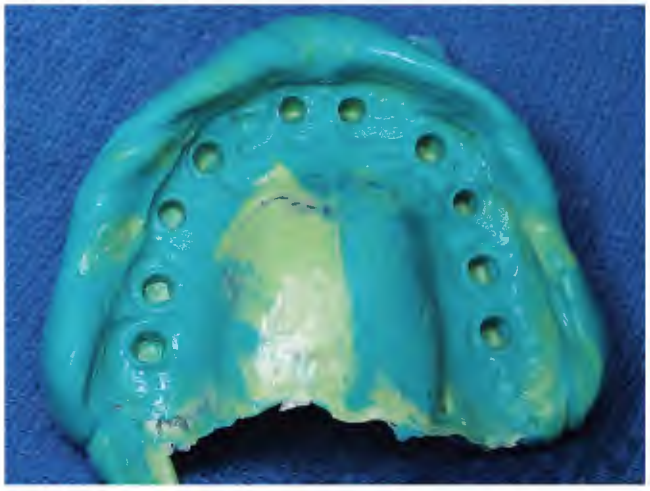


FIGURE 30-116.



FIGURE 30-117.

21. The transitional prostheses are cemented with a non-eugenol cement (Figure 30-117).

Laboratory Phase 2: Metal Framework Fabrication

22. The computer scans the impression and designs to the prosthesis (Figure 30-118).
23. The full contours of the restoration are computer generated (Figure 30-119).
24. The metal work is designed so no region will have more than 2 mm of porcelain thickness (Figure 30-120).
25. A picture of the computer-designed framework (Figure 30-121).
26. The casting is made, and anterior white wax and posterior bite blocks are added (Figure 30-122).
27. A picture of the casting and anterior white wax try-in (Figure 30-123).

Appointment 3: Metal Try-In

28. The castings are tried in the patient, and the OVD and incisal edge positions are evaluated (Figure 30-124).

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FIGURE 30-118.

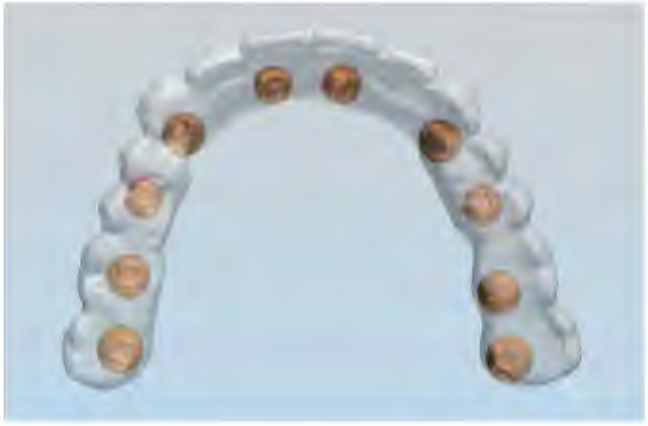


FIGURE 30-119.



FIGURE 30-120.



FIGURE 30-121.



FIGURE 30-122.



FIGURE 30-123.



FIGURE 30-124.

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Laboratory Phase 3: Final Restoration Fabrication

29. The final restoration is fabricated (Figure 30-125).
30. The final restoration is FP-3 (Figure 30-126).
31. A picture of the FP-3 prosthesis (Figure 30-127).
32. The width of the anterior teeth corresponds to the height of the tooth (Figure 30-128).
33. The maxillary prosthesis opposing FP-3 prostheses out of the mouth (Figure 30-129).

Appointment 4: Final Delivery

34. The transitional restoration is removed, and the abutments are cleaned (Figure 30-130).
35. The final restoration is delivered (Figure 30-131).
36. A final radiograph confirms seating of the restoration (Figure 30-132).



FIGURE 30-125.



FIGURE 30-126.



FIGURE 30-127.

Summary

Maxillary full-arch prostheses may be as predictable as mandibular restorations when biomechanical considerations specific to the maxilla are incorporated in the treatment plan. In general, this requires implants in greater numbers and a greater awareness of prosthetic principles.

The maxillary partial and complete edentulous arch is a common occurrence in dentistry. Implant restorations are usually the treatment of choice compared with traditional fixed or partial dentures or complete dentures. The treatment plan for an edentulous maxilla or partially edentulous premaxilla with



FIGURE 30-128.



FIGURE 30-129.



FIGURE 30-130.

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FIGURE 30-131.



FIGURE 30-132.

multiple adjacent teeth missing is often different than a mandibular restoration. As a consequence, the unique aspects of the arch include the use of grafting more often, more implants to replace the missing teeth, and a more specific implant size.

The sequence of treatment is specific for the restoration of the maxillary arch and begins with the anterior teeth position, both labial and incisal. This is followed by the OVD, usually by facial measurements. The lower anterior teeth are positioned with a 2- to 4-mm overbite and no anterior contact in centric occlusion. The posterior plane on the teeth is set in relation to Camper's plane. The horizontal dimension is positioned in relation to the mandibular central fossa on a line from the cuspid to the lingual of the retromolar pad. The active high lip line determines the height of the anterior teeth and is between 9 and 12 mm. The width of the tooth is related to the determined height of the tooth.

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CHAPTER **31**

Occlusal Considerations for Implant-Supported Prostheses: Implant-Protective Occlusion

Carl E. Misch

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The clinical success and longevity of endosteal dental implants as load-bearing abutments are controlled largely by the mechanical setting in which they function. The treatment plan is responsible for the design of the prosthesis along with the position and number of the implants. The most common complications of implant prostheses relate to biomechanical factors, such as porcelain fracture, unretained prostheses (cement or screw), abutment screw loosening, early implant failure after loading, and implant component fracture[1–4] (Figure 31-1). In addition, after achievement of rigid fixation with proper crestal bone contour and gingival health, the mechanical stress or strain beyond the physical limits of hard tissues is a primary cause of bone loss around loaded implants.[5–13] This bone loss may affect the quality of health of the implant when the probing depths are greater than 5 mm. Anaerobic bacteria are more likely to be present in these greater pocket depths and contribute to biological complications. In addition, an increased pocket depth is more prone to shrink and may result in a longer-looking crown or loss of interproximal papillae or may even expose the implant crest module (Figure 31-2).

After successful surgical and prosthetic rehabilitation with a passive prosthesis, noxious stresses and loads applied to the implant and surrounding tissues result primarily from occlusal contacts. Complications (prosthetic or bony support) reported in follow-up studies underline occlusion as a determining factor for success or failure.[13,14] Yet the choice of an occlusal scheme for implant-supported prostheses is broad and often controversial. The occlusal scheme is especially important during parafunctional activity of the jaws because the magnitude and duration of the parafunctional occlusal stresses are greater than functional stress. It is also more important when the implant foundation is not ideal in number or location to the implant–bone interface because the area of load is reduced.

Almost all implant occlusal concepts are based on those developed with natural teeth and are transposed to implant support systems with almost no modification. This approach has some justification. Complete denture wearers are reported to exhibit mandibular movement and velocity different from patients with natural dentitions. However, Jemt et al. found that after fixed implant reconstructions are placed into previous edentulous patients, the displacement of the jaw during mandibular opening and function is similar in velocity and movement to that in patients with natural teeth.[15] Gartner et al. also demonstrated similar habitual chewing for implant patients and patients with natural teeth.[16] During maximal occluding forces, electromyograms demonstrated that the implant patient group activated similar working and nonworking muscles as patients with natural dentition. Therefore, it appears logical to derive implant occlusion from occlusal principles for the natural dentition. However, several conditions indicate that implant prostheses are at greater biomechanical risk than natural teeth. As a result, some of the occlusal concepts for implants should be modified from concepts for the natural dentition.

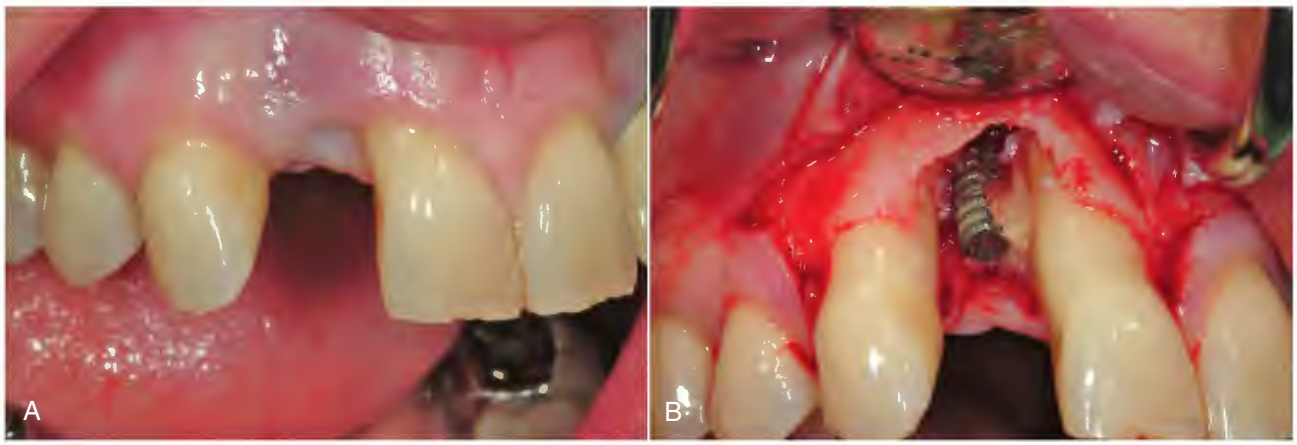


FIGURE 31-1. **A,** A missing lateral incisor with bone loss and the soft tissue drape compromised. **B,** An implant fracture after bone loss compromised the implant and adjacent tooth site.

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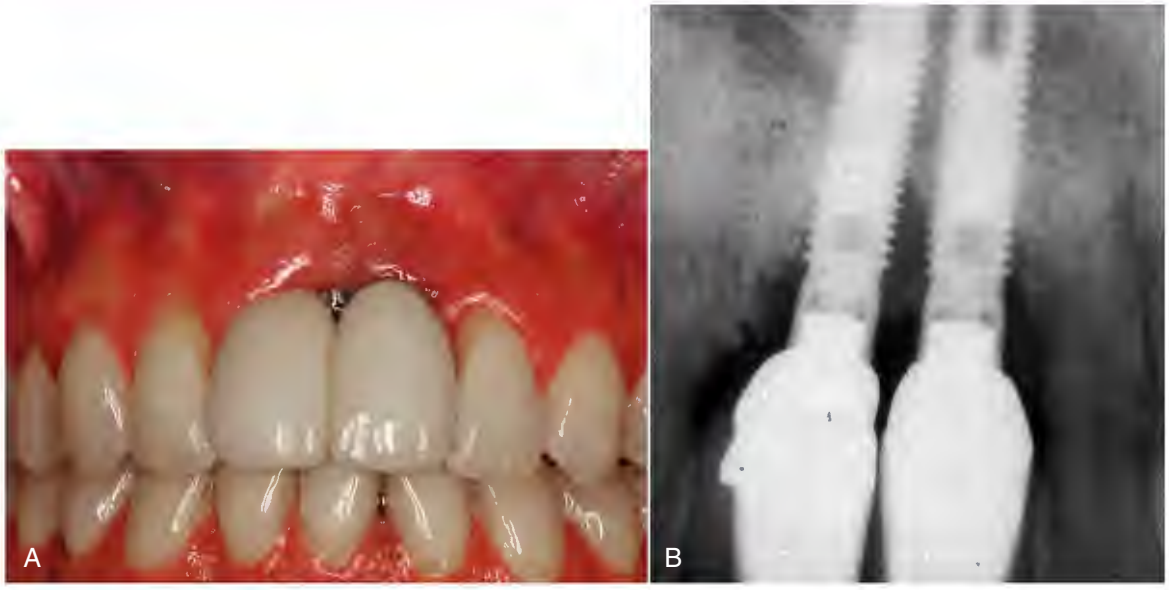


FIGURE 31-2. **A,** Two central incisor implant crowns with poor interproximal esthetics. **B,** The corresponding radiograph demonstrates crestal bone loss.

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BOX 31-1 Implant System Has Greater Biomechanical Stress

1. Prosthesis
2. Cement or screw retention system
3. Abutment screw
4. Marginal bone
5. Implant–bone interface
6. Implant components

Natural Tooth versus Implant Support Systems

Compared with an implant, the support system of a natural tooth is better designed to reduce the forces distributed to the tooth or restoration and the crestal bone region. The periodontal membrane, biomechanical design, elastic modulus of material, the nerve and blood vessel complex of the tooth, occlusal material, and surrounding type of bone blend to decrease the risk of occlusal overload to the tooth system. The implant system (prosthesis, cement or screw retention, abutment screw, marginal bone, implant–bone interface, and implant components) has higher stresses in comparison[17] (Box 31-1).

The presence of a periodontal membrane around natural teeth significantly reduces the amount of stress transmitted to the bone, especially at the crestal region.[18] The displacement of the periodontal membrane dissipates the energy to the fibrous tissue interface (periodontal ligament) surrounding natural teeth and acts as a viscoelastic shock absorber, serving to decrease the magnitude of stress to the bone at the crest and to extend the time during which the load is dissipated (thereby decreasing the impulse of the force).[19] The force transmission is so efficient and within ideal strain conditions for bone that a thin layer of cortical-like bone (cribriform plate) forms around the tooth. When the tooth is lost, the cortical plate lining disappears, demonstrating that this is not an anatomic structure but is a result of an ideal strain interface to the bone. Compared with a tooth, the direct bone interface with an implant is not as resilient. No cortical lining is present around the implant because the energy imparted by an occlusal force is not dissipated away from the crestal region but rather transmits a higher intensity force to this marginal contiguous bone interface (Figure 31-3).

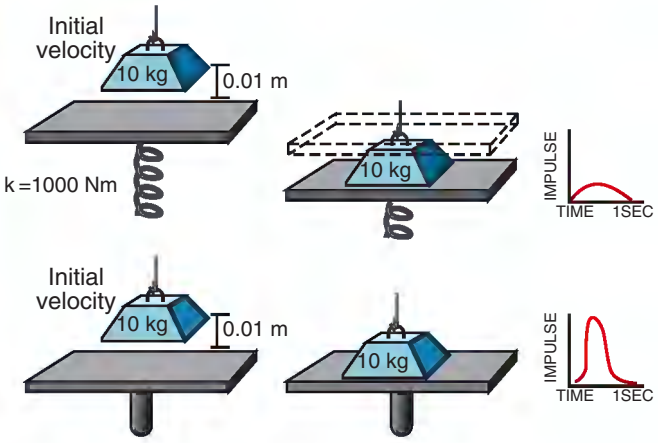


FIGURE 31-3. A weight dropped onto a platform supported by a spring results in the spring absorbing some of the stress and reduction of the impact force *(top)*. A similar weight dropped onto a rigid platform results in a greater impact force *(bottom)*.

An implant receives a greater impact force than a natural tooth because it is not surrounded by a periodontal complex. The fact that the implant is more rigid actually means that the implant system receives greater force and is more at biomechanical risk than a natural tooth. Remember that the implant system includes the occlusal porcelain on the crown (which may fracture), the prosthesis may fracture, the cement or screw that retains the prosthesis may debond or loosen, the abutment screw that contains the components may loosen, the crestal marginal bone may be lost from pathologic overload, the complete implant–bone interface may result in mobility and failure, intermediate to late periimplantitis may result in poor esthetic

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BOX 31-2 Consequences of Biomechanical Overload

1. Porcelain fracture
2. Prosthesis fracture
3. Uncemented or unretained restoration
4. Screw loosening (abutment)
5. Early crestal bone loss
6. Early implant failure
7. Intermediate to late implant bone loss
8. Periimplant disease (from bone loss)
9. Poor esthetic result (from tissue shrinkage after bone loss)
10. Intermediate to late implant failure
11. Component fracture

outcomes, and the implant components may result in fracture (Box 31-2).

An analogy of the difference in impact force between an implant and a tooth is hitting a nail with a steel hammer (a rigid structure) compared with a rubber hammer (a mobile structure). The more rigid hammer transmits a higher intensity force and drives the nail farther into the wood rather than having the energy partially dissipated through deflection of the rubber hammer.

The mobility of a natural tooth can increase with occlusal trauma. This movement dissipates stresses and strains otherwise imposed on the adjacent bone interface or the prosthetic components. After the occlusal trauma is eliminated, the tooth can return to its original condition with respect to the magnitude of movement. Mobility of an implant also can develop under occlusal trauma. However, after the offending element is eliminated, an implant does not return to its original rigid condition. Instead, its health is compromised, and failure of the entire implant system is usually imminent.

A lateral force on a natural tooth is dissipated rapidly away from the crest of bone toward the apex of the tooth. A healthy, natural tooth moves almost immediately 56 to 108 microns (primary tooth movement) and pivots two thirds down toward the tapered apex with a lateral load[19–20] (Figure 31-4). This action minimizes crestal loads to the bone. An implant does not exhibit a primary immediate movement with a lateral load. Instead (with a greater force), a more delayed secondary movement of 10 to 50 microns occurs, which is related to the viscoelastic bone movement.[21] In addition, this movement does not pivot (as a tooth) in the apical third of an implant but instead concentrates greater forces at the crest of surrounding bone. Therefore, if an initial lateral or angled load (e.g., premature contact) of equal magnitude and direction is placed on an implant crown and a natural tooth, the implant system (crown, cement or screw retention, abutment screw, marginal bone, implant–bone interface) sustains a higher proportion of the load.

The width of almost every natural tooth is greater than the width of the implant used to replace the tooth (Figure 31-5). The greater the width of a transosteal structure (tooth or implant), the lesser the magnitude of stress transmitted to the surrounding bone.[17] Molars have greater dimensions than premolars (greatest bite forces in molar region), and the maxillary molars have greater root surface area than the mandibular counterparts to compensate for the difference in surrounding bone

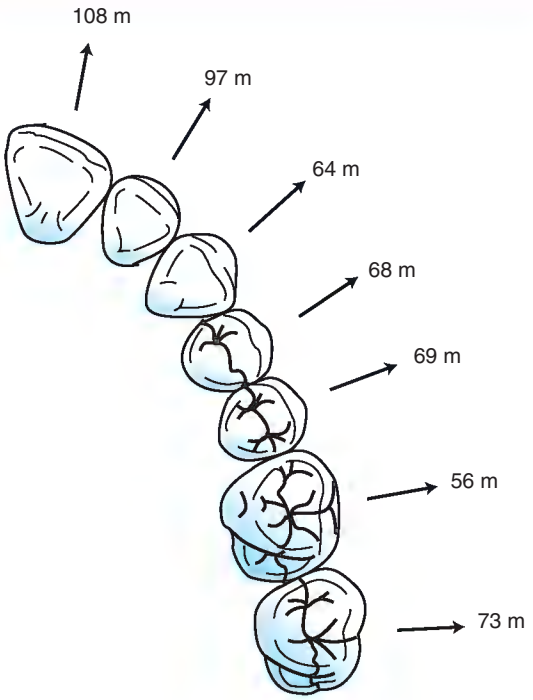


FIGURE 31-4. The natural teeth have horizontal movement that ranges from 56 to 108 microns. The horizontal movement of teeth varies, depending on their location. The anterior teeth move more than the posterior teeth. As a result, an anterior single implant surrounded by anterior teeth is more at risk of premature contacts after tooth movement than a posterior single-tooth implant. (Redrawn from Shillinburg HT, Holo S, Whitsett LD, et al: *Fundamentals of fixed prosthodontics,* ed 3, Chicago, 1997, Quintessence.)



FIGURE 31-5. The natural tooth width is almost always greater than the implant to replace it.

density and form. The size of the implant is often a polarized opposite of the natural teeth. The size of the implant often is decided by the existing bone volume rather than the amount and direction of force. Hence, the greatest-size (surface area) implants are often inserted into the anterior mandible followed by the anterior maxilla, the posterior mandible and the smallest-size implants are often inserted into the posterior maxilla.

The cross-sectional shape of the natural tooth at the crest is biomechanically optimized to resist lateral (buccolingual) loads because of the bending fracture resistance (moment of

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inertia) of the tooth and the direction of occlusal forces. Hence, mandibular anterior teeth are greater in size in the faciolingual directions (to resist protrusive forces), and canines have different cross-sections than other anterior teeth and sustain lateral loads in more directions. In contrast, implants are round in cross-section, which is less effective in resisting lateral bending loads; consequently, increases in stress concentration occur in the crestal region of the jaws.

The elastic modulus of a tooth is closer to bone than any of the currently available dental implant biomaterials. On the other hand, titanium is more than 10 to 20 times more stiff than cortical or trabecular bone. The greater the flexibility (modulus) difference between two materials (metal and bone or tooth and bone), the greater the potential relative motion generated between the two surfaces upon loading.[17] In addition, the greater the elastic modulus difference, the greater the stress concentrations where they first meet (the crest of the ridge). Hence, under similar mechanical loading conditions, implants generate greater stresses and strains (especially at the crest) to the bone compared with a natural tooth.

The precursor signs of a premature contact or occlusal trauma on natural teeth are usually reversible and include hyperemia and occlusal or cold sensitivity.[22] This condition often results in the patient's seeking professional treatment to reduce the sensitivity and usually is treated by occlusal adjustment and a reduction in force magnitude, which concomitantly decreases stress magnitude. This treatment most often reduces the hyperemia and the symptoms associated with this condition. If the patient does not have an occlusal adjustment, the tooth often increases in mobility to dissipate the occlusal forces. If an occlusal adjustment is performed, the tooth mobility will often decrease. Hence, the early warning signs and symptoms of excessive biomechanical load on natural teeth are often reversible and designed to protect the stomatognathic system. If the patient still fails to seek professional treatment for the increased mobility, the tooth may migrate orthodontically away from the cause of the occlusal stress.

The initial reversible signs and symptoms of trauma on natural teeth do not occur with endosteal implants. An absence of soft tissue interface between the implant body and bone results in the greatest portion of the force being concentrated around the transosteal implant–bone region.[17] The magnitude of stress may cause bone microfractures and place the surrounding bone in the pathologic loading zone, causing bone loss or leading to the mechanical failure of prosthetic or implant components (e.g., porcelain fracture, abutment screw loosening).[23] Unlike the reversible signs and symptoms exhibited by natural teeth, implant bone loss or unsecured restorations most often occur without any warning signs. Abutment screw loosening most often occurs within the first year of loading and is a symptom of biomechanical stress beyond the limits of the system. Marginal bone loss around the implant occurs without symptoms and is more likely during the first year. The loss of crestal bone around the implant is not reversible without surgical intervention and results in a decreased implant support and increased sulcus depth around the abutment. As a result, unless the density of bone increases after loading or the amount or duration of force decreases, the bone loss condition may progress until implant failure because the implants cannot move orthodontically away from the offending force.

The natural teeth and their periodontal ligament provide proprioception and early detection of occlusal loads and interferences. As a result, an occlusal premature contact greater than 20 microns may alter the path of mandibular closure to decrease the noxious elements of the premature, angled force.[24,25] In addition, the jaw of a dentate patient almost stops before the food is penetrated and the maximum chewing force is applied. This is why a piece of bone in meat may shear off a cusp tip because the jaws did not reduce their velocity before the contact with the piece of bone. Implant prostheses do not have as much occlusal awareness as teeth during function. As a result, the bite forces used in mastication and parafunction can be of greater magnitude, and the path of closure is not altered with a premature contact.

Several studies confirm that teeth have more occlusal awareness and less force applied compared with an implant system. For example, Trulsson and Gunne compared three patient groups holding a peanut between the teeth for 3 seconds and then biting through the peanut.[26] The natural teeth group had no problem holding the peanut or biting through it afterward. The denture group of patients experienced greater problems holding the peanut without its falling or becoming dislodged. The implant group had no problem holding the peanut in place. However, the implant and denture patients bit through the peanut with a force fourfold greater than the natural dentition group. The four times higher force in the implant patients is generated to the implant system, not the soft tissue of the denture group. Hence, the decrease in proprioawareness of implant patients can lead to a higher bite force during functional or parafunctional loading.

The proprioceptive information relayed by teeth and implants differs in quality awareness. Teeth deliver a rapid, sharp pain sensation under high pressure that triggers a protective mechanism. However, implants deliver a slow, dull pain that triggers a delayed reaction, if any.[27] Implant occlusal sensitivity is uncommon; if it occurs, it signifies more advanced complications.

Radiographic evidence of occlusal trauma on teeth includes an overall increase in the periodontal membrane space and an increased radiopacity and generalized thickness of the cribriform plate around the tooth (not just localized at the crest).[24,25] No generalized radiographic signs are apparent around an implant under excess occlusal force except at the crestal region, which demonstrates bone loss (but may be misdiagnosed as "biological width" or periimplant disease).[10]

The natural tooth can show clinical signs of increased stress such as enamel wear facets, stress lines, lines of Luder (in amalgam fillings), cervical abfraction, and pits on the cusps of teeth (Figure 31-6). An implant crown rarely shows clinical signs of increased biomechanical stress other than fatigue fracture. As a result, fewer diagnostic signs are present to warn the practitioner to reduce the stress on the implant support system.

Of all the opposing occlusal surfaces in the mouth, enamel opposing enamel has the most total volume wear (the sum total of both occluding surfaces).[28] The enamel on a tooth will wear when repeated lateral forces or premature contacts are introduced on the system and may reduce the magnitude and angle of force for the premature contact. In comparison, a porcelain occlusal implant crown does not wear as rapidly or as much when a lateral premature contact is present.

The tooth slowly erupts into occlusion and is present in the mouth from childhood. The surrounding bone has developed in response to the biomechanical loads. Note there is no organized cribriform plate around the deciduous or permanent tooth until it is loaded. The permanent teeth are gradually introduced a few at a time while other teeth are present and

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bear the load. Hence, periodontal tissues organize gradually to sustain increasing loads, including those brought to bear by an attached prosthesis. The only progressive bone loading around an implant is performed by the dentist in a much more rapid time frame and intense magnitude of load.

When implants or teeth are subjected to repeated occlusal loads, microscopic stress fractures, work hardening, and fatigue may result. Fatigue fractures are related to the amount of stress and the number of cycles of load.[17] The cementum and bone around a tooth root are able to repair the micro damage. Unlike the natural tooth system, the implant components, coping screws, or cement cannot adjust or repair to these conditions and ultimately fracture. The implant needs to perform its service for scores of years, which increases the cycles in the fatigue curve and the risk of long-term complications. As a result, forces from occlusion may result in subtle changes but may cause more serious long-term problems for survival as a result of bone or implant component complications compared with natural teeth.



FIGURE 31-6. A natural tooth with occlusal trauma may exhibit a number of clinical signs, including mobility, enamel wear, stress lines or pits, and cervical abfraction. This patient is missing a canine. As a result, the premolar and molar participate in group function. Both of these teeth have cervical abfraction as a result of increased stress.

The dentist uses mobility ratings to evaluate the quality of a natural abutment. A tooth with a Miller index mobility of 0 is considered "stronger" than a tooth with mobility of 2. Implants exhibit no clinical mobility compared with teeth. Phrases such as "solid as a rock" were used originally to describe their rigid fixation. As a result, the dentist may consider the implant a stronger abutment than a tooth, especially when the literature has implied that distal cantilevers off four anterior implants can be used to restore an entire arch.[29]

When considering stress factors, mobility is an advantage. The natural tooth, with its modulus of elasticity similar to bone, periodontal ligament, and unique cross-sections and dimensions, constitutes a near perfect optimization system to handle biomechanical stress. In fact, the stress is handled so well that bacteria-related disease is the weak link. An implant system handles stress poorly (capturing the stress at the crest of the ridge), with an elastic modulus more than 10 to 20 times that of surrounding bone, and is unable to increase mobility without failure, so that conditions related to biomechanical stress are the weakest link in the system. As a result, ways to decrease biomechanical stress are a constant concern to minimize the risk of implant system complications (Table 31-1).

An example of the higher biomechanical risk to the system is porcelain fracture on fixed prostheses. Whereas a crown on a natural tooth has a porcelain fracture risk of 3%, fixed

TABLE 31-1
Tooth versus Implant Biomechanics

Tooth	Implant
1. Periodontal membrane	1. Direct bone–implant
a. Shock absorber	a. Higher impact force
b. Longer force duration (decreased impulse of force)	b. Short force duration (increased force impulse)
c. Distribution of force around tooth	c. Force primarily to crest
d. Tooth mobility can be related to force	d. Implant is always rigid (mobility is failure)
e. Mobility dissipates lateral force	e. Lateral force increases strain to bone
f. Fremitus related to force	f. No fremitus
g. Radiographic changes related to force reversible	g. Radiographic changes at crest (bone loss); not reversible
2. Biomechanical design	2. Implant design
a. Cross-section related to direction and amount of stress	a. Round cross-section and designed for surgery
b. Elastic modulus similar to bone	b. Elastic modulus five to10 times that of cortical bone
c. Diameter related to force magnitude	c. Diameter related to existing bone
3. Sensory nerve complex in and around tooth	3. No sensory nerves
a. Occlusal trauma induces hyperemia and leads to cold sensitivity	a. Occlusal trauma induces hyperemia and leads to cold sensitivity
b. Proprioception (reduced maximum bite force)	b. Occlusal awareness of two to five times less
c. Less functional bite force (higher maximum bite force functional)	c. Functional bite force four times higher
4. Occlusal material: enamel	4. Occlusal material: porcelain (metal crown)
a. Enamel wear, stress lines, abfraction, and pits	a. No early signs of force
5. Surrounding bone is cortical	5. Surrounding bone is trabecular (may be fine)
a. Resistant to change	a. Conducive to change

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FIGURE 31-7. Porcelain fracture may occur more than two to three times more often on implant crowns compared with natural teeth.

prostheses supported by natural teeth have a 7% to 10% risk. On the other hand, in 2009, Kinsel and Lin found that porcelain fracture of implant crowns was as high as 34.9% of patients with bruxism compared with 17.2% of those without bruxism[30] (Figure 31-7). In other words, implant patients are at higher risk of complications than those with natural teeth even if they are not bruxers. When the individual crown data were evaluated, men (with higher bite forces) had 13.1% of their implant crowns fracture compared with 6.4% of crowns in women. Clearly, the biomechanical load to the implant system is a greater risk for complications than natural tooth restorations.

No controlled clinical studies have been published comparing the various theories of occlusion on teeth, let alone on implants. Implant survival rates (not quality of health) reported by different practitioners are often within similar ranges even though the restoring guidelines differ. The myriad of variables in a patient population make case series studies of different implant occlusal philosophies impossible to conduct. These statements are not meant to decrease the importance of occlusion and a quest for accurate and precise relationships but instead attempt to encourage the profession to further develop this understanding.

Rather than addressing occlusal concepts or issues that result in early implant loss, crestal bone loss, and other prosthetic complications, a risk factor analysis is of benefit. For example, smoking is a risk factor for health. Not all smokers develop health problems from smoking, but the profession considers smoking a risk factor. Likewise, uncontrolled diabetes is a risk factor for periodontal health. That certain patients with diabetes have no periodontal disease does not negate diabetes as a risk factor. In a similar fashion, risk factors for implants and their related prosthesis must include biomechanical stress: the greater the stress, the greater the risk of complications. Therefore, conditions that decrease biomechanical stress should be established for treatment plans and occlusal designs in implant dentistry. For example, implant prostheses with extended cantilevers have some success; however, an increased risk of biomechanical complications exists.[31]

Biomechanical parameters are excellent indicators of the increased risk because they are objective and can be measured. The dentist can determine which condition presents greater risk and by how much the risk is increased. Hence, the occlusal concepts developed in this chapter by the author stem from biomechanical risk factors.[32,33] In other words, if a clinical condition creates an increased biomechanical stress to the implant–prosthetic system, the dentist should implement mechanisms to decrease the stress.

Implant-Protective Occlusion

A proper occlusal scheme is a primary requisite for long-term implant prosthetic survival, especially when parafunction or a marginal foundation is present. A poor occlusal scheme increases the magnitude of loads and intensifies mechanical stresses (and strain) to the implant system. These factors increase the frequency of complications of the prosthesis and bone support. Crestal bone loss may lead to anaerobic sulcus depths and periimplant disease states. These conditions may also cause tissue shrinkage and loss of interdental papillae and poor esthetic conditions. All of these complications may be caused by biomechanical stress as a result of occlusal loads (functional or parafunctional).

The implant-protective occlusion (IPO) concept refers to an occlusal plan specifically designed for the restoration of endosteal implants, providing an environment for reduced biomechanical complications and improved clinical longevity of both the implant and prosthesis.[32,33] The biomechanical rationale for this concept was published by the author after long-term clinical evaluation and biomechanical studies (and was originally called *medial-positioned, lingualized occlusion*).[34] This concept was specifically designed for fixed prostheses in either partial or complete edentulous patients. Clinical considerations for this concept are drawn from basic prosthetic concepts, bone biomechanical principles, and finite element analyses to reduce noxious occlusal loads and establish a consistent occlusal philosophy.

A primary goal of an occlusal scheme is to maintain the occlusal load that has been transferred to the implant system within the physiologic and biomechanical limits of each patient. These limits are not identical for all patients or restorations. The forces generated by a patient are influenced by ranges of parafunction, masticatory dynamics, implant arch position and location, arch form, and crown height. The treatment plan philosophy for dental implants varies greatly and depends on these several parameters. The implant dentist can address these force factors best by selecting the proper position, number and implant size, increasing bone density when necessary by progressive bone loading, and selecting the appropriate occlusal scheme using stress-relieving design elements.

Implant and natural tooth position, number, size, and prosthesis design produce a myriad of possible combinations. However, consistent occlusal patterns may be established. The following guidelines are used to restore fixed implant–supported prostheses. A slightly different occlusal concept of the author is presented for complete dentures or removable prosthesis type 5 (RP-5) implant overdentures (implant and soft tissue support) and is called *medial-positioned, lingualized occlusion* (see Chapter 33).

The IPO principles for fixed prostheses address several conditions to decrease stress to the implant system, including existing occlusion, implant body angle to occlusal load, cusp angle of implant crowns, mutually protected articulation, cantilever or offset loads, crown height, crown contour, occlusal contact position, timing of occlusal contacts, and protection of the weakest component (Box 31-3).

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BOX 31-3 Implant-Protective Occlusion

- No premature occlusal contacts or interferences
- Mutually protected articulation
- Implant body angle to occlusal load
- Cusp angle of crowns (cuspal inclination)
- Cantilever or offset loads
- Crown height (vertical offset)
- Implant crown contour
- Occlusal contact positions
- Timing of occlusal contacts
- Protect the weakest component



FIGURE 31-8. The patient has mild bruxism (minimum tooth wear). The engram position of teeth wear indicates in the left excursion the mandibular first premolar occludes with the maxillary cuspid. The implant crowns for the posterior missing teeth should not have lateral forces. The cervical abfraction of the premolar and slight increase in mobility indicates that there is an increased biomechanical risk.

Occlusal Considerations for Fixed Implant Prostheses

Existing Occlusion

Maximal intercuspation (MI) is defined as the complete intercuspation of the opposing teeth independent of condylar position, sometimes described as the best fit of teeth regardless of the condylar position.[24] *Centric occlusion* (CO) is defined as the occlusion of opposing teeth when the mandible is in centric relation (CR).[25] This may or may not coincide with the tooth position of MI. Its relationship to CR (a neuromuscular position independent of tooth contact with the condyles in an anterior, superior position) is noteworthy to the restoring dentist. The potential need for occlusal adjustments to eliminate deflective tooth contacts as the mandible closes in CR and the evaluation of their potential noxious effects on the existing dentition and the planned restoration is important to evaluate.

Correction of the deflective contacts before treatment presents many advantages and may follow a variety of approaches depending on the severity of the incorrect tooth position: selective odontoplasty (a subtractive technique), restoration with a crown (with or without endodontic therapy), or extraction of the offending tooth. The existing occlusion is best evaluated with facebow-mounted diagnostic casts on an articulator mounted with an open-mouth bite registration in CR. (This process was addressed in Chapter 16.)

Controversy exists as to the necessity to have MI harmonious with CO (CR occlusion). A vast majority of patients around the world do not have such a relationship, yet they do not exhibit clinical pathology or accelerated tooth loss. Therefore, it is difficult to state that these two positions must be similar. However, it is important to evaluate the existing occlusion and the mandibular excursions to consciously decide whether the existing situation should be modified or be maintained. In other words, dentists should determine whether they are going to ignore or control the occlusion of the patient (Figure 31-8).

Many dentists begin to evaluate the occlusion of the patient when the final implant prosthesis is delivered to the patient. However, this time frame is often too late to properly restore the patient (Figure 31-9). The underlying question that helps determine the need for occlusal correction before restoration of the implant patient is the observation of negative symptoms related to the existing condition. This may include temporomandibular joint (TMJ) conditions, tooth sensitivity, mobility, wear, tooth fractures, cervical abfraction, or porcelain fracture.[24,25] The fewer and less significant the findings, the less likely an overall occlusal modification is required before restoration of the patient. However, to properly assess these conditions, the dentist must not ignore them before treatment.

As a general rule, the more teeth replaced or restored, the more likely the patient is restored to CO. For example, if a completely edentulous mandible is to be restored with an implant-supported fixed prosthesis, CO provides consistency and reproducibility between the articulator and the intraoral condition. The slight changes in occlusal vertical dimension (OVD) and its relationship to the position of anterior implant abutments to the direction of force may be studied and implemented on the articulator without the need to record a new occlusal vertical position on the patient. On the other hand, when one anterior tooth is being replaced, the existing MI position is often satisfactory to restore the patient even though a posterior interference and anterior slide into full interdigitation may be present (with little clinical variance from the ideal conditions). However, in a partially edentulous patient, the existing occlusion should be evaluated to determine if noxious conditions are present.

Premature Occlusal Contacts

A fundamental biomechanical formula is stress equals force divided by the area over which the force is applied (S = F/A).[17] Therefore, during either maximum intercuspation or CO, no occlusal contacts should be premature, especially on an implant-supported crown. Premature occlusal contacts often result in localized lateral loading of the opposing contacting crowns.[35] Because the surface area of a premature contact is small, the magnitude of stress in the bone increases proportionately (i.e., S = F/A). All of the occlusal force is applied to one region rather than being shared by several abutments and teeth. In addition because the premature contact is most often on an inclined plane, the horizontal component of the load increases the shear crestal stresses and the overall amount of stress to the entire implant system. The occlusal porcelain, the abutment screw, and the cement retaining the crown are all at increased risk because shear loads render more complications.

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FIGURE 31-9. **A,** A maxillary first molar is replaced with an implant. The lateral forces should be applied to the anterior teeth during mandibular excursions. **B,** The implant crown is seated, and the right mandibular excursion is evaluated. The premolars exhibit a slight working interference on the buccal cusps. The maxillary premolars have slight gingival recession and initial cervical abfraction regions below the cementoenamel junction. The excursive force is reduced when the posterior teeth do not interfere during excursions. Therefore, the buccal cusp inclines of the premolars should be reduced. If the incisal edge of the canine continues to wear in the future, the occlusal contacts will need to be modified further when the posterior teeth contact during excursions.

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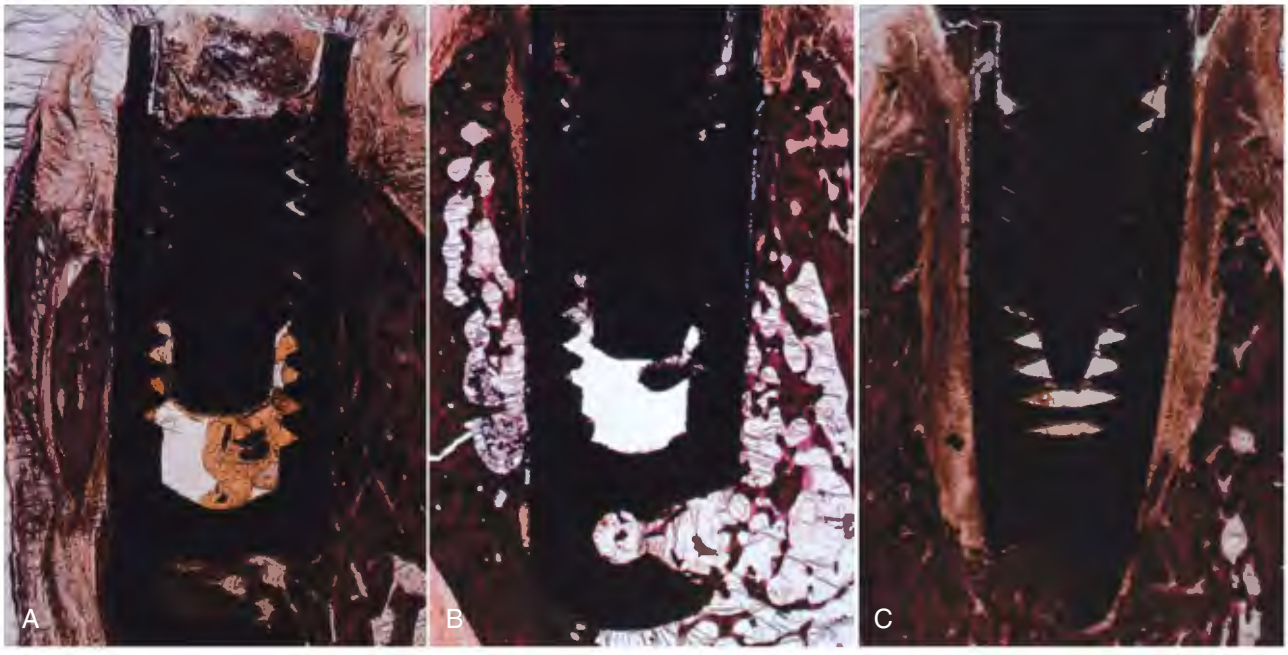


FIGURE 31-10. **A,** An implant crown with a 100-micron premature contact for 4 weeks displayed little crestal bone change. **B,** An implant crown with a 180-micron premature contact for 4 weeks had 2 to 3 mm of crestal bone loss. **C,** An implant crown with 250-micron premature contact for 4 weeks had marginal bone loss of more than two thirds of the implant length.

This is a general criterion for natural teeth, but the concept is much more important on implant prostheses with their higher impact force and less occlusal awareness for the several reasons previously addressed. Myata et al. evaluated premature contacts on implant crowns in monkeys (*Macaca fascicularis*).[11] The crestal bone was histologically evaluated on implant crowns with 100 microns, 180 microns, and 250 microns of premature contacts for 4 weeks.[12] The crowns with 100-micron premature contacts had little bone changes. The 180-micron group demonstrated a V-shaped pattern of bone loss for several millimeters. The 250-micron implant crowns for 4 weeks had a large V-shaped defect around the implants that extended for more than two thirds of the implant body (Figure 31-10). The implant is rigid, and the premature implant load cannot be released by increased mobility or occlusal material wear as with a natural tooth.

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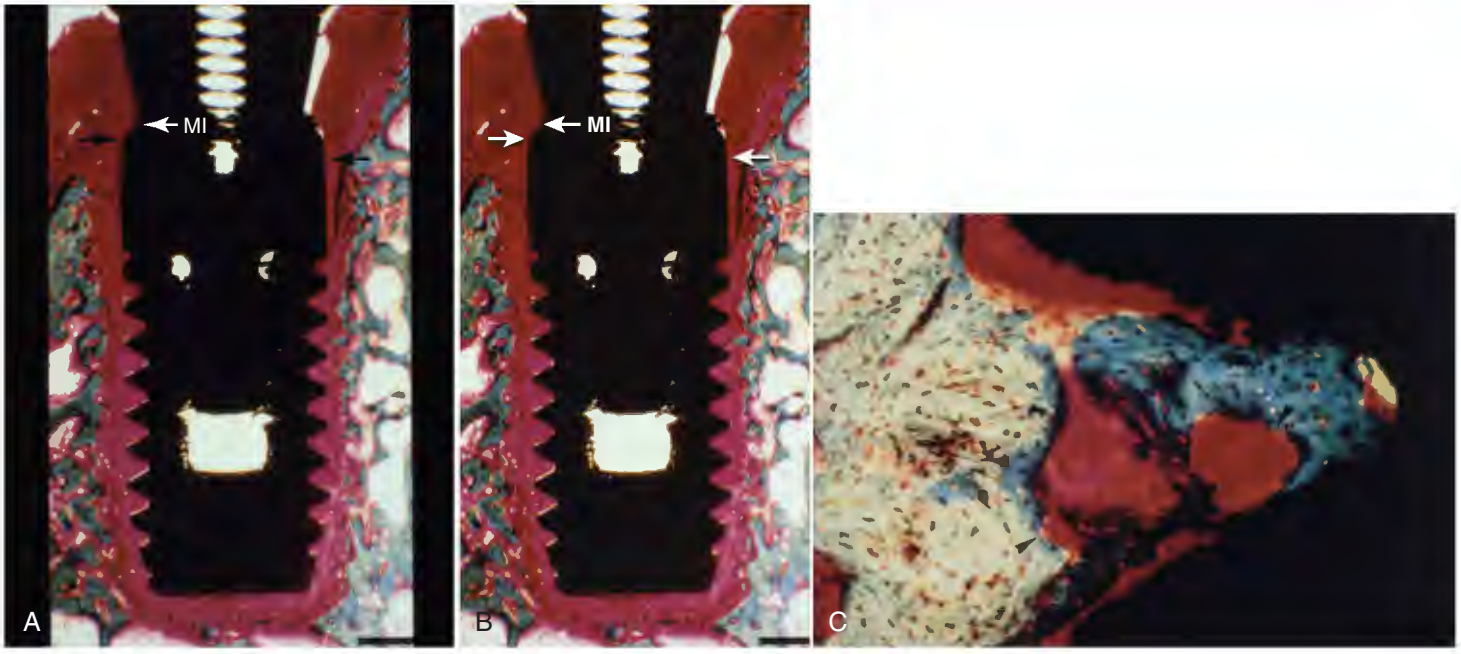


FIGURE 31-11. **A,** Three fourths of integrated implants with premature occlusal contacts failed from 2 to 14 months after loading. **B,** The implants that did not fail had crestal bone loss. **C,** The implants that did not fail had osteoclastic activity within the threads. (From Isidor R: Histological evaluation of peri-implant bone at implants subjected to occlusal overload or plaque accumulation, *Clin Oral Implants Res* 8:1–9, 1997.)

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Isidor et al. evaluated excessive premature contacts on implants in monkeys over a 20-month period on eight integrated implants.[13] Implant failure occurred in six of eight implants between 2 and 14 months. The implants that did not fail had greater bone density and crestal bone loss with osteoclastic activity within the threads of the implants (Figure 31-11). The premature contact on an implant system contributes to a higher risk of early abutment screw loosening, porcelain fracture, early loading failure, and crestal bone loss.

The elimination of premature occlusal contacts is especially important when habitual parafunction is present because the duration and magnitude of occlusal forces are increased. The elimination of premature contacts is more critical than in natural teeth because of the lack of proprioception and the implant inability to move and dissipate the forces. Because of increased proprioception, an initial premature occlusal contact on a tooth often affects the closure of the mandible to result in an MI position different from CO. A premature contact on an implant crown does not benefit from such protective features; as a result, the implant system is at increased risk. Therefore, occlusal evaluation in CO and MI and adjustment as necessary in partially edentulous implant patients are more critical than in natural dentition because the premature contacts can result in more damaging consequences on implants compared with teeth.[36]

Implant Body Orientation

Forces acting on teeth and dental implants are referred to as *vectors* (defined in magnitude and direction).[17] Occlusal forces are typically three dimensional, with components directed along one or more of the clinical coordinate axes. The primary forces of occlusion can be resolved into a combination of components in any given plane. The same magnitude of force can have dramatically different effects on the implant system, solely because of the direction of the applied load. This is especially noted on implant support systems because they are more rigid.

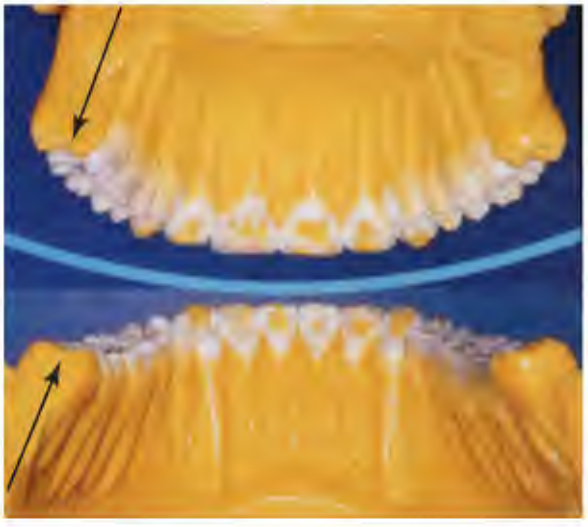


FIGURE 31-12. The natural teeth occlude perpendicular to the curves of Wilson and Spee.

The teeth are designed primarily for long-axis loads. The natural tooth roots in the majority of the mouth are perpendicular to the curves of Wilson and Spee. Although chewing is in an elliptical "tear drop" pattern, when the teeth finally contact, the forces are in the long axis of the roots, especially during power biting (Figure 31-12). The apical movement of teeth is minimal compared with their lateral movement. The maxillary anterior teeth receive a lateral load. The consequences of a lateral force to a tooth are reduced because of the increased tooth mobility, which decreases the effects of the lateral force component of a load.

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Implants are also designed for long-axis loads. Two-dimensional finite element analysis by Binderman in 1970 evaluated 50 endosteal implant designs and found that all designs sustained stress contours concentrated primarily at the transosteal (crestal) region.[37] In addition, less stress was observed under a long-axis load compared with angled loads. Since then, two- and three-dimensional finite element analyses by several authors have yielded similar results[38–51] (Figure 31-13).

An axial load over the long axis of an implant body generates less overall stress and a greater proportion of compressive stress compared with an angled force to the implant body. When an implant body is loaded along its long axis, a 100-N force results with an axial force component of 100 N, and no lateral force component is observed. Therefore, the implant body should be positioned perpendicular to the curves of Wilson and Spee, just as with natural teeth.

Most anatomical variations of the bone (e.g., bony concavities) are located on the facial aspect and influence implant body inclination. An implant body may be positioned with a 15-degree angle to avoid the facial concavity and therefore is positioned at 15 degrees to the occlusal load. This angled implant may be restored during prosthetic reconstruction with a 15-degree angle abutment. From the level of the crest of the ridge to the occlusal plane, the implant abutment looks similar to one in an axial implant body. Hence, the laboratory technician and restoring dentist often treat the angled implant and axial implant in similar fashion. However, in the 15-degree angled implant body, the load to the facial bone increases by 25.9% compared with an axial load[32] (Figure 31-14). If the implant surgeon places the implant body with a 30-degree angulation, the buccal force component of any occlusal load will result in a 50% increase of the load applied to the facial bone.[32]

Hence, the risk of crestal bone loss is increased with an angled implant.[52,53] In addition, the greater force is applied to most of the implant system. The occlusal porcelain may be loaded in the long axis with the angled abutment, but the abutment screw loosening and implant component fracture risks increase in direct comparison to the load applied to the bone. Therefore, although the restoring dentist may place a 30-degree angled abutment and restore the case similar to the axial implant, the conditions and risks of early loading failure, crestal bone loss, and loose abutment screws are dramatically different (Figure 31-15).

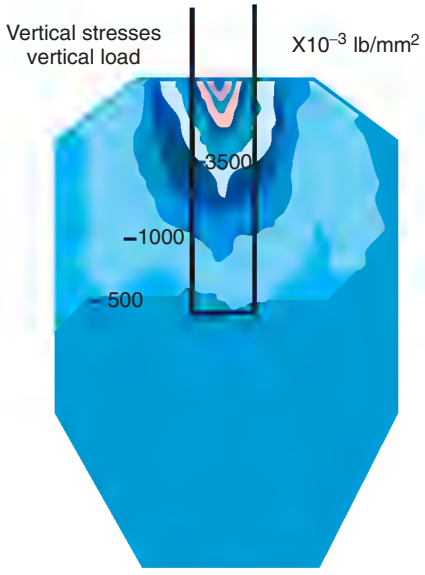


FIGURE 31-13. A three-dimensional finite element analysis of an implant with a long-axis load. The stresses are mainly at the crestal region and primarily have compressive forces.

Force Direction and Bone Mechanics

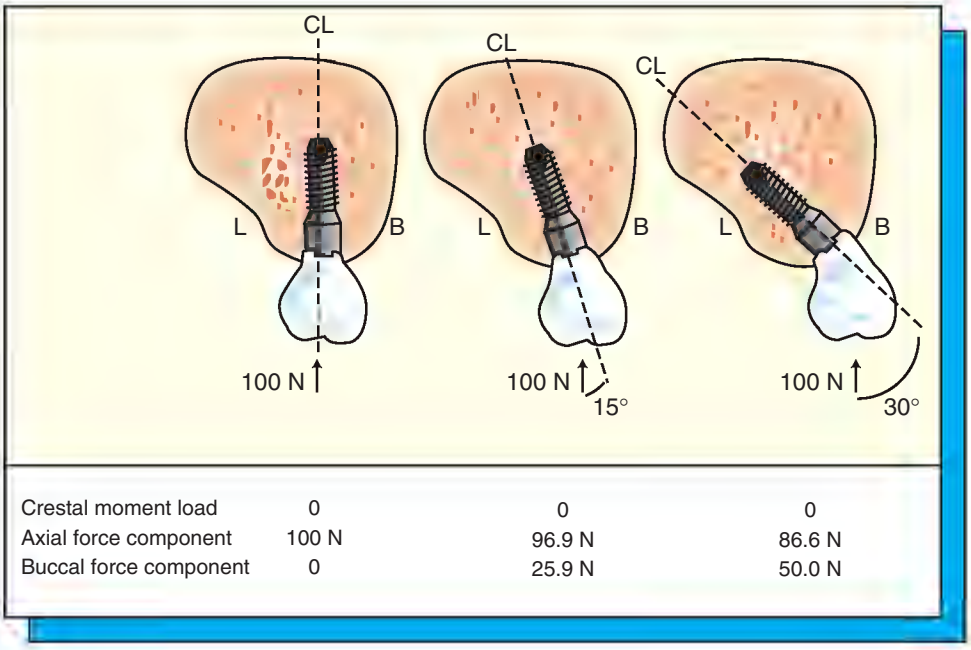
The noxious effect of offset or angled loads to bone is exacerbated further because of the anisotropy of bone. *Anisotropy* refers to the character of bone whereby its mechanical properties, including ultimate strength, depend on the direction in which the bone is loaded and the type of force applied. For example, cortical bone of human long bones has been reported as strongest in compression, 30% weaker in tension, and 65% weaker in shear[54] (Figure 31-16). Porcelain, titanium components, and cements are also weakest to shear components of a load. Therefore, IPO attempts to eliminate or reduce all shear loads to the implant system because the bone, porcelain, titanium components, and cement are weakest to shear loads.

Any occlusal load applied at an angle to the implant body may be separated into normal (compressive and tensile) and shear forces. As the angle of load to an implant body increases, the amount of compressive and tensile forces is modified by the cosine of the angle. Hence, the force is slightly reduced. However, the angled component of force is a shear force, and the shear force is the amount of force times the sign of the load, which considerably increases the load. The force the bone observes is the sum of the compressive, tensile, and shear forces. For example, a 100-N force applied at 12 degrees off-axis will increase the total force to the bone by 100 N × cosine 12 degrees = 97.81 N + 100 N × Sine 12 degrees = 20.79 N. The total force is 97.81 N + 20.79 N = 118.60 N (or almost a 20% increase in total force).The greater the angle of load to the implant long axis, the greater the compressive, tensile, and shear stresses (Figure 31-17).

In finite element analysis, when the direction of the force changes to a more angled or horizontal load, the magnitude of the stress is increased by three times or more.[51,52] In addition, rather than a primarily compressive type of force, tensile and shear components are increased more than 10-fold compared with the axial force. In a photoelastic block with implants inserted, the strain contours in the bone may be observed (Figure 31-18). The axial-loaded implants have less strain in the system (*left side* and *lower right* of figure). The angled implant has more strain lines indicating greater loads *(right upper implant)*.

An angled load to the implant long axis increases the compressive forces at the crest of the ridge on the opposite side of the implant, increasing the tension component of force along the same side as the load. The greater the angle of force to the long axis of the implant body, the greater the potentially damaging load at the crest of the bone. For example, three-dimensional finite element analysis demonstrates that a vertical load on an implant with 100% bone contact may have compressive stress of 4000 psi (27.6 MPa) and almost no tensile stress at the bone-to-implant crest interface.[51] With a load at a 45-degree angle on the same implant design, the compressive stress may increase to 14,000 psi (96.6 MPa), and on the opposite side, tensile stress may increase to 4000 psi (27.6 MPa). Hence, the compressive stresses are tripled, and the tensile stress increases 1000-fold with a load from a 45-degree angle.

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Crestal moment load	0	0	0
Axial force component	100 N	96.9 N	86.6 N
Buccal force component	0	25.9 N	50.0 N

FIGURE 31-14. An implant loaded in the long axis does not increase the buccal force component of the load *(far left)*. A 15-degree angle increases the buccal force component by 25.9% *(middle)*. A 30-degree angle load increases the force by 50%. When the forces are applied along the long axis of an implant body, stresses are concentrated on the crestal region *(far left)*. The intensity of the stress is not increased as a result of the position of the implant. The implant body in the center is 15 degrees off the long axis. With an angled abutment of 15 degrees, the implant restoration is similar to the previous situation. However, now 25.9% greater stress is on the crestal bone; all other factors are similar. The implant body on the *far right* is 30 degrees off the long-axis load. With a 30-degree angled abutment, the crown may appear similar. However, the abutment screw, abutment–implant connection, and implant–bone interface are subject to a 50% increase in stress on the facial aspect of the system. (From Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, 1999, Mosby.)

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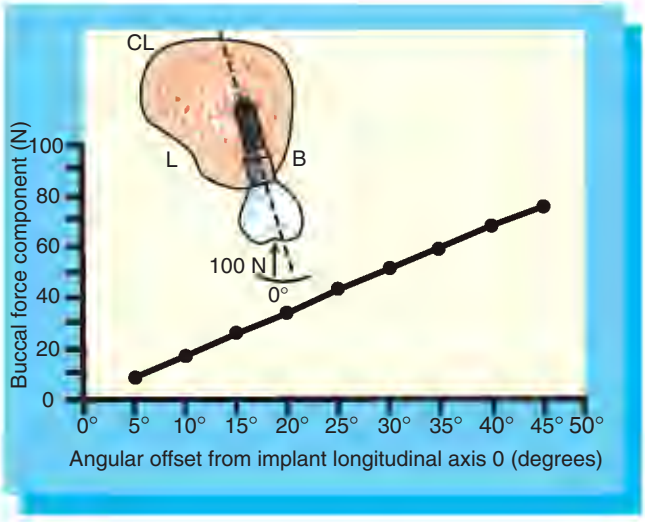


FIGURE 31-15. As the angle of the implant body load direction increases, the stresses to the entire crown implant–bone system increase. *B,* Buccal; *L,* lingual. (From Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, 1999, Mosby.)

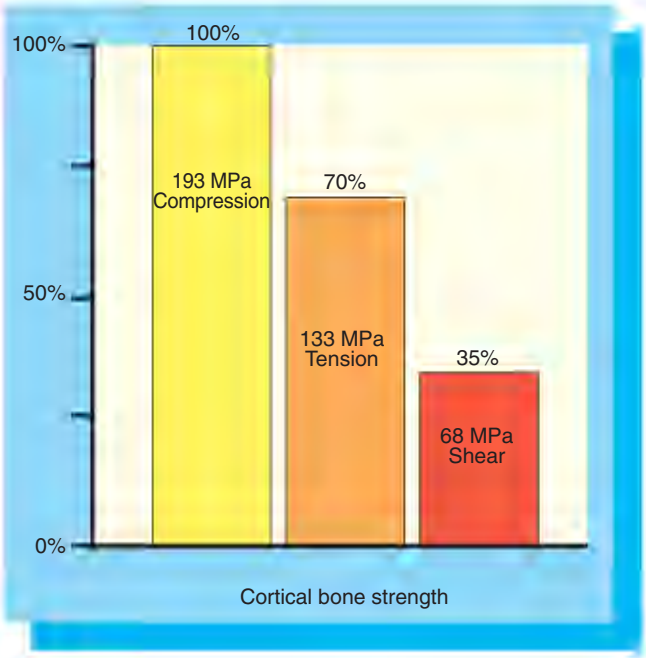


FIGURE 31-16. The strength of the bone before fracture depends on the type of force applied to the bone. Bone is strongest to compression forces, 30% weaker to tensile forces, and is only 35% as strong to shear loads. Therefore, whenever possible, bone should be loaded with compressive loads. (From Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, 1999, Mosby.)

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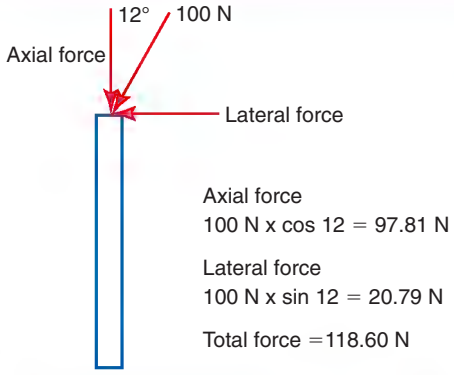


FIGURE 31-17. A 12-degree angled force increases the force to the implant system by 18.6%.



FIGURE 31-18. A photoelastic study of opposing implants in a maxilla and mandible. One of the maxillary implant bodies is angled in relation to the direction of load. The number of stress contour lines in the material is similar for the three implants with a long-axis load. The stress contour lines are increased for the angled implant body.

The stress contours in the bone simulant of the three-dimensional studies resemble the clinical pattern of early crestal bone loss on implants. Therefore, not only does the magnitude of stress increase under angled loads, but it also evolves into a more noxious shear component, which is more conducive to bone loss and screw loosening.[39] The greater the angle of the force, the greater the shear component. Bone is 65% weaker to shear load. Hence, the amount of the force increases, and the strength of the bone decreases. It has been reported that angled occlusal forces decrease the ability of successful bone repair on natural teeth. It may also impair successful bone remodeling around an implant.[55]

Not only is the bone weakest to shear loads, but forces applied at an angle to the bone also further affect the physiologic limit of compressive and tensile strengths of bone.[54,56] A force applied at a 30-degree angle may decrease the bone strength limits by 10% under compression and 25% with tension (Table 31-2). A 60-degree force reduces the strength 30% under compression and 55% under tension. Therefore, not only does the crestal bone load increase around the implant with angled forces, but also the amount of stress the bone may withstand (i.e., the ultimate strength) decreases in shear, tension, and compression. The greater the angle of load, the lower the ultimate strength of bone. Therefore, IPO attempts to eliminate lateral or angled loads to an implant-supported prosthesis because the magnitude of the force increases and the strength of the bone decreases.

TABLE 31-2
Cortical Bone Strength Related to Angle of Load

Type	Strength (mPa)	Direction of Load
Compression	193	Longitudinal
	173	30 degrees off axis
	133	60 degrees off axis
	133	Transverse
Tension	133	Longitudinal
	100	30 degrees off axis
	60.5	60 degrees off axis
	51	Transverse

From Reilly DT, Burstein AH: The elastic and ultimate properties of compact bone tissue, *J Biomech* 80:393–405, 1975.

Barbier and Schepers histologically evaluated implants loaded in the long axis versus off-axis loading in dogs.[57] The long-axis–loaded implants had lamellar bone at the interface. Lamellar bone is mineralized and organized and is called *load-bearing bone* in orthopedics. The off-axis–loaded implants had woven bone at the interface. Woven bone is bone of repair. It is less mineralized, unorganized, and weaker than lamellar bone (Figure 31-19). Hence, the greater strains in the bone with off-axis loading may cause the bone to repair and places it at a higher risk of overload and resorption.

In conclusion, the microstrain of the crestal bone is increased with an angled load and may shift from an axial load within physiologic limits to an angled load in the pathologic overload zone and, as a consequence, result in bone loss. The greater force, especially in shear, is generated to the entire implant system. The occlusal porcelain is weaker to shear and may fracture, the cement that retains the prosthesis is weakest to shear and may become unretained, the abutment screw more likely becomes loose with shear loads, the crestal bone region may resorb, and implant components fracture more often with higher shear loads. Therefore, when shear forces are increased with an angled load to the implant system, an attempt should be made to reduce the negative effect of angled loads.[58]

The primary component of the occlusal force therefore should be directed along the long axis of the implant body, not at an angle or following an angled abutment post (Figure 31-20). Angled abutments should be used only to improve the path of insertion of the prosthesis or improve the final esthetic result. The angled abutment, which is loaded along the abutment axis, transmits a significant moment load (i.e., tending to rotate or rock the implant) to the entire implant system.

Prosthetic Angled Loads

Greater crestal bone strains with angled forces have been confirmed with photoelastic and three-dimensional finite element

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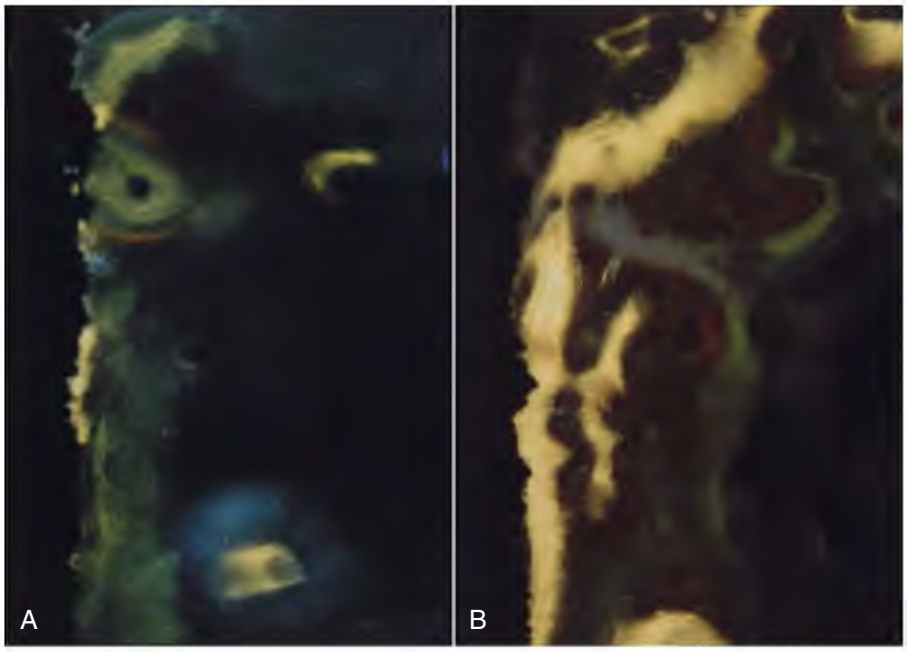


FIGURE 31-19. **A,** A long-axis load to an implant found lamellar bone at the interface. **B,** An off-axis load to an implant found woven bone (bone of repair) at the interface, indicating higher strain conditions than ideal. (From Barbier L, Schepers E: Adaptive bone remodeling around oral implants under axial and nonaxial loading conditions in the dog mandible, *Int J Oral Maxillofac Implants* 12(2):215–223, 1997.)

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FIGURE 31-20. An implant body ideally should be positioned perpendicular to the occlusal plane and along the primary occlusal contact. These maxillary posterior implants are placed over the opposing mandibular buccal cusps and are not vertical but perpendicular to the curves of Wilson and Spee.

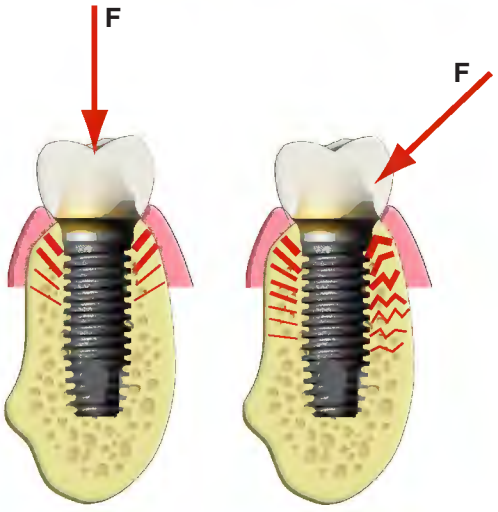


FIGURE 31-21. When an angled load is placed on an implant body, the compressive stresses on the opposite side of the implant increase and the tensile and shear loads on the same side of the implant increase. Because bone is weaker to tensile and shear forces, the risks to the bone are increased for two reasons: (1) the amount of the stress increases, and (2) the type of stress is changed to more tensile and shear conditions. *F,* Force.

analysis methods. Whether the occlusal load is applied to an angled implant body or an angled load (e.g., premature contact on an angled cusp) is applied to an implant body perpendicular to the occlusal plane, the results are similar (Figure 31-21). A biomechanical risk increases to the implant system.

The implant surgeon may place the implant body ideally, perpendicular to the occlusal plane, yet the restoring dentist then may load the implant crown at an angle. Similar noxious forces are increased in shear, and a decrease in bone strength occurs to the crestal bone, an increase of shear loads on implant components, and the abutment screws. Hence, an angled implant body or an angled load on the implant crown increases the amount of crestal stresses on the implant system, transforms a greater percentage of the force to shear force, and reduces bone, porcelain, and cement strength. In contrast, the surrounding implant system stress magnitude is least, and the strength of bone, porcelain, and cement is greatest under a load axial to the implant body and perpendicular to the occlusal plane. All of these factors mandate the reduction of angled forces to the implant system (Figure 31-22).

Most implant bodies inserted at an angle of greater than 12 degrees to the occlusal plane require an angled abutment. The surgeon and restoring dentist should understand that angled abutments are fabricated in two pieces and are weaker in design than a two-piece straight abutment without an angle. Because less metal flanks the abutment screw on one side of an angled abutment, it therefore is at more risk of fracture or is less able to be reduced in width for ideal crown contours. Furthermore, a larger transverse load component develops at the abutment

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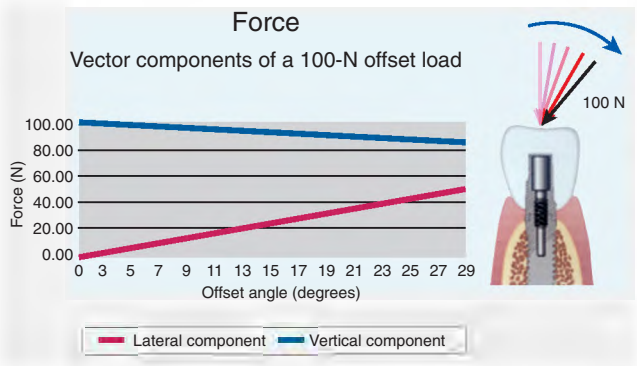


FIGURE 31-22. The force applied to an implant body with an angled load or angled direction of force is increased in direct relation to the force angle. The major increase of force is a result of the offset angle of the load.



FIGURE 31-23. Maxillary anterior implants most often are placed at an angled load to the lower anterior teeth. As a result, the amount of the load should be reduced. Fortunately, the anterior teeth bite force is reduced when the posterior teeth do not occlude. However, clenching patients may develop a considerable anterior bite force. Occlusal contact reduction, larger-diameter implants, increasing implant number, splinting implants, and night guards are possible solutions.

screw and crest of the ridge as a result of angled loads and increases the risk of abutment screw loosening. In a study by Ha et al., the angled abutment was compared with a straight abutment for screw loosening in the anterior maxilla. The angled abutments showed more screw loosening with cyclic loading than the straight abutments.[59]

Solutions to Angled Loads

When lateral or angled loads cannot be eliminated, a reduction in the force magnitude or additional surface area of implant support is indicated to reduce the risk of biomechanical complications to the implant system. For example, if three adjacent implants are inserted with the first in the long axis to the load, the second at 15 degrees, and the third implant at 30 degrees, the surgeon may decrease the overall risk by (1) adding an additional implant in the edentulous space next to the most angled implant, (2) increasing the diameter of the angled implants, or (3) selecting an implant design with greater surface area. Of the three options, increasing the implant number is most effective to reduce overall stress to the system.[60] In addition, a greater number of implants also has more retention for the restoration.

The restoring dentist may reduce the overload risk by (1) splinting the implants together, (2) reducing the occlusal load on the second implant and further reducing the load on the third implant, and (3) eliminating all lateral or horizontal loads from the most angled implant and completely eliminating them in all posterior regions.

The anterior mandible (with a force magnitude similar to the anterior maxilla) often has the implant body positioned perpendicular to the occlusal plane and restored with a straight abutment. In the anterior maxilla, even under ideal conditions, the implant should be angled away from the labial bone and results with the abutment toward the facial crown contour. An angled prosthetic abutment is required, and these implant bodies are more frequently loaded at an angle. In fact, maxillary anterior teeth are usually loaded at a 12- to 15-degree angle to the occlusal plane (Figure 31-23).

The natural dentition reduces the increased stress to the maxilla by increasing the size of the roots compared with mandibular incisors and increasing the mobility of the tooth. Therefore, in the maxilla, a larger-diameter implant or a greater number of implants are indicated to minimize the crestal bone stress on each abutment, especially in patients exhibiting severe bruxism. Ridge augmentation may be necessary before implant placement to improve implant position or facilitate the use of a wider-diameter implant. IPO aims at reducing the force of occlusal contacts, increasing the implant number, or increasing the implant diameter for implants subjected to angled loads.

Posterior Crown Cusp Angle

The angle of force to the implant body may be influenced by the cusp inclination of the implant crown in similar fashion as an angled load to an implant body. The posterior natural dentition often has steep cuspal inclines, and 30-degree cusp angles have been designed in denture teeth and natural tooth prosthetic crowns (Figure 31-24). The greater cusp angles are often considered more esthetic and may even incise food more easily and efficiently.[61] To negate the negative effect of an angle cusp contact, the opposing teeth need to occlude at the same time in two or more exact positions on the ipsilateral cusp angles of the crowns (Figure 31-25). This is not possible in a clinical setting.

The occlusal contact along only one of the angled cusps result in an angled load to the implant system even when it is not premature to other occlusal contacts (Figure 31-26). The magnitude of the force is minimized when the angled occlusal contact is not a premature contact but instead is a uniform load over several teeth or implants. However, the angled cusp load does increase the resultant tensile and shear stress with no observable benefit. Hence, no advantage is gained, but the biomechanical risk is increased (e.g., increased abutment screw loosening, porcelain fracture, and unretained restoration).

The occlusal contact over an implant crown therefore should be ideally on a flat surface perpendicular to the implant body. This occlusal contact position usually is accomplished by increasing the width of the central fossa to 2 to 3 mm in posterior implant crowns, which is positioned over the middle of the implant abutment. The opposing cusp is recontoured to

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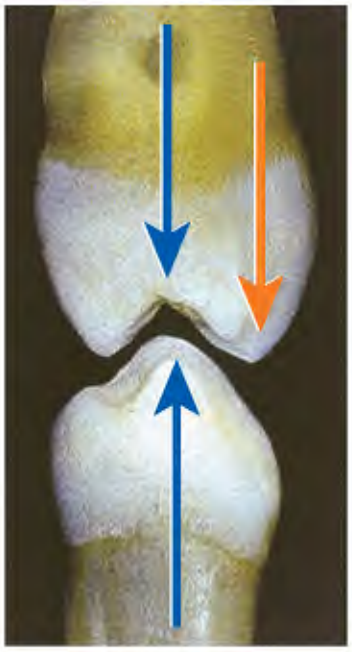


FIGURE 31-24. Natural teeth often have cusp angles of 30 degrees. Therefore, if a premature contact occurs on a cuspal incline, the direction of load may be 30 degrees to the implant body if the implant crown duplicates a natural tooth cusp angle.

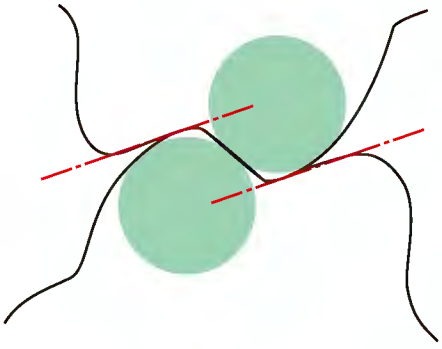


FIGURE 31-25. When opposing crowns occlude, the three cuspal inclines must hit at the same time to result in a long-axis load.

occlude the central fossa of the implant crown directly over the implant body (Figure 31-27). In other words, the laboratory technician should identify the middle of the implant body and then make a central fossa 2 to 3 mm wide over this position parallel to the curves of Wilson and Spee (Figure 31-28). The buccal and lingual contour of the crown may then be established (reduced on the buccal for the posterior mandible and the lingual for the posterior maxilla). The opposing tooth may require recontouring of an opposing cusp to help direct the occlusal force along the long axis of the implant body.

Mutually Protected Articulation

Anterior, compared with posterior, bite force measurements and electromyographic studies provide evidence that the stomatognathic system elicits significantly less force when the posterior segments are not in contact when the anterior teeth occlude.[62,63] For example, the maximum bite force in the posterior regions of the mouth (with no anterior occlusal contact) is 200 to 250 psi. The maximum bite force in the anterior region (with



FIGURE 31-26. The mandibular buccal cusp incline is occluding with the lingual incline of the maxillary cusp. An occlusal contact on a cusp angle transmits an angled load to the implant body.



FIGURE 31-27. A posterior implant crown should have a wider central fossa perpendicular to the implant body and parallel to the occlusal plane. The opposing tooth occluding cusp should be modified to occlude with the widened central fossa.

no posterior occlusal contact) is 25 to 50 psi. This difference results from a biological response and a mechanical condition when the posterior teeth do not contact. Almost two thirds of the temporalis and masseter muscles do not contract when posterior teeth do not occlude.[62] In addition, the TMJ and teeth complex form a class 3 lever condition (i.e., the nutcracker).[25] As a result, the closer the object is placed toward the hinge (TMJ), the greater the force on the object. In addition, the greater lateral mobility of the anterior teeth compared with the posterior teeth (108 microns vs. 56 microns) also decreases the consequences of the lateral forces during excursions.

Many occlusal schemes for natural teeth opposing each other suggest the use of anterior teeth to disocclude the posterior teeth during excursions (i.e., incisal guidance steeper than

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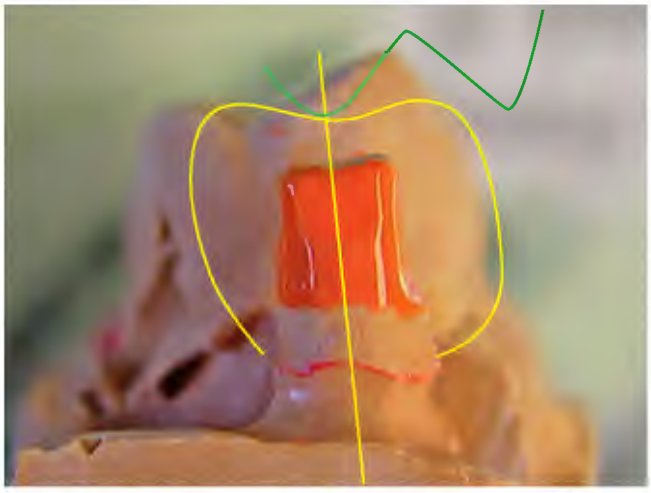


FIGURE 31-28. The laboratory technician usually will place the implant abutment under the central fossa of the implant crown.



FIGURE 31-29. In all mandibular excursions, the anterior teeth should disocclude the posterior teeth.

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the condylar disc assembly).[63–69] This has been called *mutually protected occlusion* because the posterior teeth protect the anterior teeth in CO, and the anterior teeth protect the posterior teeth in mandibular excursions. This occlusal design is based on the concept of using the maxillary canine as the key of this occlusion scheme to avoid lateral forces on the posterior teeth.[69] In CO, the anterior teeth contacts are shared and protected by the occlusal contacts of the posterior teeth. When the canine separates the posterior teeth in right or left lateral excursions, the term *canine* or *cuspid protected occlusion* may be used.

If healthy anterior teeth or natural canines are present, the mutually protected occlusion scheme allows those teeth to distribute horizontal (lateral) loads during excursions while the posterior teeth disocclude during excursions (e.g., canine guidance or mutually protected articulation) (Figure 31-29). The posterior teeth are protected from lateral forces by the anterior guidance during excursions, and the anterior teeth have lighter forces in excursions because the posterior teeth do not contact. In other words, when lateral or angled forces are applied to the anterior teeth, the magnitude of the stress is increased. However, when mutually protected occlusal philosophies are applied, the consequences of the lateral forces are reduced.

The mutually protected articulation concept is used in IPO. In protrusive mandibular movements, the central and lateral incisors disocclude the posterior teeth. In lateral excursions, the canine (and lateral incisor when possible) disocclude the posterior teeth. In CO, the posterior and canine teeth occlude. When the centrals and lateral incisors are natural, they may also occlude in CO (or MI). When the anterior teeth are implants, they may not occlude in centric, especially when the opposing dentition is also implant supported.

Group function (or unilateral balance) has been suggested with periodontal bone loss on the remaining teeth. The concept was to share the lateral loads during excursions with more teeth. For example, in this philosophy, a mandibular excursion to the right contacts as many anterior and posterior teeth on the right as possible. This is not indicated in IPO. The lateral posterior forces increase the moment loads to posterior implants. The posterior contacts during excursions also have greater forces to the posterior implants because more muscle mass contracts and the occlusal contacts are closer to the TMJ (class 3 lever). In addition, the posterior lateral loads increase the force to the anterior teeth or implants during the excursions. As a result, both the anterior and posterior implant components receive a greater force (Figure 31-30).

In a study by Jemt et al., when implant-supported restorations were used in the maxilla opposing natural dentition, the velocity of the mandible during excursions was greater with group function than when incisal guidance was present.[15] Hence, the force to the implant system was greater with group function. It is interesting to note that Kinsel and Lin reported that group function in patients with implant-supported prostheses had a porcelain fracture rate of 16.1% and occurred in 51.9% of implant patients.[30] When anterior disclusion was the occlusal scheme in excursions, the fracture rate on implant crowns was 5.3%, and this complication affected 15.9% of patients (more than a threefold difference).

The steeper the incisal guidance, the greater the force on the anterior teeth or implants. Therefore, the anterior guidance of an implant prosthesis with anterior implants should be as shallow as practical. According to Weinberg and Kruger, for every 10-degree change on the angle of disclusion, there is a 30% difference in load[70] (Figure 31-31). A 10-degree force on the anterior implants with a 68-psi load will increase to 100 psi when the incisal guidance is 20 degrees and will further increase to 132 psi if the incisal guidance is 30 degrees. As a consequence, the impression by these authors is the incisal guidance should be less than 20 degrees. However because the condylar disc assembly is usually 20 to 22 degrees, the incisal guidance should be greater than this amount to separate the posterior teeth.[25] When the incisal guidance is less than the angle of the eminentia of the TMJ, the posterior teeth will still contact in excursions. Hence, in most patients, an incisal guidance of at least 23 to 25 degrees is suggested in IPO.

The increase in load that occurs from the incisal guidance angle is further multiplied by the crown height above the initial occlusal contact (the vertical overbite) because it acts as a lever while the mandible slides down the incline plane (Figure 31-32). An ideal vertical overbite in prosthetics has been reported to be 5 mm and often is more, especially in Angle's class II, division II patients. However, especially in parafunctional patients, incisal guidance should be as shallow as possible in implant prostheses (23–25 degrees) and the vertical overbite reduced to less than 4 mm, yet the posterior teeth should disocclude in the excursions (Figures 31-33 and 31-34).

A clinical condition that sometimes causes confusion is the occlusal scheme for a single-tooth implant replacing a maxillary

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FIGURE 31-30. **A,** This patient was restored in group function. **B,** The posterior maxillary right two implants fractured. **C,** The posterior mandibular right two implants fractured. **D,** The maxillary anterior implants lost integration.

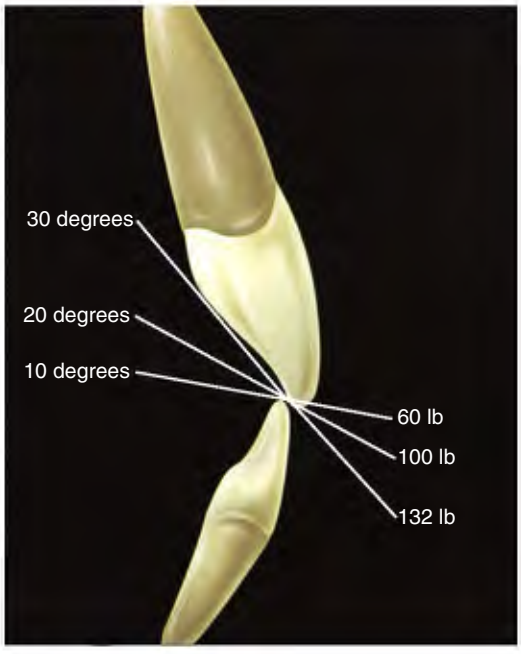


FIGURE 31-31. For every 10-degree change on the angle of disclusion, there is a 30% difference in load. (From Weinberg LA, Kruger G: A comparison of implant/prosthesis loading for clinical variables, *Int J Prosthodont* 8:421–433, 1995.)

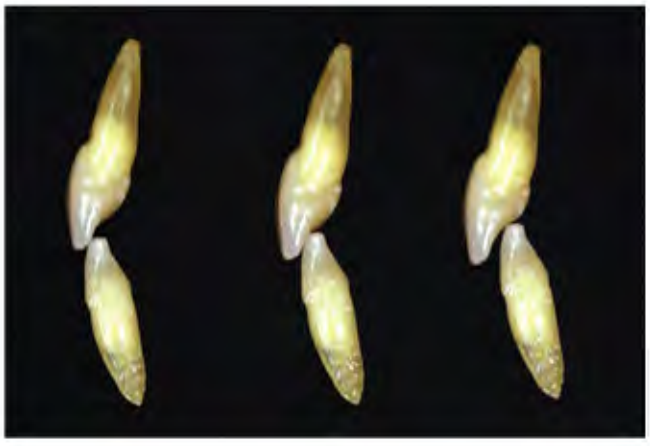


FIGURE 31-32. The anterior load during excursions is increased from the centric occlusal contact *(far right)* to the incisal edge *(far left)*.

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canine. A missing maxillary canine is indicated for a single-tooth implant crown. The lateral incisor is the weakest anterior tooth, and the first premolar is often the weakest posterior tooth. Hence, these abutments are not great candidates for a three-unit prosthesis, especially because lateral forces would be placed on the premolar.

The proprioceptive mechanism of the natural canine in excursions blocks approximately two thirds of the activity of the masseter and temporalis muscles and decreases the bite force when posterior teeth disocclude.[62] An anesthetized canine has more muscle mass that contracts in both clenching and in the lateral excursion compared with the same patient before anesthesia.[71] Hence, the natural canine periodontal ligament nerve complex helps decrease the force in excursions.

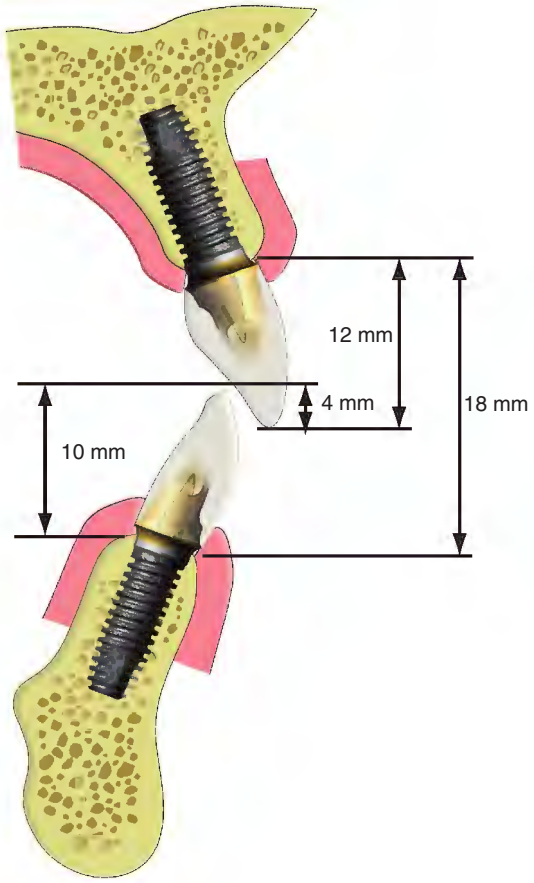


FIGURE 31-33. The vertical overbite in implant prosthesis should be reduced to 4 mm or less. When implants oppose each other, there is no occlusal contact between the canines in centric occlusion.

The anesthetized natural canine has been compared with the proprioawareness of an implant.[72] There is a proprioawareness transmitted through the bone from an implant but a reduced amount compared with a natural tooth. A mutually protected occlusion is still a benefit when a single-tooth canine implant is restored. In other words, a greater decrease in lateral forces occurs when a natural anterior tooth root is involved in the excursion compared with an implant crown, but an implant crown also can decrease the force and is better than a pontic in the canine position. In addition, the class 3 lever mechanism of the canine position still is able to reduce the force in excursions when the posterior teeth do not contact.

No occlusal contact occurs on the single-tooth canine implant crown during mandibular excursions to the opposite side. During protrusion, no contact on the canine implant crown is ideal. If a contact is necessary, it is adjusted so a light bite force has no occlusal contact on the implant crown. Under a heavy bite force in protrusive movements, the canine implant crown may contact.

The occlusion during the working excursion toward the canine implant crown is of particular concern. The dentist should make an attempt to include a natural tooth in the lateral excursion because teeth have greater proprioception than implants. To create a mutually protected articulation scheme that includes a lateral incisor is preferable because this tooth is farther from the TMJ. Hence, with a light working lateral excursion, the lateral incisor occludes first and moves 97 microns (when in health), and then the canine implant crown engages and helps disocclude the posterior teeth. During a heavy bite force excursion, the lateral incisor and implant crown contact with similar magnitude (Figure 31-35). However, in Angle's skeletal class II, division 1 patients, the first premolar may need to be included in the excursion process, rather than the lateral incisor, because the horizontal overjet may be excessive.

In summary, all lateral excursions in IPO opposing fixed prostheses or natural teeth use anterior teeth or implants whenever possible to disocclude the posterior components. The

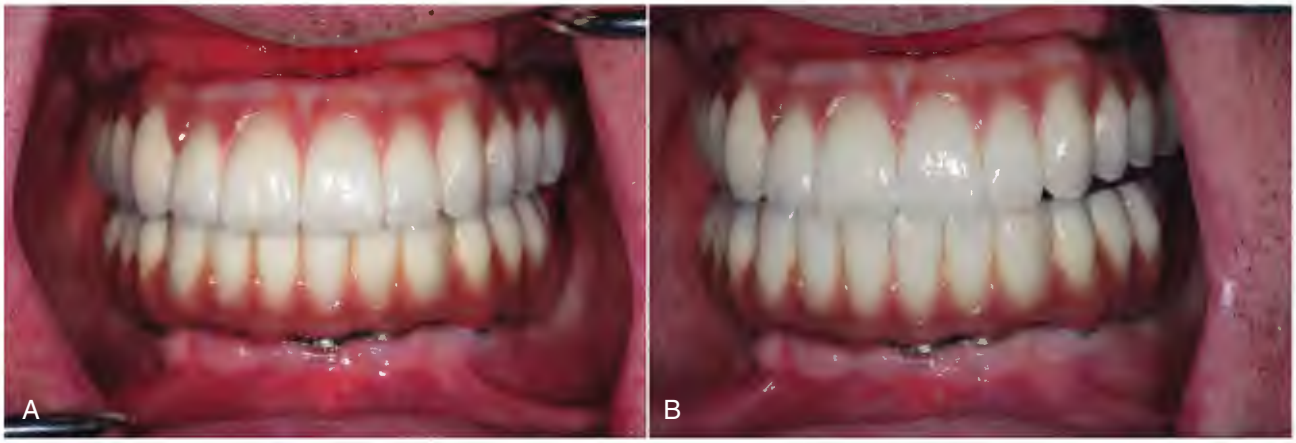


FIGURE 31-34. **A,** A full-arch maxillary and mandibular implant prosthesis with a vertical overbite of 3 mm. **B,** The incisal guidance is 25 degrees, so the posterior teeth separate in any mandibular excursion.

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FIGURE 31-35. **A,** A maxillary right canine is replaced with an implant. This patient is an Angle's class II, division 2 patient and therefore has a deep vertical overbite. A steep incisal guidance places greater force than a shallow incisal guidance, which may be why the canine tooth fractured after endodontic therapy. **B,** The right mandibular excursion is evaluated first with a light and then a heavy bite force. Ideally, the lateral incisor should contact first and then the canine. Therefore, the first premolar contact should be eliminated to decrease the force to the implant.

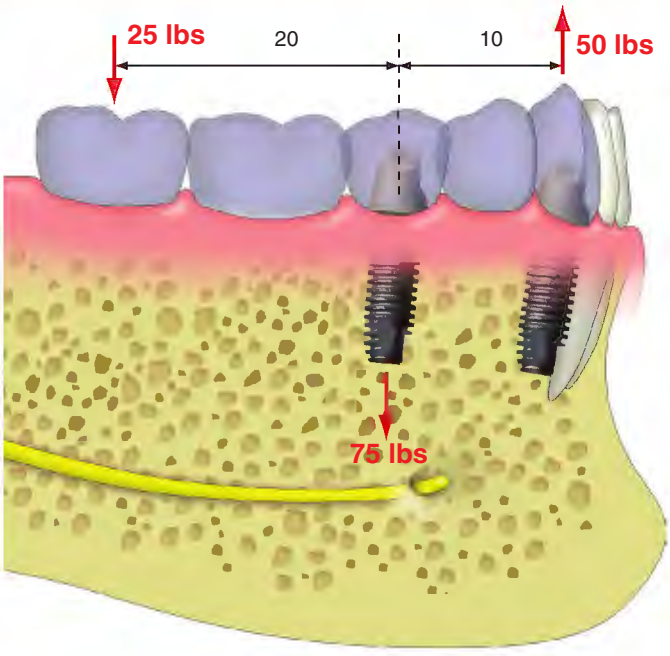


FIGURE 31-36. A cantilever on two implants may be considered a class 1 lever. When the implants are 10 mm apart, with a 20-mm cantilever, a mechanical advantage of 2 is created. Therefore, the load on the cantilever will be multiplied by 2 on the far implant, and the implant close to the cantilever receives the total stress of the two loads.

resulting lateral forces are distributed to the anterior segments of the jaws, with an overall decrease in force magnitude. This occlusal scheme should be followed whether or not anterior implants are in the arch. However, if anterior implants must disocclude posterior teeth, natural teeth (whenever possible) are first used during the initial primary tooth movement. When multiple anterior teeth are missing, two or more implants splinted together (when possible) should help dissipate the lateral forces.

Cantilevers and Implant-Protective Occlusion

A cantilever may be considered a class 1 lever.[17] For example, if two implants are 10 mm apart and are splinted with a cantilever of 20 mm, the following mechanics result: the mechanical advantage of the cantilever is 20 mm/10 mm, or 2. Therefore, whatever force is applied to the cantilever, a force twice as great will be applied to the farthest abutment from the cantilever. Whereas the force on the cantilever is a compressive force, the force to the distal abutment is a tensile and shear force. The load on the abutment closest to the cantilever (which acts as a fulcrum) is the sum of the other two components and is a compressive force (Figure 31-36). Hence, in this example, a 100-N force on the cantilever equals a 200-N tensile or shear force on the most distal abutment and a 300-N compressive force on the abutment (the fulcrum) next to the lever.

Because cement and screws are weaker to tensile loads, the implant abutment farthest from the cantilever often becomes unretained, resulting in the fulcrum abutment's bearing the entire load. Because the implant is more rigid than a tooth, it acts as a fulcrum with higher force transfer. It is a higher risk to cantilever from an implant than a tooth (Figure 31-37). As a consequence, crestal bone loss, fracture, and implant failure are often imminent after the distal abutment becomes no longer connected to the prosthesis. In summary, cantilevers increase the amount of stress to the implant system.

The greater the force on the cantilever, the even greater the forces on the implants because the cantilever is a force magnifier. Hence, parafunctional loads are particularly dangerous for biomechanical overload. The greater the length of the cantilever, the greater the mechanical advantage and the greater the loads on the implants. The shorter the distance between the implants, the greater the mechanical advantage and the greater the force on the implant system (Figure 31-38). The cantilever force also varies as a result of implant number.[73,74] Cantilevers are known to cause more biomechanical occurrences of implant and prosthesis component failure, particularly failure of prosthesis retaining screws or uncemented prostheses. A clinical report by Lundquist et al. also correlated long cantilevers with increased crestal bone loss around implants.[75]

The goal of IPO relative to cantilevers is to reduce the force on the pontics of the lever region compared with that over and between the implant abutments. To reduce the amount of force that is magnified by the cantilever, the occlusal contact force may be reduced on the cantilevered portion of the prosthesis.

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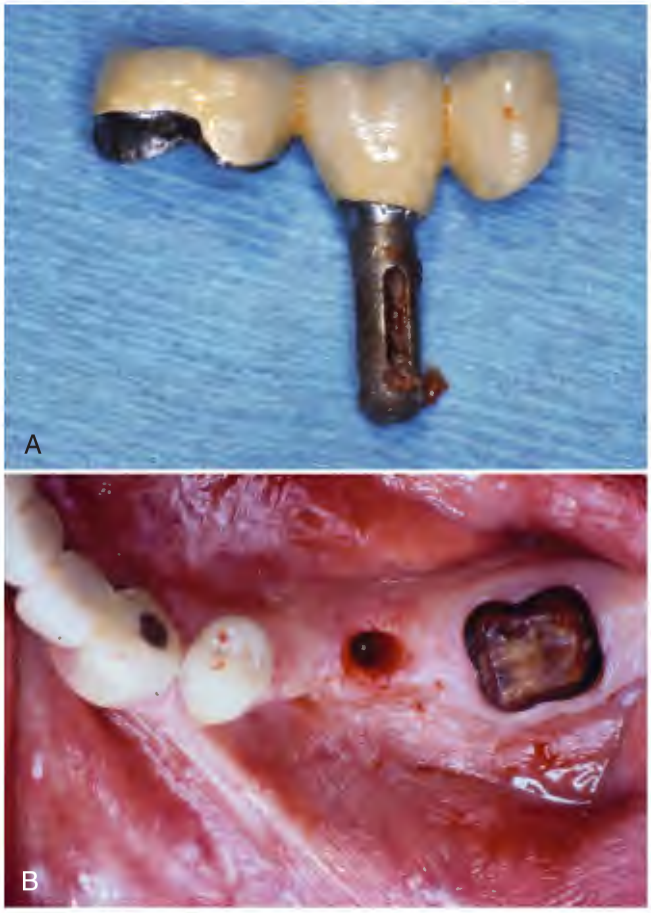


FIGURE 31-37. **A,** A tooth is more mobile than an implant. Therefore, an implant as a fulcrum transmits more tensile and shear load to the distal abutment from the cantilever than a tooth. **B,** The cantilever to the mesial caused the cement to seal to break in the distal molar. Hence, the fulcrum implant carried all the load, and the implant failed.

A gradient of force type of load that gradually decreases the occlusal contact force along the length of the cantilever is beneficial. In addition, no lateral load is applied to the cantilever portion of the prosthesis (whether it is in the posterior or anterior region). Although the functional forces of occlusion during mastication may not be significantly altered by this technique, parafunctional forces (which are the most damaging) are significantly reduced with a gradient of force occlusal adjustment.

Crown Height and Implant-Protective Occlusion

The implant crown height is often greater than the original natural anatomical crown even in division A bone. If the implant is loaded on the long axis, crown height does not magnify the force (Figure 31-39). However, crown height is a force magnifier (vertical cantilever) when any lateral load, angled force, or cantilever load is applied[17] (Figure 31-40). A crown height with any of these conditions acts as a magnifier of stress to most of the implant system (cement or screw retaining the crown, abutment screw, marginal bone, and implant–bone interface). The greater the crown height, the greater the resulting crestal moment with any lateral component of force, including those forces that develop because of an angled load. Angled abutments loaded in the direction of the angled abutment with an increase in crown height are subject to similar greater crestal moment loads because of the lateral load to the implant body and the increased lever effect from the crown height.

A 30-degree angled load to an implant body, the implant crown with a 30-degree load, or a 30-degree cusp angle contact results in a similar condition: 50% of the occlusal load is transformed into a horizontal or shear component to the implant system. However, the angled load on an implant crown is at greater risk to the crestal bone than the angled implant body because the crown height acts as a vertical cantilever. Therefore, whatever load is applied to the occlusal table (or cusp angle) is magnified by the crown height. For example, a 12-degree angled load of 100 N on the implant crown results in 21 N of additional load as a lateral force component. However, if the crown is 15 mm high, the final load to the crest of bone and abutment screw is 21 N × 15 mm = 315 N-mm moment force (Figure 31-41). Therefore, the doctor should be aware the noxious effects of a poorly selected cusp angle, or an angled load to the implant crown will be magnified by the crown height measurement.

If a load perpendicular to the curves of Wilson and Spee is applied to an angled implant body, the increase in load is not magnified by the crown height. The angled implant will increase the force components but will not be magnified by the crown height. Hence, the angle of load to the occlusal surface is more important to control than the angle of the implant body position.

Axial loading of the implant is especially critical when the crown height increases, intensity of force increases, or the duration of force increases (i.e., parafunction). Remember, the crown height is not a force magnifier (lever) when there is no cantilever or lateral load. A long-axis load of 100 N is similar to the implant system, whether the crown height is 10 or 20 mm. Occlusal schemes and crown occlusal anatomy should incorporate axial loads to implant bodies and, when not applicable, should consider mechanisms to decrease the noxious effect of lateral loads. Because horizontal or lateral loads cause an increase in the amount of tension and shear forces to the implant system, these loads should be reduced within the occlusal scheme, especially in mechanical systems that increase the magnitude of the biomechanical load.

Posterior Implant Crown Contour

A buccal or lingual cantilever in the posterior regions is called an offset load, and the same principles of force magnification from class 1 levers apply. In other words, the greater the offset, the greater the load to the implant system. Offset loads may also result from buccal or lingual occlusal contacts and create moment forces, which increase compressive, tensile, and shear forces to the entire implant system (Figure 31-42).

Wider root form implants can accept a broader range of vertical occlusal contacts while still transmitting lesser forces at the permucosal site under offset loads. Narrower implant bodies are more vulnerable to occlusal table width and offset loads. Therefore, in IPO, the width of the occlusal table is related directly to the width of the implant body.[33]

The laboratory technician often attempts to fabricate an implant crown with occlusal facial and lingual contours similar to that of natural teeth. When out of the esthetic zone, the posterior implant crown should have a reduced occlusal width compared with a natural tooth. A wide occlusal table favors offset contacts during mastication or parafunction. The narrower occlusal contour of an implant crown also reduces the risk of

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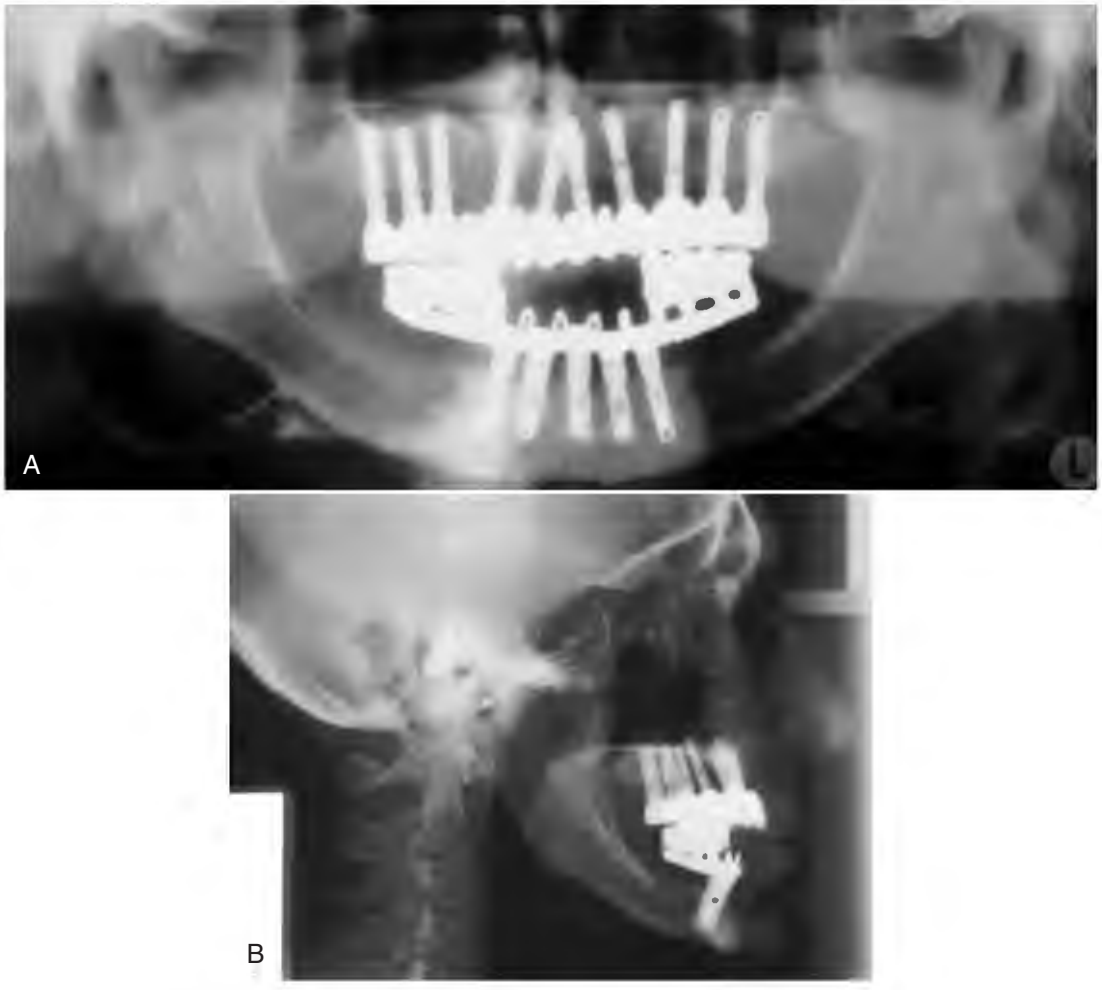


FIGURE 31-38. **A,** A panoramic radiograph of a maxillary and mandibular implant fixed prosthesis. The mandibular restoration is cantilevered from implants positioned between the mental foramina. **B,** A lateral cephalogram demonstrates that the anteroposterior (A-P) distance of the implants is about 6 mm. The prosthesis is cantilevered more than four times the A-P distance. The posterior occlusal load is magnified more than four times to the anterior implants, and the most distal implants receive the total sum of the loads. In addition, the opposing arch is implant supported and with less proprioception and higher bite forces than natural teeth. All of these risk factors make this mandibular restoration less predictable. The cantilever should be reduced, the posterior occlusal contacts should be reduced, an anterior contact occlusal night guard should be worn, and preventive changes of the prosthetic screws should occur every few years.

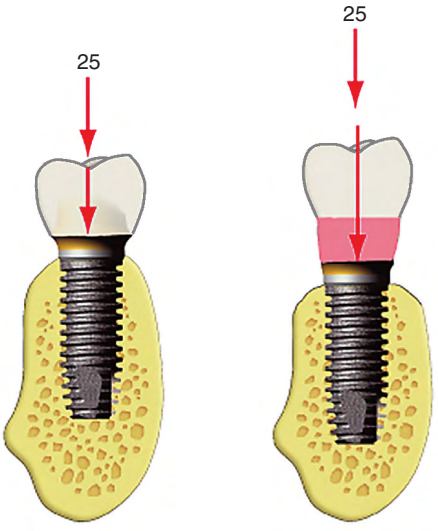


FIGURE 31-39. Crown height does not magnify the stress to the implant system when the force is applied in the long axis of the implant body.

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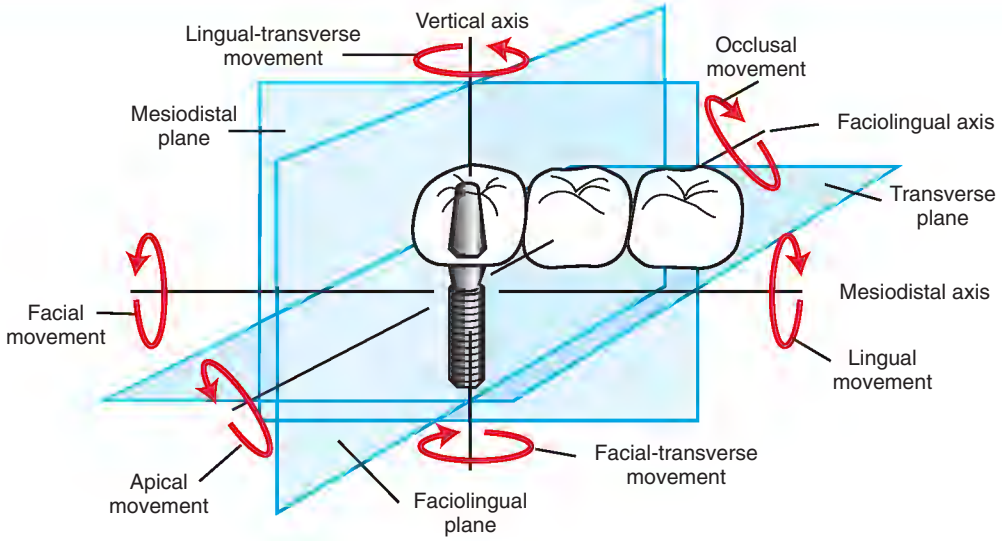


FIGURE 31-40. A cantilever load on an implant results in six different moments applied to the implant body. An increase in crown height directly increases two of six of the moment forces.

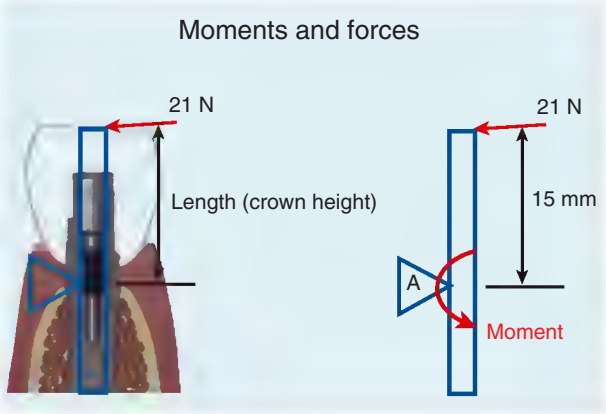


FIGURE 31-41. The crown height directly increases the effect of an angled force. For example, a 100-N load at a 12-degree angle increases the lateral or shear force component by 21 N. A crown height of 15 mm increases the 21-N force to a 315–N-mm moment force.

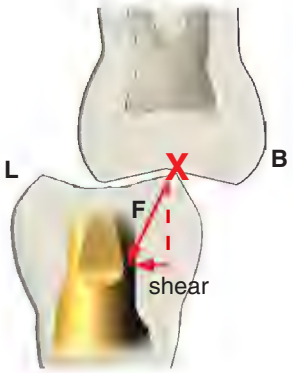


FIGURE 31-42. A cantilever occlusal contact to the facial or lingual is called an offset load. Cantilever or offset loads increase the force by the length of the lever and increase the shear component of the force. A posterior implant most often is placed under the central fossa of the implant crown. A buccal cusp contact is an offset or cantilever load. The ideal occlusal contact is over the implant body. *B,* Buccal; *F,* force; *L,* lingual. (From Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, 1999, Mosby.)

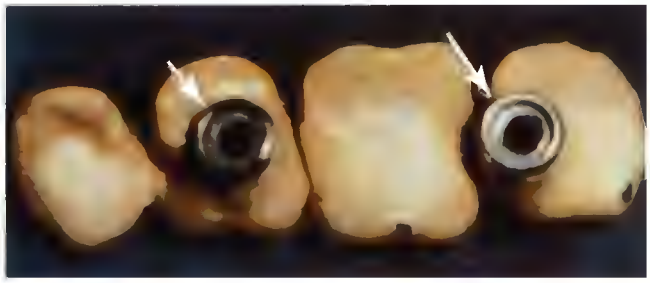


FIGURE 31-43. The diameter of the implant is smaller than the posterior natural tooth. When the crown contour is similar to a tooth, a facial cantilever is necessary, which often has a ridge lap design (as a pontic in a fixed partial denture).

porcelain fracture. A facial profile similar to a natural tooth on the smaller-diameter implant (e.g., 10-mm tooth versus 4- to 6-mm implant) results in cantilevered restorative materials. This cantilever crown contour is often designed as a ridge lap pontic of a fixed partial denture (Figure 31-43). The facial porcelain most often is not supported by a metal substructure because the gingival region of the crown is also porcelain. As a result, shear forces result on the buccal cusp on the mandibular crown or lingual cusps in the maxillary crown and are more likely to increase the risk of porcelain fracture. This risk is compounded further by the higher impact force developed on implant abutments compared with natural teeth. The extended crown contours not only increase offset loads but also often result in ridge laps or porcelain extension at the facial gingival margin of the implant abutment (Figure 31-44). As a result, home care in the sulcular region of the implant is impaired by the overcontoured crown design. The dental floss or probe may reach under the ridge lap to the free gingival margin, but it cannot enter the gingival sulcus. Hence, daily hygiene is almost impossible to perform. The narrower posterior occlusal table facilitates daily sulcular home care. Thus, a narrow occlusal table combined with a reduced buccal contour (in the posterior mandible) facilitates daily care, improves axial loading, and decreases the risk of porcelain fracture. However, in the esthetic zone, the ridge lap design may be necessary to restore the implant rather than removing it, bone grafting, and replacing the implant.

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FIGURE 31-44. **A,** A posterior mandibular implant in the second premolar position. A posterior implant (in the position of the second premolar (in this case) often is inserted under the central fossa position. **B,** The implant body is narrower than the natural tooth. When the laboratory fabricates an implant crown the same size as the missing tooth, a facial ridge lap crown often results so as to restore the complete tooth contour. The ridge lap crown does not allow sulcular hygiene or facial probing. A ridge lap crown contour was made by the laboratory to restore the full contour of the missing teeth. **C,** In situ, the crown appears as a crown on a natural tooth, but the cervical aspect is not in the esthetic zone. Hence, offset loads, porcelain fracture, and abutment screw loosening risk are increased. **D,** The ridge lap was eliminated and the buccal contour reduced. (Note there was no metal work to support the cantilevered porcelain.) **E,** The modified crown in situ. Daily hygiene is improved and biomechanical risk reduced. The second premolar implant crown restores the function and occlusal aspect of the missing tooth. The esthetic facial cervical region is compromised to improve hygiene and force resistance because this region is not seen during function, speech, or smiling.

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Mandibular Posterior Crowns

The posterior mandible resorbs lingually as the bone resorbs from division A to B. As a result, endosteal implants are also more lingual than their natural tooth predecessors. The division C–h and D mandibular ridge shifts to the buccal compared with the maxillary arch. However, endosteal implants typically cannot be inserted because the available bone above the mandibular nerve is inadequate for endosteal implants (Figure 31-45).

The mandibular implant crown should be reduced from the buccal and the maxillary crown reduced from the lingual. Thus, the "stamp cusp" offset load is reduced. The reduced buccal contour in the posterior mandible is of no consequence to cheek biting because the buccal horizontal overjet is maintained (and increased). The lingual contour of the mandibular implant crown is similar to a natural tooth (Figure 31-46). This permits a horizontal overjet to exist and push the tongue out of the way during occlusal contacts (just as natural teeth). As with the natural tooth, the lingual cusp has no occlusal contact.

In the posterior mandible, as the implant diameter decreases, the buccal cusp contour is reduced. This decreases the offset length of cantilever load. The lingual contour of the crown remains similar regardless of the diameter of the implant. The lingual contour permits a horizontal overlap with the maxillary lingual cusp, so the tongue is pushed away from the occlusal table during function. The lingual cusp is not occlusal loaded (as with natural teeth) (Figure 31-47).

During mastication, the amount of force used to penetrate the food bolus may be related to occlusal table width. For example, less force is required to cut a piece of meat with a sharp knife (narrow occlusal table) than with a dull knife (wider occlusal table). The greater surface area of a wide occlusal table requires greater force to achieve a similar result. Hence, the wider the occlusal table, the greater the force developed by the biological system to penetrate the bolus of food. However, these functional forces are typically less than 30 psi. The real culprit in biomechanical forces relate to parafunction because forces 10 to 20 times greater may be generated.

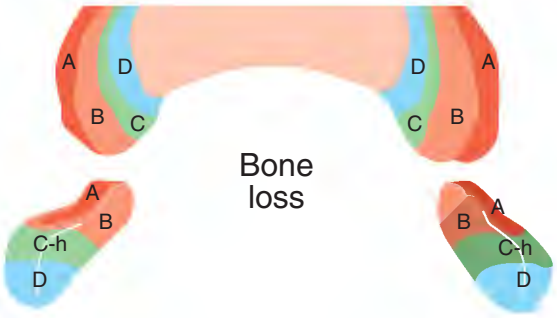


FIGURE 31-45. The posterior maxillary and mandibular edentulous arches resorb lingually as bone volumes change from division A to B to B minus width to C minus width. The mandibular posterior arch resorbs facially as the edentulous site becomes C minus height and D bone volume.

Maxillary Posterior Crowns

In the esthetic zone (high lip position during smiling), the buccal contour of the maxillary implant crown is similar to a natural tooth. This improves esthetics and maintains the buccal overjet to prevent cheek biting. But just as with the natural teeth, there is no occlusal contact on the buccal cusp. Ideally, when maxillary posterior implants are in the esthetic zone, they are positioned more facial than the center of the ridge. The lingual contour of a maxillary implant crown should be reduced because it is out of the esthetic zone and is a stamp cusp for occlusion (which is an offset load) (Figure 31-48).

The ideal functional position for the maxillary posterior implant is under the central fossa when the cervical region is not in the esthetic zone. Hence, the lingual cusp is cantilevered from the implant similar to the buccal cusp of the posterior mandible. Therefore, the reduced lingual contour reduces the offset load to the lingual (Figure 31-49).

The maxillary dentate posterior ridge is positioned slightly more facial than its mandibular counterpart because the teeth have a maxillary overbite. When the maxillary teeth are lost, the edentulous ridge resorbs in a medial direction as it evolves from division A to B, division B to C, and division C to D (see Figure 31-45). As a result, the maxillary permucosal implant site gradually shifts toward the midline as the ridge resorbs. Sinus grafts permit the placement of endosteal implants in the posterior maxilla even in previous division D ridges. However, because of resorption in width, the maxillary posterior implant permucosal site may even be palatal to the opposing natural mandibular tooth.

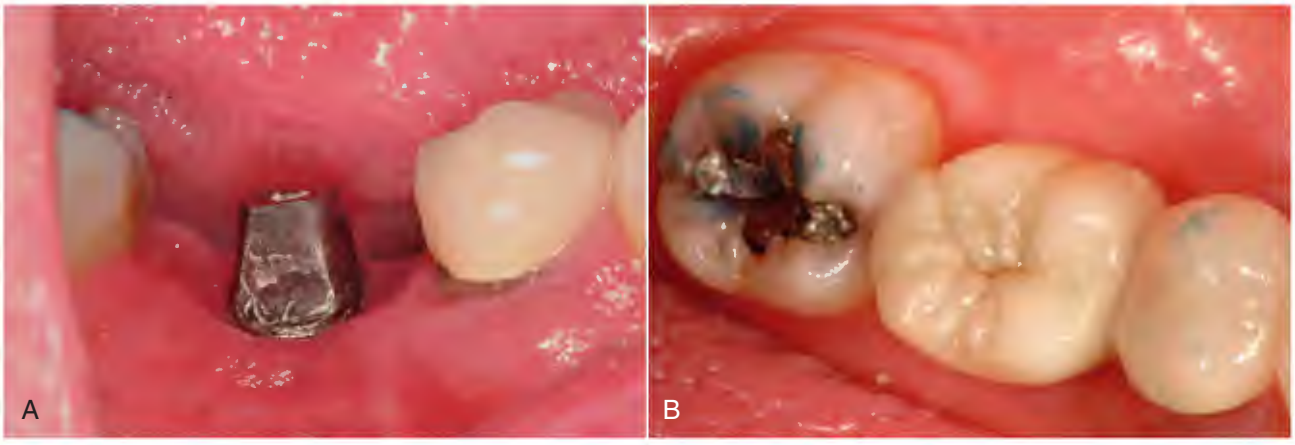


FIGURE 31-46. **A,** A mandibular implant in the first molar position. **B,** The first molar crown in situ. The lingual contour is similar to the natural tooth. The buccal contour is reduced in width.

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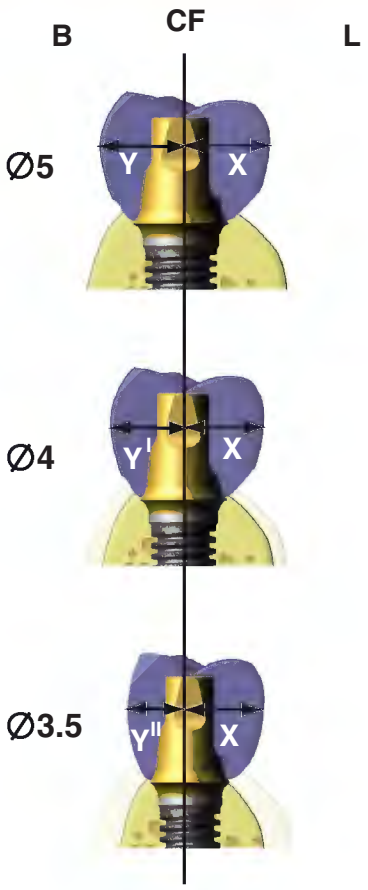


FIGURE 31-47. The wider the implant body, the wider the occlusal table width of the implant crown. As the mandibular bone width decreases, the implant body may decrease in width. The lingual contour of the implant crown remains similar regardless of the width of implant. The buccal contour is reduced as the implant diameter decreases. A narrow ridge in an esthetic zone may require bone augmentation so that a wider implant may be used to support an implant crown, which appears as a natural tooth. *B,* Buccal; *CF,* central fossa; *L,* lingual.

In the esthetic zone, many of the crown contours are made to resemble the natural tooth as close as possible. However, out of the esthetic zone, in the posterior regions of the mouth, the crown contour should be different than a natural tooth. The implant body buccolingual dimension is smaller than the natural tooth. The center of the implant most often is placed in the center of the edentulous ridge. Because the crest of the ridge shifts lingually with resorption, the implant body is most often not under the opposing cusp tips but rather near the central fossa or even more lingual and in the maxilla may even be under the lingual cusp of the original natural tooth position (Figure 31-50). Most often the laboratory fabricates a posterior implant crown that is similar in size to a natural tooth, with a cantilevered facial contour. In addition, the occlusal contacts are often on the "stamp cusp" of the mandible (buccal cusps). However, these "stamp cusps" are often offset loads (buccal cantilevers) (Figure 31-51).

When the maxillary posterior teeth are out of the esthetic zone, the crown may be designed for a crossbite (Figure 31-52). The lingual overjet prevents tongue biting, the buccal overjet (from the mandibular tooth) prevents cheek biting, the implant

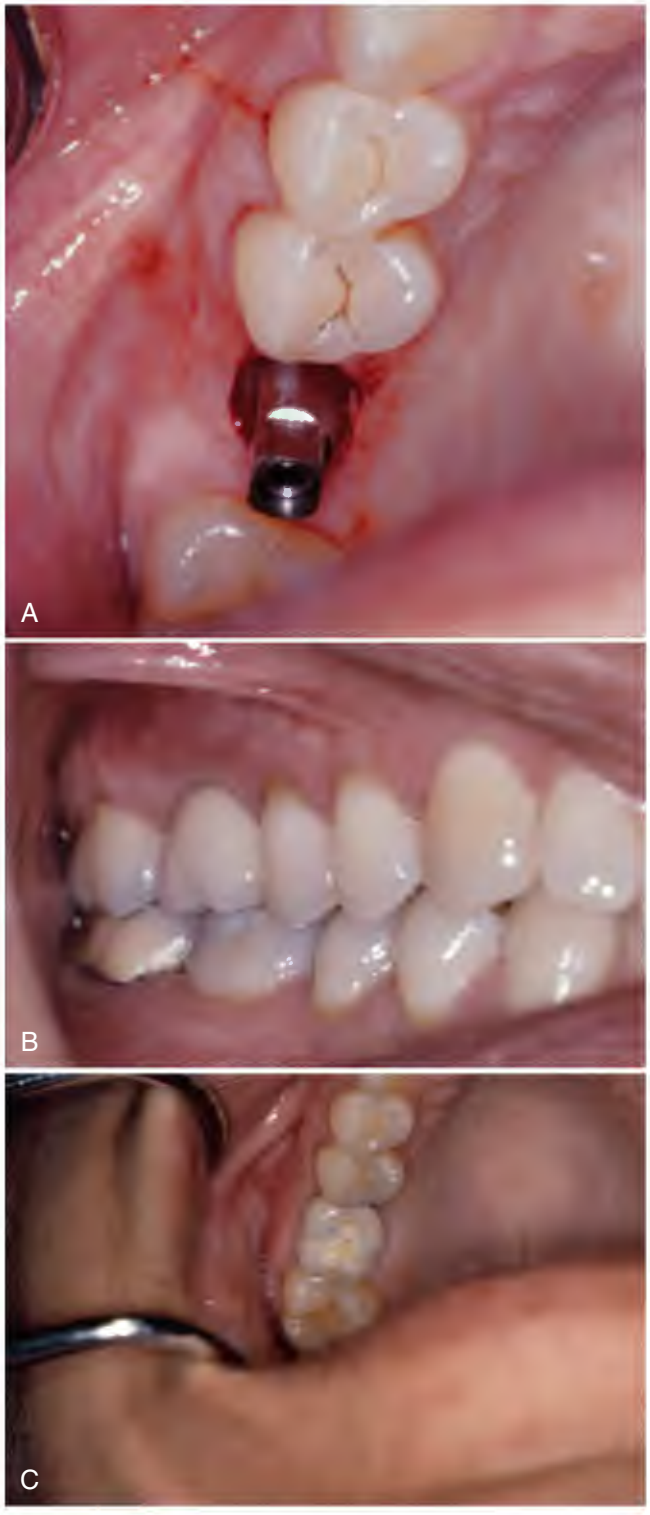


FIGURE 31-48. **A,** A maxillary posterior implant in the esthetic zone is positioned slightly more to the facial position than the central fossa. **B,** The facial contour of the maxillary first molar implant crown is contoured similar to the adjacent teeth. **C,** The lingual crown contour of the maxillary first molar implant crown is reduced, compared to the natural tooth.

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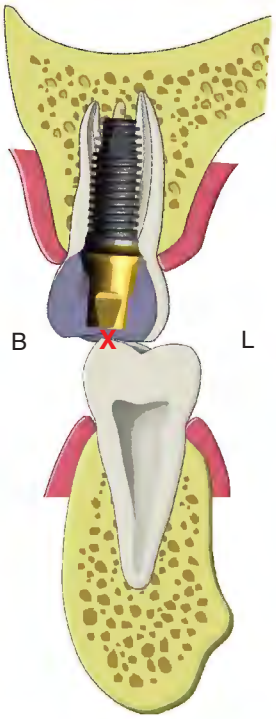


FIGURE 31-49. Posterior maxillary implants most often are positioned under the central fossa when the cervical region is not in the esthetic zone. The posterior maxillary lingual contours of implant crowns usually are reduced for improved hygiene and less offset loads to the implants.



FIGURE 31-50. The implants in the second premolar and first molar are positioned under the lingual cusps. The laboratory made the buccal crown contour similar to the missing teeth. Hence, a facial offset load is present. The cantilever force should not be compounded by occlusal loads in the central fossa from a mandibular buccal cusp.



FIGURE 31-51. In the maxillary posterior region, the implant may be positioned under the lingual cusp. The laboratory often cantilevers the facial crown profile, to make it appear as a natural tooth.

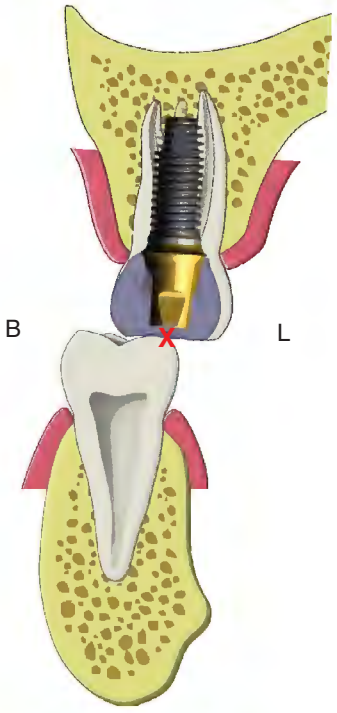


FIGURE 31-52. When maxillary posterior implants are placed in division B to D bone volumes out of the esthetic zone, the implant crown often is restored in posterior crossbite. The maxillary lingual horizontal overjet prevents tongue biting, the mandibular buccal overjet prevents cheek biting, and the primary occlusal contact is in the central fossa over the implant body. *B*, Buccal; *L*, lingual.

is axial loaded by the lingual cusp of the mandible, and hygiene is improved (Figure 31-53).

Some authors encourage the placement of implants in the posterior jaws to be staggered to improve biomechanical resistance to loads.[76] This concept is most effective when narrower implants are positioned in wider ridges, so the staggered position is increased. However, increasing the diameter of the implants and splinting them together to decrease crestal loads is more efficient than offsetting an implant. Unavoidable, less ideal implant orientations should be accommodated through adjustments in occlusion, increasing implant diameter or number of implants placed to reduce the overall load magnitude applied to any one implant, as well as the resultant interfacial stress and strain profiles.

In summary, restorations mimicking the crown contour and occlusal anatomy of natural teeth often result in offset loads (increased stress and risk of associated complications), complicated home care, and an increased risk of porcelain fracture. As a result, in nonesthetic regions of the mouth, the occlusal table

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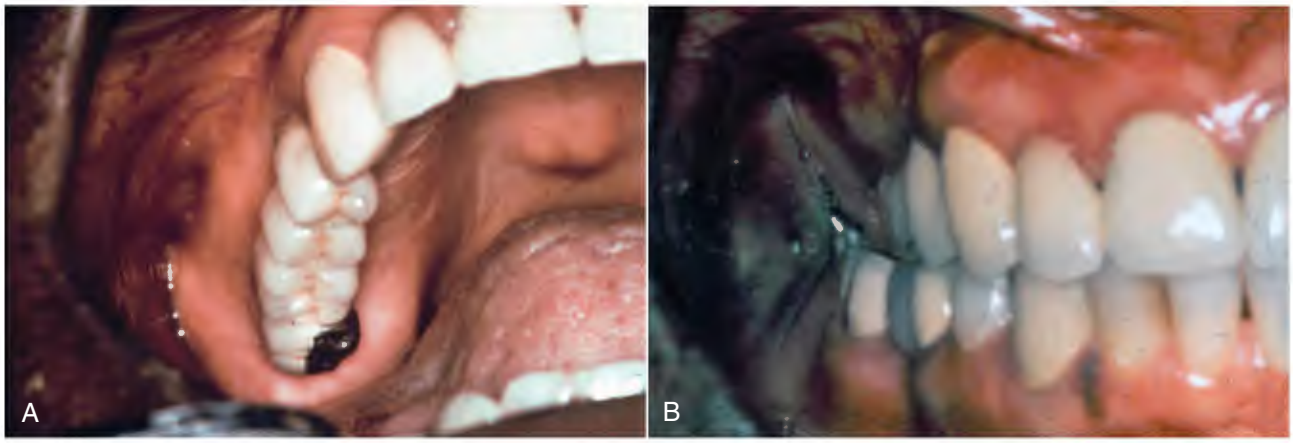


FIGURE 31-53. **A,** The maxillary first and second molar implant was placed under the lingual cusp position of the natural tooth. **B,** The maxillary molar implant crowns are restored in crossbite because they are out of the high smile esthetic zone.



FIGURE 31-54. A mandibular first molar implant crown. The lingual contour is similar to the adjacent teeth, but the lingual cusp tip is not loaded. The buccal contour is reduced compared with the adjacent teeth.



FIGURE 31-55. **A,** Implants in the esthetic zone (replacing a canine and premolar in this photo) are placed more facial so that the crown emergence may appear natural without using a facial ridge lap crown. **B,** Implants are used to restore the maxillary canine and first premolars. Natural tooth crowns restore the second premolar and first molar. The canine and first premolar have a reduced lingual contour compared with the crowns on natural teeth.

should be reduced in width compared with natural teeth (Figures 31-54 and 31-55).

Posterior Occlusal Contact Positions

The ideal number of occlusal contacts in different occlusal schemes varies. For example, Peter K. Thomas' occlusal theories suggest that there should be a tripod contact on each occluding cusp (stamp cusp), on each marginal ridge, and in the central fossa with 18 and 15 individual occlusal contacts on a mandibular and maxillary molar, respectively[77] (Figure 31-56). Other occlusal contact schemes indicate the number of occlusal contacts for molars may be reduced to five or six contacts, including the dominant cusp (stamp cusp) of the buccal cusps in the mandible and the lingual cusps in the maxilla, the marginal ridges, and the central fossa.

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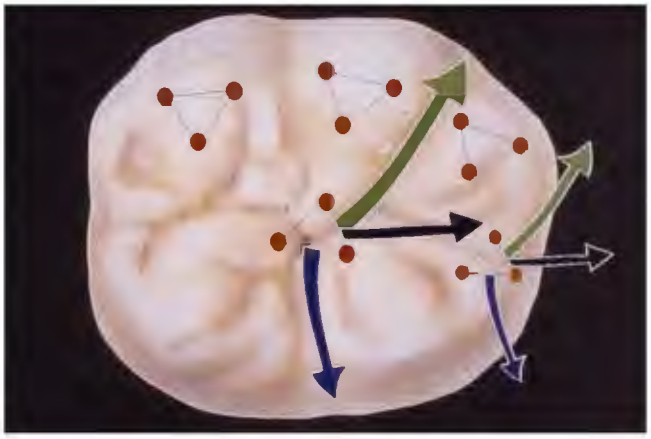


FIGURE 31-56. The ideal number of occlusal contacts varies in the literature. As many as 15 to 18 tripod occlusal contacts have been designed.

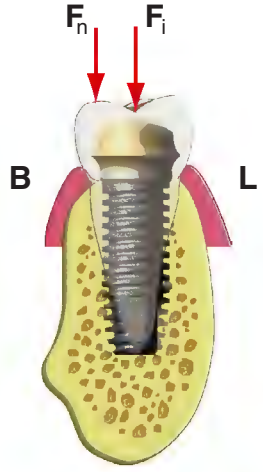


FIGURE 31-57. An offset load to the implant body increases the stress to the implant system. A buccal cusp occlusal contact in the posterior mandible or lingual cusp contact in the maxilla is an offset load to the implant. *B,* Buccal; F_n, buccal cusp contact; F_i, central fossa contact; *L,* lingual.

Most laboratory technicians wax or bake the occlusal surface and do an occlusal adjustment with the opposing casts until the unrestored natural teeth are in occlusion. No thought is given to how many contacts should be present or where they should occlude. Hence, it is almost impossible for the dentist to control the number and locations of occlusal contacts.

Occlusal contact position determines the direction of force, especially during parafunction. A cantilevered load is a force applied on the mesial or distal from the implant, which acts as a fulcrum. An offset load is a force applied to the buccal or lingual and increases the stress to the implant system. An occlusal contact on a buccal cusp of a mandibular premolar and molar or lingual cusp in the maxilla is usually an offset load when the implant is positioned under the central fossa because the occluding cusp is cantilevered from the implant body (Figure 31-57). In addition, the angle of the cusp tip also introduces an angled load to the implant body.

The most common implant body position for a posterior implant is in the middle of the buccolingual dimension of the bone. The surgeon begins the osteotomy in the middle of the ridge, and the implant diameter maintains 1.5 mm or more of bone on each side. The center of an edentulous ridge more often corresponds to the central fossa of a posterior crown in either arch. On occasion, it may correspond to the natural tooth lingual cusp region but less often is under the buccal cusp in either arch.

The marginal ridge contacts are also a cantilever load on the single-tooth implant crown because the implant is not under the marginal ridge but may be several millimeters away. If the implant body is 5 mm in diameter and replaces a 12-mm molar in the mesiodistal dimension, a marginal ridge contact may create a magnified moment load equal to 3.5 mm times the amount of the force. Hence, a 100-N load will be multiplied to a 350–N-mm force on the marginal ridge (Figure 31-58).

The mesiodistal dimension of the molar crown often exceeds the buccolingual dimension, so the marginal ridge contact may contribute more to the biomechanical risk. In addition, the laboratory often creates an all-porcelain marginal ridge completely unsupported by the metal substructure, which places a shear load on the porcelain. The shear loads further increase the risk of porcelain fracture. The moment forces on marginal ridges also may contribute to forces that increase abutment screw loosening. Therefore, marginal ridge contacts on individual implant crowns or the most mesial or distal splinted crown should be avoided whenever possible.

The marginal ridge occlusal contact is not a cantilevered load when located between two implants splinted to each other. In addition, the metal framework that splints the implants supports the porcelain in the marginal ridge region and minimizes the risks of fracture. The splinted crowns decrease occlusal forces to the crestal bone, reduce abutment screw loosening, decrease the force to the cement interface, increase retention of the crowns, and reduce the force to the bone–implant interface. Hence, adjacent implant crowns should most often be splinted together, and the occlusal contact position may be extended from the most mesial to most distal implants (minus the marginal ridges at each extreme) (Figure 31-59).

A posterior screw-retained restoration often requires cantilevered occlusal contacts. The occlusal screw hole rarely is loaded because the obturation material easily wears or fractures. As a result, the occlusal contacts of screw-retained crowns are not often directed over the top of the implant but are offset several millimeters away. This results in a higher moment load to the implant system, yet the occlusal access hole is the best position for the occlusal contact.

The average number of occlusal contacts found on natural posterior teeth of individuals never restored or equilibrated by a dentist and with no occlusal-related pathologic condition has been observed to average only 2.2 contacts (Figure 31-60) with a range of one to three occlusal contacts per tooth.[78] If the tooth had an occlusal restoration, the occlusal contact number was reduced to an average of 1.6 occlusal contacts. The number of occlusal contacts on a natural tooth apparently may be reduced to one to three contacting areas without consequence. Therefore, a more simplified occlusal approach than often taught is logical. Hence, if the ideal occlusal contacts per tooth should have minimum offset loads to the implant body, the central fossa is the logical primary occlusal contact position when the implant is positioned in this region.

The central fossa of an implant crown should be 2 to 3 mm wide in posterior teeth and parallel to the occlusal plane. The ideal implant body position for function is most often directly under the central fossa in the mandible and maxilla. The ideal primary occlusal contacts therefore will reside within the

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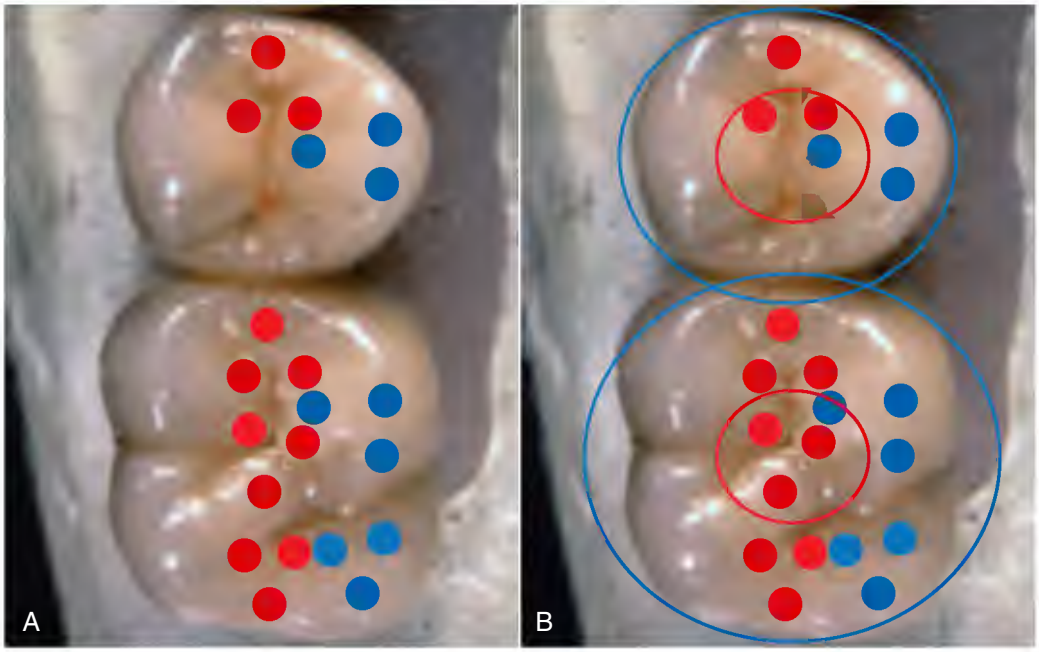


FIGURE 31-58. The ideal occlusal contact on a single-tooth implant crown is directly over the implant. A marginal ridge occlusal contact is an offset load similar to the lingual cusp in the posterior maxilla.

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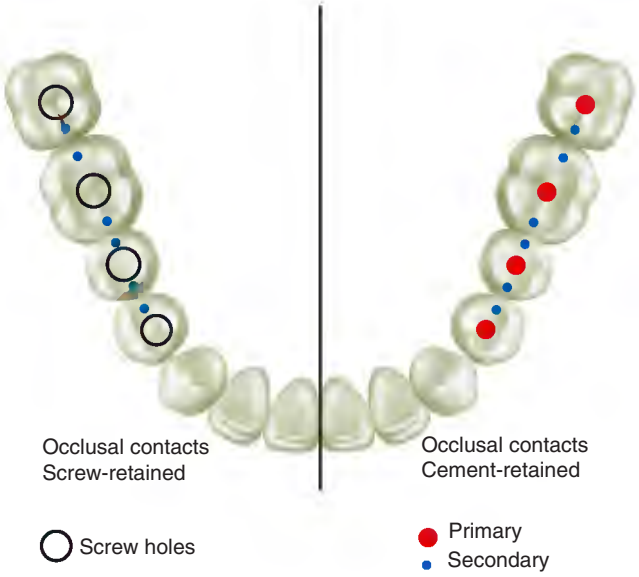


FIGURE 31-59. When the implants are splinted together, the occlusal contacts ideally should be in the central fossa, over the implant bodies, and in a zone extending between the implants. The marginal ridges between the implants may also have a secondary occlusal contact.

diameter of the implant within the central fossa. Secondary occlusal contacts should remain within 1 mm of the periphery of the implant to decrease moment loads. Marginal ridge contacts usually should be avoided unless implants are splinted together. When the implant is positioned closer to a stamp cusp (buccal in the mandible and lingual cusp in maxilla), the cusp angle is flat and the contact is over the implant (Figure 31-61).

On occasion, when a maxillary posterior tooth is in the esthetic zone, the implant may be 1 to 2 mm to the facial aspect of the midcrest (when bone is abundant) to be closer to the buccal cusp in order to improve the esthetic emergence of maxillary implant crowns. Under these conditions, the central fossa is positioned more facial, the lingual contour of the crown is reduced, and the occlusal contact is over the lingual aspect of the implant body (which is under the central fossa).

Timing of Occlusal Contacts

The most common method a dentist uses to determine the timing of occlusal contacts at the prosthesis delivery is to ask the patient, "How does the bite feel? Is the crown too high?" Jacobs and van Steenberghe evaluated occlusal awareness by the perception of an interference.[79,80] When teeth oppose each other, an interference is perceived at approximately 20 microns.[24,25] An implant opposing a natural tooth detects an interference at 48 microns; therefore, it is more than twice as poor. An implant crown opposing an implant crown perceives the interference at 64 microns, and when a tooth opposes an implant overdenture, the awareness is 108 microns (five times poorer than teeth opposing each other). Mericske-Stern et al. measured oral tactile sensitivity with steel foils.[81] The detection threshold of minimal pressure was significantly higher on implants than on natural teeth (3.2 vs. 2.6 foils). Similar findings also were reported by Hammerle et al. in which the mean threshold value for implants (100.6 g) was 8.75 times higher than that of natural teeth (11.5 g).[82] An occlusal adjustment performed by occlusal awareness—"How does the bite feel? Is the implant crown high?"—is a poor indicator for hyper contacts compared with a crown on a natural tooth. As a consequence of decreased quantity and quality of occlusal awareness, a premature occlusal contact may remain on an implant crown after occlusal adjustment.

Controversy has been ongoing regarding whether a rigidly fixated implant may remain successful when splinted to natural teeth.[83,84] Because the implant has no periodontal membrane, concerns center around the potential for the "nonmobile" implant to bear the total load of the prosthesis when joined to

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FIGURE 31-60. **A** to **C,** An average of 2.2 occlusal contacts (range, 1–3) usually is found on natural posterior teeth.



FIGURE 31-61. **A,** The occlusal contact position is ideally directly over the implant. When under a cusp tip, the cusp angle is more flat. **B,** The implant crowns are reduced from the lingual compared with the natural tooth molar crown.

the "mobile" natural tooth. The mobility of potential natural abutments joined to implants may influence the treatment more than almost any other factor. However, the biomechanical concern for the difference in tooth movement and implant movement should not be restricted to situations in which these entities are directly connected within the same prosthesis. When an implant is placed in a partially edentulous arch, many similar biomechanical elements are present, whether the teeth are splinted to the implant or are independent.

Vertical Movement

The sudden, initial (primary) tooth movement ranges from 8 to 28 microns in a vertical direction under a 3- to 5-lb load, depending on the size, number, and geometry of the roots and the time elapsed since the last load application.[19,20] This tooth movement has been called "primary" tooth movement and is a result of the movement within the periodontal complex. An implant has no initial or primary vertical tooth movement. An

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implant with a heavy bite force may move apically up to 5 microns. When the initial tooth movement occurs, secondary tooth movement is present during a greater load and reflects the viscoelastic property of the surrounding bone. The vertical secondary tooth movement is minimal and may approach 3 to 5 microns for a natural tooth (Figure 31-62).

The secondary tooth movement is similar to the bone–implant movement. In other words, the initial axial movement during a light bite force of an implant has no initial, sudden movement. Contrary to the teeth that move immediately, even with light loads, implants only move under a heavy occlusal load and even under these conditions have almost no mobility. The implant may move up to 5 microns after additional force causes the bone to deform, with little correlation of movement to the implant body length.[21] In fact, the mobility of implant "secondary" movement is more related to bone density than any other factor.

When teeth oppose each other, the combined intrusive movements of the contacting elements may be 56 microns (28 + 28 microns). When a tooth opposes an implant, the initial combined intrusive movement is only 28 microns (28 + 0 microns). In other words, when implant prostheses oppose natural teeth, the difference in movement between teeth in the rest of the mouth and the implants causes a condition with greater loads to the implant.

Under a light load, the total combined implant movement when implant crowns oppose each other may remain at 0 microns compared with 56 microns in the rest of the mouth. Therefore, although the occlusal contact design for the natural teeth may be ideal under a light load, premature-like occlusal contacts may exist on the implants, especially with a greater bite force. Because the initial difference in vertical movement of teeth and implants in the same arch may be as much as 28 microns, the initial occlusal contacts should account for this difference, or the implant will sustain greater loads than the adjacent teeth.

The dentist should first evaluate the existing occlusion before implant reconstruction and ideally eliminate occlusal prematurities on teeth before the final evaluation of the occlusion on the implant reconstruction. A decision is then made whether an MI or CO is desired before implant placement.

At the delivery of the implant prostheses, any premature contact on the implant restoration should be eliminated. It is interesting to note that a coating of petroleum jelly on the articulating paper will help release the dye and allow more precise occlusal contact identification on the teeth and implant restoration (Figure 31-63). After this step, the dentist uses thin articulating paper (less than 25 microns thickness) for the initial implant occlusal adjustment in occlusion under a light tapping force (Figure 31-64). The implant prosthesis should barely contact during this light bite force, and the surrounding teeth in the arch should exhibit greater initial occlusal contacts. In other words, only light axial occlusal contacts should be present on the implant crown.



FIGURE 31-63. Petroleum jelly applied to articulating paper helps release the dye and makes the occlusal marks more specific.

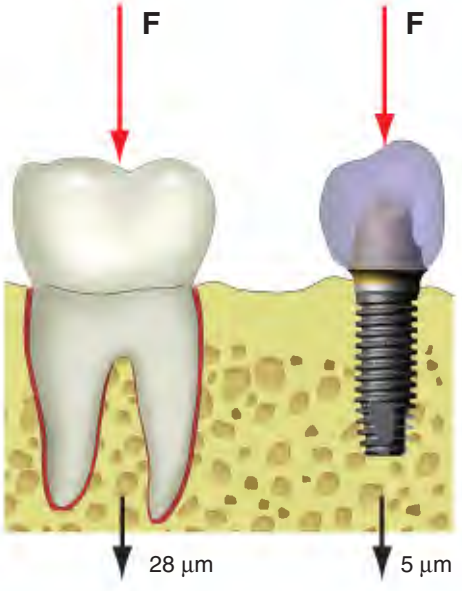


FIGURE 31-62. The physiologic vertical movement of a natural tooth is 28 microns with a light force (F). An implant has up to 5 microns of vertical movement but requires a heavy occlusal load.



FIGURE 31-64. A light occlusal force is applied first to the implant and teeth. The first molar implant crown has less initial contact than the teeth.

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After the equilibration with a light bite force is completed, the patient applies a heavier occlusal force and grinds on the articulating paper (Figure 31-65). A plastic articulatory paper is a benefit, so the "paper" will not tear during the heavy bite and grind force on the teeth (e.g., 20 micron, Accufilm; Parkell, Farmingdale, NY). The occlusal contact point on the implant crown should remain axial over the implant body and may be of similar intensity on the implant crown and the adjacent teeth. When greater bite forces are used, all of the occlusal elements react similar under the heavy occlusal load. Hence, to harmonize the occlusal forces between implants and teeth, the dentist evaluates a heavy bite force occlusal adjustment because it depresses the natural teeth, positioning them closer to the less depressed implant position, and therefore permits equal sharing of the occlusal load.[33]

When all posterior teeth in one quadrant of the same arch are implant supported, the same occlusal timing is suggested. Under a light bite force, the occlusal contacts between the anterior and posterior teeth on the other side are slightly heavier in CO than the implant prosthesis. Under a heavy bite force in occlusion, similar contacts are created around the arch. To evaluate these occlusal contacts, a full-arch articulating paper is required (Figure 31-66).

When implant prostheses oppose each other on one side of the mouth, the heavy bite force occlusal adjustment must account for a 56-micron difference in vertical movement between the opposing implant crowns and the rest of the natural teeth. Hence, the light bite force occlusal adjustment should again be performed with a full-arch-size articulating paper, and the implant–implant section should barely contact, but the tooth—tooth anterior and posterior sections have more occlusal contact. Under a heavy bite force in occlusion, similar occlusal contacts are present on both sides of the arch.

It is interesting to note that in a report on porcelain fracture associated with implant crowns, Kinsel and Lin found when the opposing dentition was a denture to an implant prosthesis, no fracture was reported.[30] An opposing natural tooth had 3.2% implant crown fracture and a crown on a natural tooth 5.7% fracture, and when an implant crown opposed another implant crown, a 16.2% fracture rate was reported. Hence, the heavy bite force occlusal adjustment becomes more critical when both arches are involved with implant prostheses.

A complete-arch implant-supported prosthesis in one arch opposing complete natural teeth does not require a difference in a light and heavy bite force occlusal evaluation. Likewise, when implants support both maxillary and mandibular prostheses, a light and heavy bite force difference in occlusal timing is not required.



FIGURE 31-65. The first molar implant crown is evaluated with a heavy bite force during grinding movements (especially in a parafunction patient). The implant crown in this patient needs to be adjusted because the occlusal markings on the lingual cusps and marginal ridge are offset loads.

Horizontal Movement

The initial lateral movement of healthy anterior teeth ranges from 68 to 108 microns before secondary tooth movement, or two to four times more movement than their apical movement[20] (see Figure 31-4). Horizontal (lateral) implant movements are not immediate and with heavier forces range from 10 to 50 microns[21] (Figure 31-67). Therefore, anterior teeth exhibit even greater differences in lateral movements compared with implants than posterior teeth. Hence, one follows a similar equilibration scenario when anterior implants and teeth are not connected and disocclude the posterior dentition during mandibular excursions.

When anterior teeth disocclude the posterior teeth in excursions, the lateral tooth movement of the posterior teeth (56–73 microns) does not have to be accounted for because no lateral force exists. Because anterior teeth and implants have lateral movement during mandibular excursion that results in greater



FIGURE 31-66. To equilibrate the occlusion when multiple implants and natural teeth are in an arch, a full-arch articulating paper is required.

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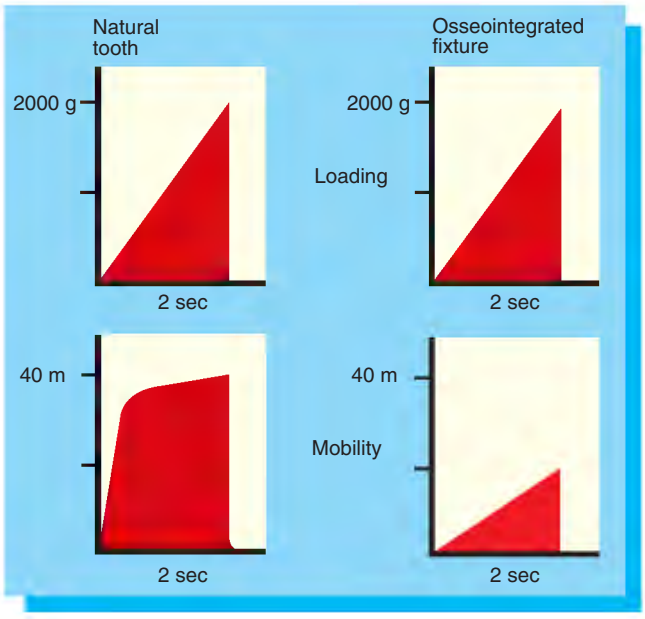


FIGURE 31-67. When a gradually increasing load is applied to a tooth *(top left)* and an implant *(top right)*, the range of movement is completely different. The tooth *(bottom left)* moves immediately under very little force (primary tooth movement). As the force intensity is increased gradually, the tooth gradually moves (secondary tooth movement). The primary tooth movement results from the periodontal ligament. The secondary tooth movement results from bone–tooth movement. The implant follows a gradual movement as the force gradually increases. The movement is similar to secondary tooth movement. The occlusal adjustment of implants and teeth in the same arch should compensate for the primary tooth movement, which is sudden and ranges from 56 to 108 microns in a horizontal dimension. The light occlusal contact evaluates the primary tooth movement. The heavy occlusal contact equilibration evaluates the secondary tooth movement and accounts for the slight implant movement.

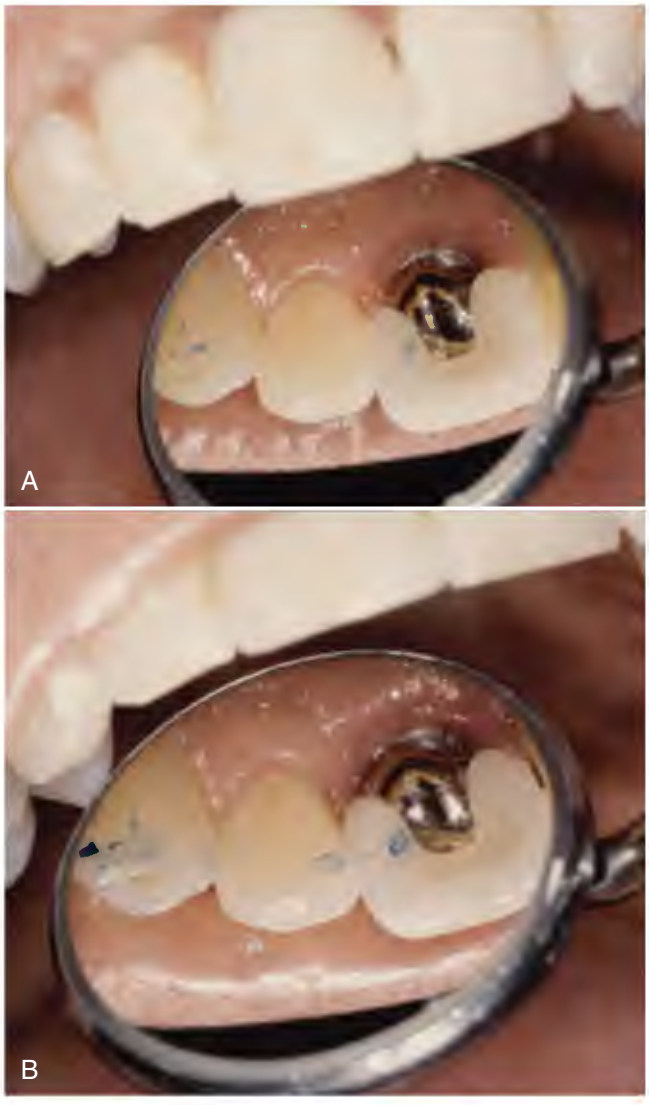


FIGURE 31-68. **A,** The occlusal equilibration of an anterior implant crown is made first with a light occlusal contact in centric occlusion (CO) and during mandibular excursions. **B,** The anterior implant crown then is equilibrated under a heavy bite force in CO and during mandibular excursions. The difference between primary tooth movement and implant movement is greater in the anterior regions of the mouth.

discrepancies, the occlusal adjustment in this direction is more critical to the implant system. The dentist first uses light force and thin articulating paper to ensure that little to no implant crown contact occurs during the initial occlusal or lateral movement of the teeth. Then the dentist uses a heavier force during CO and excursions to develop similar occlusal contacts on anterior implants and natural teeth (Figure 31-68).

To compensate for the difference in 100 microns of horizontal movement between maxillary anterior implants and anterior teeth, two modifications are required. The first is to enameloplasty the facial incisal contact of the mandibular incisal edge. The patient is told the height of the tooth is not reduced, only the facial incisal edge. Very often, when maxillary anterior tooth is lost, the opposing mandibular incisor shifts to the facial and makes the implant position and occlusal adjustment more critical. The second modification is often the lingual contour of a maxillary anterior crown is more concave than a natural tooth to accommodate the heavy bite force occlusal adjustment (Figure 31-69).

The concept of a heavy bite force occlusal adjustment is underestimated by some practitioners. A comparison of the importance of this concept may be made with the restoration of a single posterior natural tooth with a crown. Can a restoring dentist insert a crown from the laboratory without an occlusal



FIGURE 31-69. The lingual surface of a maxillary anterior implant crown often has a concave appearance to accommodate for the occlusal contact differences compared with the adjacent natural teeth.

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adjustment? Despite accurate impressions, bite registrations, face-bows, and full-arch mounted casts, the crown most always requires some occlusal adjustment. Why?

The laboratory cannot equilibrate the occlusion accurately on the working casts. The technician taps two stone casts together to evaluate the occlusal contacts. The stone dies do not move 28 to 108 microns. As a result, the occlusal adjustment in the mouth compensates for the primary and secondary tooth movement. When a heavy bite force occlusal adjustment is not performed at the delivery of an implant crown, the dentist may not be aware that the implant may be overloaded similar to a new crown on a natural tooth that has not been equilibrated in the mouth.

The proposed heavy bite force occlusal adjustment does not encourage tooth migration or changes in tooth position because regular occlusal contacts still occur. The teeth opposing implants are not taken out of occlusion. Brief occlusal contacts on a daily basis maintain the tooth in its original position (similar to the rest of the mouth). In addition, because most teeth in a skeletal class I occlusion occlude with two opposing teeth (with the exception of the mandibular central incisor), the opposing teeth positions are even more likely to remain in the same positions. In other words, the two opposing natural teeth to an implant crown still have occlusal contacts on the adjacent natural teeth to the implant. However, teeth do move over time. Unlike teeth, implants do not extrude, rotate, or migrate under occlusal forces. As such, the restoring dentist may vary the intensity of the force applied to an implant without causing the implant to change its position readily in the bone. On the contrary, natural teeth do exhibit mesial drift, and slight changes in occlusal position do occur over time.

No occlusal scheme will prevent mesial drift and minor tooth movement from occurring. In addition, enamel may wear approximately 30 microns each year. Therefore, an integral part of the IPO philosophy is the regular evaluation and control of occlusal contacts at each regularly scheduled hygiene appointment. This permits the correction of minor variations occurring during long-term function and helps prevent porcelain fracture and other stress-related complications (abutment screw loosening) on the implant prostheses.

Similar biomechanical considerations can be discussed for implants joined to natural teeth and a similar scenario is used for the occlusal equilibration. A light force and thin articulating paper are used, and the implant crown exhibits minimum contact compared with the natural abutment crown in occlusion. A gradient of force is designed on the pontics. A heavy bite force then is used to establish equal occlusal contacts for all the natural teeth and the entire prosthesis, whether implant or natural tooth supported. When possible, lateral forces on the implant abutments are discouraged even in the anterior regions of the mouth.

Design to the Weakest Arch

Any complex engineering structure typically will fail at its weakest link, and dental implant structures are no exception. Thus, all treatment planning decisions for IPO should be based on careful consideration of (1) identifying the weakest link in the overall restoration and (2) establishing occlusal and prosthetic schemes to protect that component of the structure.

The amount of force distributed to a system can be reduced by stress-relieving components that may dramatically reduce impact loads to the implant support. For example, the soft tissue of a traditional completely removable prosthesis opposing an implant prosthesis is displaced more than 2 mm and is an efficient stress reducer. Because the opposing prosthesis is not rigid, the resulting lateral loads are not as great. In addition, the amount of force the patient may generate is significantly reduced as a consequence of edentulism. The maximum bite force of a long-term denture wearer may be less than 6 lb/in^2. As a result, the occlusal concept may be selected to favor the complete removable denture, which is the weakest arch. A common implant treatment plan for an edentulous patient consists of a traditional soft tissue–supported complete maxillary denture opposing a mandibular implant-supported restoration. The occlusal scheme of choice is a bilaterally balanced occlusion, with a medial positioned lingualized tooth setup and raised posterior plane. Whether the mandibular restoration is a fixed prosthesis type 1 (FP-1), FP-2, FP-3, RP-4, or RP-5, the occlusal scheme follows these guidelines.

Bilateral balanced occlusion often provides contacts for all centric and eccentric occlusal movements and is a popular occlusal scheme for soft tissue–supported removable prostheses to improve denture stability, especially during parafunction. However, the mandibular implant-supported restoration may exert greater force on the premaxilla than a mandibular denture and cause accelerated bone loss. Therefore modification of the occlusal scheme aims at protecting the premaxilla under a maxillary denture by the total elimination of anterior contacts from the mesial of the canines with the mandibular anterior teeth in CO.

The weakest component philosophy also applies to occlusal contacts in the regions of the implant bodies in the presence of cantilevers or offset-loaded areas. Heavier occlusal contacts are applied over the implant bodies and gradually reduced toward the cantilever to reduce the magnification of the compressive forces from the most distal cantilevered contact and the tensile and shear forces on the most anterior implant abutment. Reduced occlusal forces with an absence of lateral contacts during excursions are recommended on posterior cantilevers or anterior offset pontics whenever possible. This minimizes the moment forces on the abutments and decreases the loads on terminal implant abutments (Figure 31-70). If the implants for both arches cannot be loaded in an axial position, bone density, implant surface area, and prosthesis type determine the area to be protected. The maxillary implants are most likely to be protected with the axial load (Figure 31-71).

To follow the weaker component theory, when cantilevered pontics are in both arches, they should ideally oppose each other. However, posterior cantilevers in the maxillary arch are less indicated than in the mandible. When maxillary posterior implants support cantilevered anterior teeth and mandibular anterior implants support cantilevered posterior teeth, the occlusal scheme cannot minimize forces on both. In this scenario, the weaker component is usually the anterior maxilla, and reduced force in the region would be appropriate. Mandibular cantilevered pontics opposing maxillary implants is better than the reverse situation. A detailed laboratory prescription indicates implant crown contours and primary occlusal contacts for the implant prosthesis (Figure 31-72).

Summary by Bone Volume

Division A Bone

In a posterior edentulous ridge with abundant height and width and little resorption, the implant may be placed in a more ideal

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position for occlusion and esthetics. The most common implant placement in the mandible corresponds to a central position in the residual ridge. The implant osteotomy begins in the center of the crest and gradually is increased to the optimal width indicated in relation to the recipient bone. Facial concavities are avoided, and the thinner facial cortical bone is protected to limit surgical complications such as labial dehiscence. As a result, the implant frequently is placed under the central fossa region of the former natural tooth. To load the implant body in an axial direction, the primary occlusal contact should be the central fossa region in division A bone.

When the posterior ridge is abundant in width in the maxilla and the cervical region is in the esthetic zone, the implant may be positioned 1 or 2 mm from the center of the ridge toward the facial bone. This position is used when the facial margin of the crown is in the esthetic zone to enhance the emergence profile. In this situation, the palatal portion of the implant platform is still located under the central fossa, and the occlusal load is placed on the central fossa. If the cervical region of the maxilla is not in the esthetic zone during a high lip position, the implant should be positioned in the center of the ridge to minimize the lingual cusp cantilever.

In either arch, the stamp cusp (buccal in the mandible and lingual in the maxilla) is a cantilevered load and should not have occlusal contact. This also pertains to the marginal ridges for single-tooth implants.

After the socket of the tooth heals, bone resorption occurs at the expense of the facial plate, and the implant most often is positioned under the central fossa with a modified buccal contour anatomy in the mandible. The dentist reduces the buccal aspect of the occlusal table width to promote axial loading in nonesthetic regions. This buccal contour increases the horizontal overjet during occlusion with the maxillary molar without esthetic or cheek-biting consequences. The central fossa of the mandibular implant crown is increased to 2 to 3 mm in width. When opposing a natural maxillary molar, the primary contacting cusp becomes the maxillary lingual cusp contacting the mandibular central fossa of the implant crown, with the mandibular buccal cusp of decreased height and width. Hence, all contacts are situated medially compared with those on natural teeth. The lingual contour of the mandibular implant crown is similar to the original natural dentition (and the adjacent teeth), complete with horizontal overlap to the maxillary lingual cusp to prevent tongue biting during function. No occlusal contact occurs on either the buccal or the lingual cusps so as to eliminate offset loads during parafunction.

The esthetics in a maxillary implant reconstruction should not be compromised by a facial reduction of the occlusal table width. Just as with the natural teeth, the maxillary buccal cusp receives no occlusal load. However, the lingual cusp in the maxillary arch is not in the esthetic zone. In maxillary premolar and first molar regions out of the high smile lip esthetic zone with abundant bone width, the implant is placed under the central fossa of the crown, and occlusal contact occurs with the central fossa and opposing mandibular buccal cusp of the natural tooth.

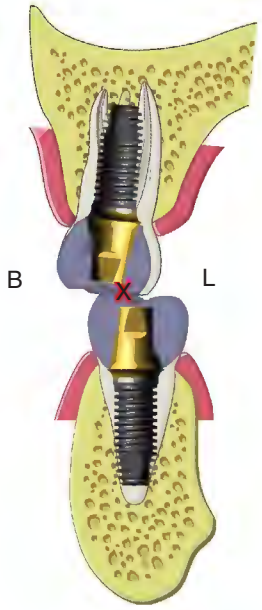


FIGURE 31-70. Posterior implants in opposing arches are positioned under the respective central fossae when the facial cervical regions are not in the esthetic zones. The maxillary lingual cusp is reduced in width, and the mandibular buccal cusp is reduced. The primary occlusal contact is often over the maxillary implant when the bone is less dense or fewer implants are splinted together or the implant sizes are less than the mandibular implant support. *B*, Buccal; *L*, lingual.



FIGURE 31-71. **A,** Full-arch maxillary and mandibular implant prostheses. The vertical overbite is 3 mm, and there is no occlusal contact from the mesial of each maxillary canine to canine in centric occlusion (CO). **B,** In CO, the implants are loaded in their long axis. When this is not possible in both arches, the maxillary implants are favored for long-axis loads.

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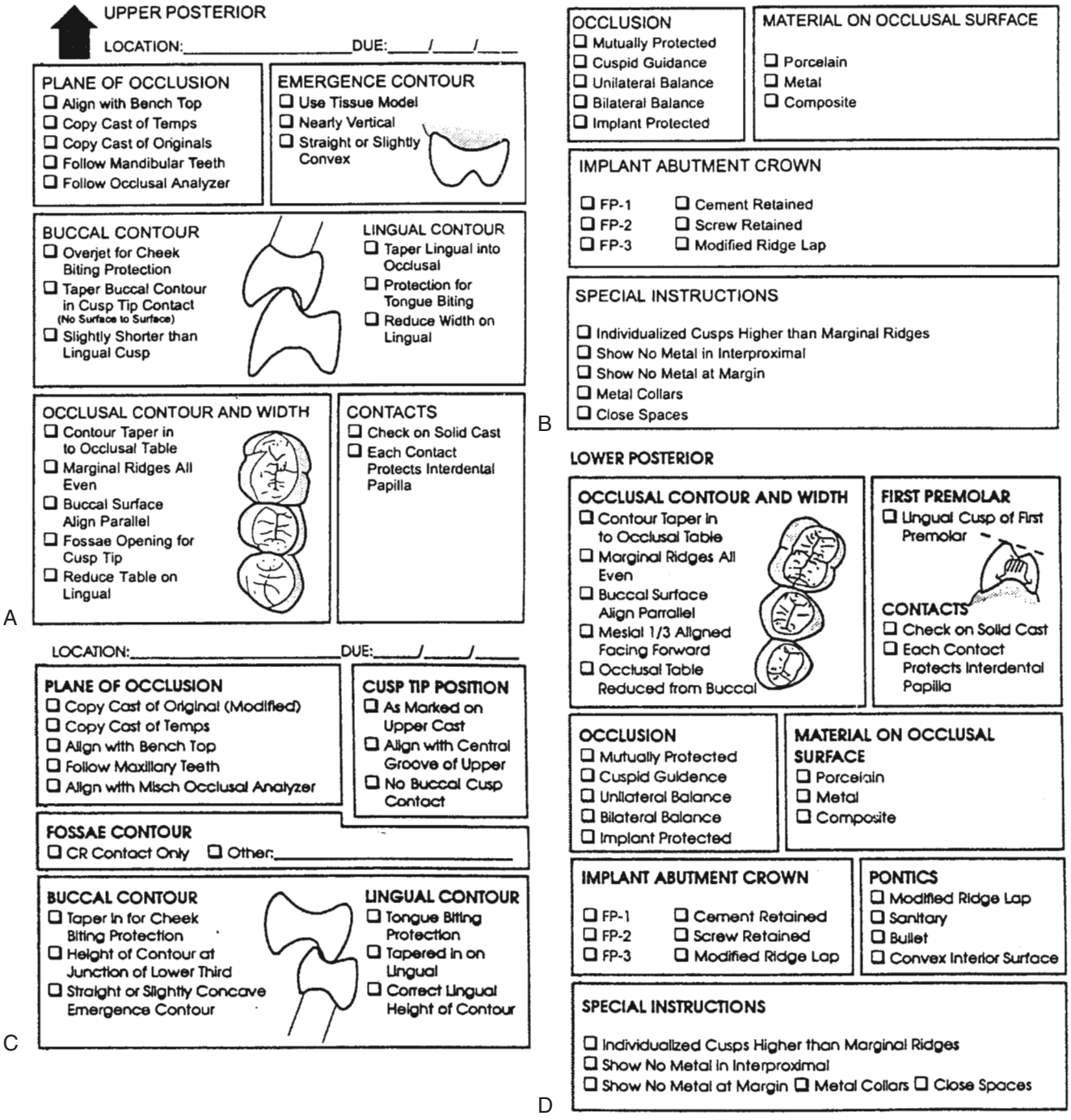


FIGURE 31-72. A laboratory sheet developed by Peter Dawson and Carl Misch permits the doctor to communicate the implant crown contour and primary occlusal contacts. A separate form for maxillary and mandibular posterior implant crowns helps the laboratory technician design the prosthesis. **A-C,** Maxillary crowns. **D,** Mandibular crowns.

Thus, for maxillary implants opposing mandibular natural teeth, the mandibular buccal cusp acts as the primary tooth contact. The dentist reduces the posterior maxillary crown only from the lingual aspect, compared with a natural maxillary molar, to reduce the occlusal table width. Such a reduction increases the lingual overjet when the teeth are in occlusion, which is of no consequence relative to esthetics or tongue biting.

For maxillary and mandibular implants opposing each other, the facial cusp of the maxillary crown is required for esthetics. The other contours of the opposing crowns are reduced in width to minimize the occlusal table width and axially load the implants. When axially loading both arches is not possible, the weakest arch is favored. This usually is the maxilla because of lesser bone density. In conclusion, whenever possible, occlusal contacts should be avoided on the areas of an implant crown that are not supported directly by an axially positioned implant. Alternatively, several additional implants should be used to dissipate the force.

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Division B Bone

In division B bone, maxillary and mandibular implants are positioned more toward the lingual cusp of the original natural tooth position. As a result, the buccal aspect of the mandibular crowns is further reduced to avoid offset occlusal contacts. The primary occlusal contact on an opposing natural posterior maxillary tooth is the lingual cusp, which is reshaped to load the implant axially. The buccal cusp of the mandibular implant crown is located toward the original central fossa of the natural tooth. The medially positioned division B mandibular implant crown may have a central fossa, but it is more lingual than the original position. The lingual contour of the crown is similar to that of the original natural tooth and with proper horizontal overlap with the opposing natural tooth to prevent tongue biting.

The mandibular posterior implant on occasion may be angled lingually to avoid the undercut of the submandibular fossa. As a result, an angled abutment and a straight lingual emergence are used to minimize the lingual volume of the restoration. Under these conditions, augmentation of the mandibular division B ridge may be required when stress factors are moderate to improve the implant position and prosthetic guidelines.

In a division B maxillary bone situation, the implant is placed more toward the palatal cusp region of the original natural tooth. The maxillary occlusal table cannot always be reduced from the facial aspect for esthetic reasons; therefore, the buccal cusp is offset facially but left completely out of occlusion (as with natural teeth) in CO and during all mandibular excursions. The buccal cusp of the opposing natural tooth is recontoured in width and height to reduce offset loads to the opposing crown on the maxillary implant. The palatal cusp angle is reduced and a flat area, parallel to the occlusal plane, over the implant abutment is designed in the implant crown. The primary occlusal contact in CR occlusion is the maxillary palatal cusp over the implant body and the central fossa region of the mandibular natural tooth. Bone augmentation for the placement of wider implants is more indicated in the maxilla than the mandible because of the less dense bone and the prosthetic needs to replace an esthetic buccal crown contour.

In the presence of division B bone in both edentulous arches, the maxillary and mandibular prostheses are similar to that described in the previous scenario. However, placement of axial loads on both arches usually is not possible, and the weakest implant related to bone density, width, or prosthesis type (fixed vs. removable) determines the axial load requirements because it is the most vulnerable arch.

Division C and D Maxillae

On occasion, the maxillary ridge atrophy from division A to C or D bone results with the maxillary ridge under the position of the maxillary lingual cusp tip. A sinus graft restores the available bone height but does not reposition the resorbed residual ridge. As a consequence, the implant may be inserted under the lingual cusp of the maxillary tooth.

When mandibular natural teeth oppose maxillary implant crowns, the buccal cusps of natural mandibular teeth (or crowns on implants) should be recontoured to minimize offset loads in CR occlusion. The dentist then may retain the maxillary buccal cusp for esthetics but reduce the functional occlusal table.

In posterior esthetic regions of the maxilla (cervical high lip line during smiling), a wider occlusal table is required for proper facial contours and esthetics. Bone grafting to increase width may be required in these esthetic zones along with placement of a larger-diameter implant to permit restoration of the proper cervical and buccal contours with emergence profiles for esthetics and maintenance. Ideally, the dentist positions the implant platform between the buccal cusp and central fossa position, with a facial emergence similar to an anterior implant position.

Nonesthetic areas such as the distal half of the first molar and the second molar may often be restored in crossbite when these conditions exist to improve the direction of forces. The implant ideally is placed in these cases directly over the lingual cusp of the mandibular tooth. Occlusal contacts over the implant body are located in the maxillary widened central fossa of the crown. The maxillary lingual horizontal overlap is designed for protection from tongue biting. The mandibular buccal cusp is more buccal than the maxillary buccal cusp for protection from cheek biting.

Conclusion

The implant body should be loaded in an axial direction. In a division A maxillary ridge the implant can be placed between the central fossa region and buccal cusp of the natural teeth. The buccal cusp of the natural tooth in the mandibular arch is the dominant occluding cusp. The palatal contour of the maxillary posterior implant crown is reduced to eliminate offset loads. The position of the maxillary buccal cusp should remain similar to that of the original tooth for proper esthetics and should remain out of occlusion in CR and all mandibular excursions. When further resorption occurs and the ridge evolves into division B to C bone, the maxillary palatal cusp may become the primary contact area, situated directly over the implant body. The palatal cusp angle is reduced, and a contact area is created directly over the implant abutment. Hence, the occlusal contacts differ from those of a natural tooth.

In mandibular division A bone, the implant is located under the central fossa, but in division B, the implant is located closer to the lingual cusp region of the preexisting natural tooth. In other words, mandibular endosteal implants are always positioned more medial than the original buccal cusp of the natural tooth. All occlusal contacts are in a widened central fossa and often more medial than those on natural mandibular teeth.

In the edentulous maxilla, a full-arch prosthesis may be fabricated in one section. However, the dentist may elect to place two rigid attachments (Pin Des Marets) distal to the canine. This maintains the biomechanics of an arch, yet the prosthesis may be removed in three sections to facilitate the management of uncemented restoration or porcelain fracture. The anterior lateral forces generated during excursions should be distributed to the anterior teeth only. However, the one-piece rigid structure does distribute a reduced force to some posterior implants. Seven to 10 maxillary implants most often are required for a 12-unit fixed prosthesis opposing a fixed dentition on teeth or implants with moderate to severe stress factors. Posterior implants are more critical in the maxilla to eliminate posterior cantilevers and increase the anteroposterior implant distance, which further decreases stress to the maxillary anterior implants.

Summary

Any complex engineering structure typically will fail at its weakest link, and dental implant structures are no exception.

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Thus, all treatment planning decisions for IPO should be based on careful consideration of (1) identifying the weakest link in the overall restoration and (2) establishing occlusal and prosthetic schemes to protect that component of the structure.

The local occlusal considerations in implant dentistry include the transosteal forces, bone biomechanics, basic biomechanics, differences in natural teeth and implants, muscles of mastication and occlusal force, and bone resorption. The incorporation of these factors leads to an occlusal scheme (IPO) developed by the author.

In this chapter, clinical considerations are drawn from basic prosthetic concepts, bone biomechanical principles, and finite element analyses to reduce noxious occlusal loads and establish a consistent occlusal philosophy. The IPO concept addresses several conditions to decrease stress to the implant system, including implant body angle to occlusal load, cusp angle of crowns, mutually protected articulation, cantilever or offset distance, crown height, crown contour, the timing of occlusal contacts, and protection of the weakest component. The implant body should ideally be loaded in the long axis of force (perpendicular to the occlusal plane). The occlusal contact in posterior regions should be over the implant (most often in the central fossa of the crown). Mutually protected occlusion should eliminate all lateral forces to the posterior implant restorations. Cantilevers should be eliminated in the complete edentulous maxilla and partially edentulous patients of either arch. When crown heights are greater than 15 mm, the cantilevers in the edentulous mandible should be reduced. The timing of occlusal contacts in partially edentulous patients should form the natural teeth. The weakest component in the system should be protected from occlusal forces. This chapter blends experience and biomechanical principles for a consistent approach to occlusal considerations.

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CHAPTER 32

Progressive Bone Loading: Increasing the Density of Bone with a Prosthetic Protocol

Carl E. Misch

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The surgical and prosthetic protocols for the development of a predictable direct bone–implant interface with root-form implants were developed and reported by Brånemark et al.[1] After an initial direct bone–implant interface has been obtained and confirmed at the posthealing stage II surgery, the implant is most at risk for failure or crestal bone loss within the first year after loading.[2–8] Failure and crestal bone loss occurs primarily from excessive occlusal stress or poor bone strength at the interface during early implant loading. If the treatment plan provides adequate support, the three most common causes of early prosthetic-related implant complications are nonpassive superstructures, partially unretained restorations, and loading of the implant support system beyond the strength of the bone–implant interface.[9,10]

The external (cortical) and internal (trabecular) structure of bone may be described in terms of quality or density, which reflects a number of biomechanical properties, such as strength, modulus of elasticity, bone implant contact percent, and stress distribution around a loaded endosteal implant (Box 32-1). The density of available bone in an edentulous site is a determining factor in treatment planning, surgical approach, implant design, healing time, and the need for initial progressive bone loading during prosthetic reconstruction.[11–15]

Influence of Bone Density on Implant Success Rates

Several independent groups have reported different failure rates related to the quality of the bone. In fact, the early implant failure most often is more related to bone density than arch location. For example, Zarb and Schmitt reported early loading failures in 3.3% of primarily completely edentulous mandibular patients with good-quality bone.[16] Naert and Quirynen observed a 2.5% early loading failure rate in partially edentulous patients.[8] Salonen et al. reported a 3.9% failure rate in a study of 204 implants.[7]

BOX 32-1 Biomechanical Properties of Bone

1. Strength
2. Modulus of elasticity
3. Bone–implant contact percent
4. Stress distribution

On the other hand, a more early loading failure is also reported, especially in softer bone types. For example, Johns et al. reported 3% failure of implants in moderate bone densities but a 28% implant failure in the poorest bone type.[17] Engquist et al. observed that 78% of all reported implant failures were in soft bone types when they supported overdentures.[18] Friberg et al. observed that 66% of implant failures occurred in the resorbed maxilla with soft bone.[19] Jaffin and Berman, in a 5-year report, observed a 44% implant failure when poor density bone was observed in the maxilla and 35% implant loss in any region of the mouth when bone density was poor, with 55% of all implant failures in the soft bone type.[4] Smedberg et al. reported a 36% failure rate in the poorest bone density.[20]

Hermann et al. found that implant failures were strongly correlated to patient factors, including bone quality, especially when coupled with poor bone volume (65% of these patients experienced failure).[21] Schnitman et al. reported 22% failure in the soft bone of the posterior maxilla and a 0% failure in the good bone of the anterior mandible during a 3-year period[3] (Figure 32-1). Jemt et al., reported early implant failures as great as 35%, especially in poor bone quality, after successful surgical survival of implants.[5] Sullivan et al. reported late failures in 7% of the maxillae and 1.4% of mandibles after reverse torque testing had identified 6.4% maxillary and 3.2% mandibular implant failures at stage II recovery.[22]

These reported failures are not primarily related to surgical healing but instead occur after prosthetic loading. In other words, early loading failure rate has a wide range of survival, with many reports noting that poor bone density dramatically increases the risk of failure. Therefore, over the years, many independent clinical groups, following a standardized surgical and prosthetic protocol, documented the influence of bone density on clinical success.[23–25]

In a report of 22,177 implants, Root Laboratory found that 5.9% of the implants were lost from the final impression to the initial delivery of the prosthesis.[26] The 22,177 implants were used to restore 7403 patients, and each implant prosthesis averaged three implants. The number of prostheses affected by 5.9% implant failure was 15% of the restorations (Table 32-1). In other words, when early implant failure is reported, the number of restorations affected may be multiplied by approximately three times. Hence, early loading failure is a considerable risk to both patient and restoring dentist.

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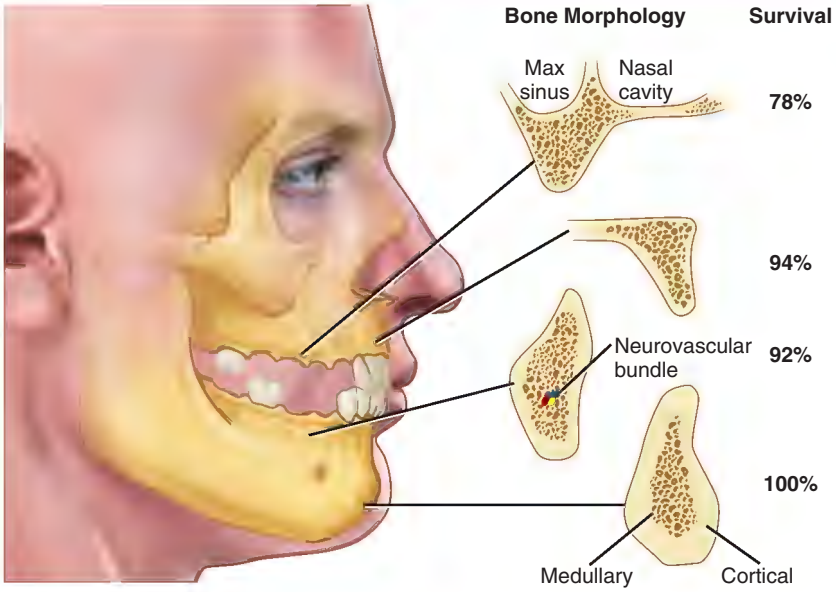


FIGURE 32-1. The implant survival rate over a 3-year period, as reported by Schnitman et al., ranged from 100% in the anterior mandible to 78% in the posterior maxilla.[3]

TABLE 32-1
Implant versus Prostheses Failure

	Total Root Forms*
7403 patients	22,177 implants
7403 patients	1107 (15.0%) lost one or more*
22,177 fixtures	1319 (5.9%) lost*

*Loss occurred between final impression and time of loading.
Data from Root Laboratory: *Statistics report on implant and prosthesis failure during the first year,* Leawood, KS, 1992, Root Laboratory.

TABLE 32-2
Early Loading Failure in Soft Bone

Reference	Early Loading Failure (%)
Johns et al.[17]	28
Jaffin and Berman[4]	35
Smedberg et al.[20]	36
Jemt et al.[5]	35
Misch et al.[27]	0
Misch et al.[29]	0
Kline et al.[31]	1
Misch et al.[30]	1

Misch first proposed the concept of progressive or gradual bone loading during prosthetic reconstruction to decrease early implant failure in 1980 based on empirical information.[27] The theory was that bone reacts to mechanical stress similar to a muscle. When it is not stimulated, the muscle (bone) becomes weaker. It was logical to assume when the muscle (bone) is stimulated, the muscle (bone) will become stronger.

A protocol established by the author in 1988, which adapts the treatment plan, implant selection, surgical approach, healing regimen and initial prosthetic loading, has resulted in similar implant success rates in all bone densities and all arch positions.[12–15] Misch et al. reported on 364 consecutive implants in 104 patients with 98.9% survival at stage II uncovery followed by a progressive loading format and found no early loading failures during the first year of function.[28] In another report by Misch et al., no early loading failures were observed in the posterior maxilla over a 5-year period with 453 implants and 131 prostheses using a bone density–based implant design and progressive bone loading.[29] A 10-year report by Misch et al. of short implants using progressive loading observed a 99.5% success rate during this time frame.[30] Kline et al. also reported a 99.5% success rate at 5 years for 495 implants following a similar progressive loading approach[31] (Table 32-2).

Over the years, the author has evaluated and modified this concept to incorporate time intervals, diet, occlusion, prosthesis design, and occlusal materials. In addition, it was noted that early crestal bone loss in softer bone types was also reduced with a gradual loading process.[32,33] This chapter presents the aspects of bone density related to progressive loading of an implant prosthesis.

Etiology of Variable Bone Density

Bone is an organ that is able to change in relation to a number of factors, including hormones, vitamins, and mechanical influences. However, biomechanical parameters, such as the amount of strain transmitted to bone, are predominant.[34] Awareness of this adaptability in the skeletal system has been reported for more than a century. In 1887, Meier qualitatively described the architecture of trabecular bone in the femur.[35] In 1888, Kulmann noticed the similarity between the pattern of trabecular bone in the femur and stress trajectories in construction beam concepts used by Eiffel[36] (Figure 32-2). Wolff, in 1892, further elaborated on these concepts and published, "Every change in the form and function of bone or of its function alone is followed by certain definite changes in the internal architecture, and equally definite alteration in its external conformation, in accordance with mathematical laws."[37] The modified function of bone and the definite changes in the internal and external formation of the vertebral skeleton as influenced by mechanical load were also reported by Murry.[38]

When bone is not stimulated enough, the bone mass and size are reduced. This phenomenon occurs throughout the skeletal system as evidenced by a 15% decrease in the cortical plate

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FIGURE 32-2. The trabecular bone in the femur is arranged to resist the stress trajectories of the body during function.



FIGURE 32-3. The biomechanical function of the maxilla is a force distribution unit. The mandible is a force absorption unit.



FIGURE 32-4. The dentate mandible has a dense to porous cortical plate surrounding coarse trabecular bone.

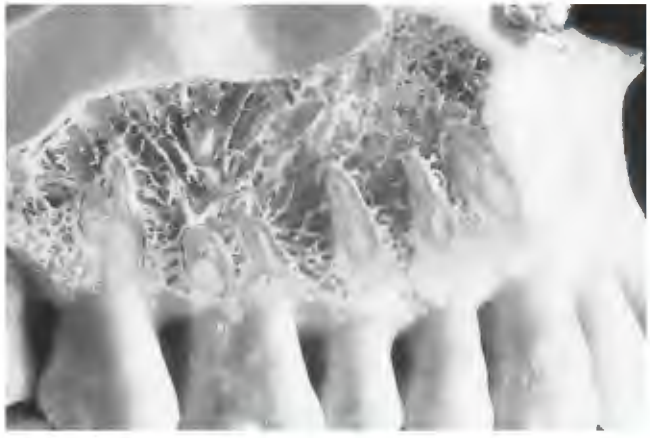


FIGURE 32-5. The dentate maxilla has a thinner porous cortical plate with fine trabecular bone.



FIGURE 32-6. The bone around the teeth is a cortical lining and is usually more dense near the crest and least dense between the root apices.

and extensive trabecular loss to bone immobilized for 3 months.[39] Cortical bone decrease of 40% and trabecular bone decrease of 12% also have been reported in response to disuse.[40,41] On the other hand, bone also can respond to increased stress, if within physiologic limits, by an increase in density.[42] Dahlin and Olsson report an increase in cortical bone thickness and overall mineral content under stressful stimuli.[43] Weight lifters have skeletal systems with larger diameter and more dense bone. Professional tennis players have larger-diameter wrists, humeri, and ulnas on their dominant playing arms. Hence, bone loss or gain may occur in relation to the amount of strain to the skeletal system.

The structural changes in bone as a consequence of mechanical influences have also been noted in the jaws. As example, both MacMillan and Parfitt have reported on the structural characteristics and variation of trabeculae in the alveolar regions of the jaws.[43,44] The maxilla and mandible have different biomechanical functions (Figure 32-3). The mandible, as an independent structure, is designed as a force absorption unit. Therefore, when teeth are present, the outer cortical bone is denser and thicker, and the trabecular bone is more coarse (Figure 32-4). On the other hand, the maxilla is a force distribution unit. Stresses to the maxilla are transferred by the zygomatic arch and palate away from the brain and orbit. As a consequence, the maxilla has a thin cortical plate and fine trabecular bone surrounding the teeth (Figure 32-5).

Neufeld noted that the bone is most dense around the teeth (cribriform plate) and more dense around the teeth at the crest compared with the regions around the apices[45] (Figure 32-6).

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Alveolar bone resorption associated with orthodontic therapy also illustrates the biomechanical sensitivity of the alveolar processes.[46,47] Orban demonstrated a decrease in the trabecular bone pattern around a maxillary molar with no opposing occlusion compared with a tooth with occlusal contacts on the contralateral side[48] (Figure 32-7).

Bone density in the jaws also decreases after tooth loss. This loss is primarily related to the length of time the region has been edentulous and not appropriately loaded, the initial density of the bone, flexure and torsion in the mandible, and parafunction before and after tooth loss.[49–51] In general, the density change after tooth loss is greatest in the posterior maxilla and least in the anterior mandible.

Misch Bone Density Classification

Dense or porous cortical bone is found on the outer surfaces of bone and includes the crest of an edentulous ridge. Coarse and fine trabecular bone types are found within the outer shell of cortical bone and occasionally on the crestal surface of an edentulous residual ridge. These four macroscopic structures of bone may be arranged from the most dense to the least dense, as first described by Frost and Roberts: dense cortical bone, porous cortical bone, coarse trabecular bone, and fine trabecular bone[34,52] (Figure 32-8). In combination, these four macroscopic densities constitute the four bone categories described by Misch (D1, D2, D3, and D4) located in the edentulous areas of the maxilla and mandible[13] (Figure 32-9). The regional locations of the different densities of cortical bone are more consistent than the highly variable trabecular bone.

D1 bone is primarily dense cortical bone. D2 bone has dense-to-porous cortical bone on the crest and lateral to the implant site. The bone within this cortical housing has coarse trabecular bone (Figure 32-10). D3 bone types have a thinner porous cortical crest and facial and lingual regions, with fine trabecular bone in the region next to the implant (Figure 32-11). D4 bone has almost no crestal cortical bone and porous cortical lateral plates. The fine trabecular bone comprises almost all of the total volume of bone next to the implant (Figure 32-12). The bone density may be determined by the general location,



FIGURE 32-8. The different types of bone appear different and have different densities[34]: *1*, fine trabecular bone, *2*, coarse trabecular bone, *3*, porous cortical bone, and *4*, dense cortical bone.

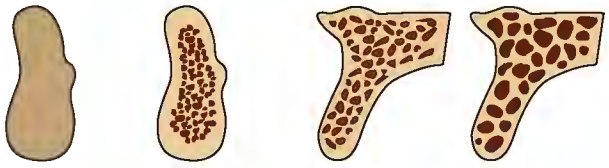


FIGURE 32-9. Type D1 bone *(far left)*, when found, is usually in the anterior mandible. Type D2 bone is found in either jaw but is more common in the mandible. Type D3 bone is often found in the maxilla and posterior mandible. Type D4 bone is often found in the posterior maxilla.

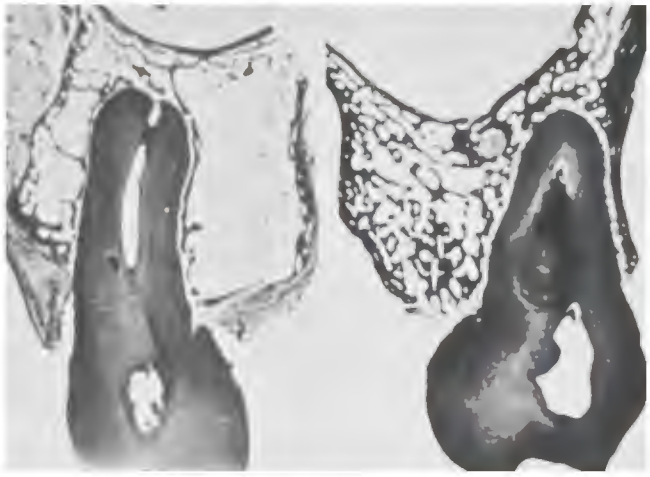


FIGURE 32-7. The molar on the left was unopposed with no occlusal function. The molar on the right opposed a natural tooth. The alveolar process bone density reflects the function of the tooth.[48]



FIGURE 32-10. An anterior mandible with type D2 bone has porous to dense cortical plate on the crest and coarse trabecular bone around the implant site.

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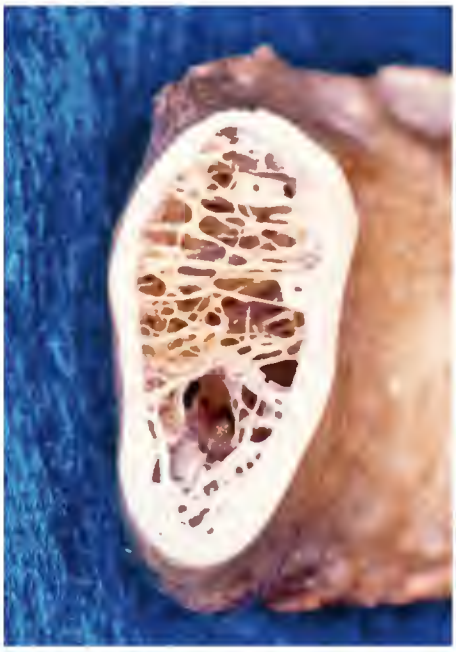


FIGURE 32-11. A posterior mandible with type D3 bone has porous cortical bone on the crest and fine trabecular bone in the implant site.



FIGURE 32-12. A posterior maxilla with type D4 bone has primarily fine trabecular bone in the implant site.

tactile sense during surgery, or computerized radiographic evaluation.

Scientific Rationale of Bone Density–Based Implant Treatment

Numerous investigators have generated in vitro data to determine the direct relationships of elastic modulus, structural density, and ultimate strength of bone to the relative density of bone.

Bone Strength and Density

Bone density is directly related to the strength of bone before microfracture.[53] The bone densities that originally relied on clinical impression are now fully correlated to quantitative objective values obtained from computed tomography scans

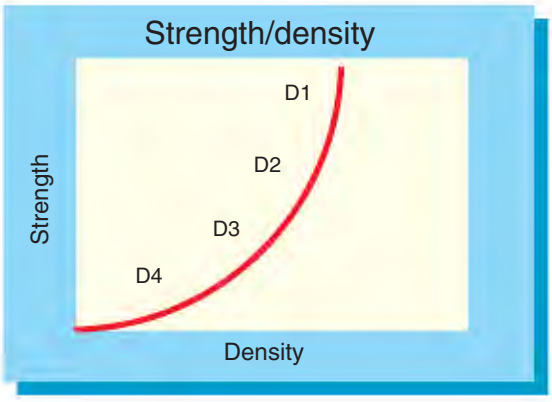


FIGURE 32-13. The different densities of bone have a different strength. Type D1 bone is strongest, and type D4 bone is the weakest.

BOX 32-2 Strength of Bone by Density (Scale of 1–10)

D1 bone	9, 10
D2 bone	7, 8
D3 bone	3, 4
D4 bone	1, 2

and bone strength measurements. These values can help prevent failure in specific situations of weak densities. Misch et al. reported on the mechanical properties of trabecular bone using the Misch density classification.[54] A 10-fold difference in bone strength may be observed from D1 to D4 bone (Figure 32-13). D2 bone exhibited a 47% to 68% greater ultimate compressive strength compared with D3 bone. In other words, on a scale of 1 to 10, D1 bone is a 9 to 10 relative to strength, D2 bone is a 7 to 8 on this scale, D3 bone is 50% weaker than D2 bone and is a 3 or 4 on the strength scale and D4 bone is a 1 to 2 and up to 10 times weaker than D1 bone (Box 32-2).

It should be noted that the strength of bone studies were performed on mature bone types. Bone is 60% mineralized at 4 months after implant surgery, and the strength of bone is related to the amount of mineralization. Hence, it is rational to wait longer before loading an implant when the bone density is D3 or D4. A healing period after surgery of 3 to 4 months is adequate for D1 and D2 bone. A healing period of 5 to 6 months is beneficial in D3 to D4 bone.

Elastic Modulus and Density

The elastic modulus describes the amount of strain (changes in length divided by the original length) as a result of a particular amount of stress. It is directly related to the apparent density of bone.[55] The elastic modulus of a material is a value that relates to the stiffness of the material. The elastic modulus of bone is more flexible than titanium. When higher stresses are applied to an implant prosthesis, the titanium has lower strain (change in shape) compared with the bone. The difference between the two materials may create microstrain conditions of pathologic overload and cause implant failure. When the stresses applied to the implant are low, the microstrain difference between titanium and bone is minimized and remains in the adapted window zone, maintaining load-bearing lamellar bone at the interface.[56]

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Misch et al. found the elastic modulus of the trabecular bone in the human jaw to be different for each bone density[54] (Figure 32-14). As a result, when a stress is applied to an implant prosthesis in D1 bone, the titanium–D1 bone interface exhibits very small microstrain difference. In comparison, when the same amount of stress is applied to an implant in D4 bone, the microstrain difference between titanium and D4 bone is greater and may be in the pathologic overload zone (Figure 32-15). As a result, D4 bone is more likely to cause implant mobility and failure. Conclusions agree with prior reports and show the importance of bone quality in the treatment planning and early loading phase for improved long-term prognosis.

Bone Density and Bone–Implant Contact Percentage

The initial bone density not only provides mechanical immobilization of the implant during healing but after healing also permits distribution and transmission of stresses from the prosthesis to the implant–bone interface. The mechanical distribution of stress occurs primarily where bone is in contact with the implant. Open marrow spaces or zones of unorganized fibrous tissue do not permit controlled force dissipation or microstrain conditions to the local bone cells. Because stress equals force divided by the area over which the force is applied, the less the area of bone contacting the implant body, the greater the overall stress, other factors being equal. Therefore, the bone–implant contact (BIC) percent may influence the amount of stress and strain at the interface.

In 1990, Misch noted that the bone density influences the amount of bone in contact with the implant surface, not only at first-stage surgery but also at the second-stage uncovery and early prosthetic loading.[13] The BIC percentage is significantly greater in cortical bone than in trabecular bone. The very dense D1 bone provides the highest percentage of bone in contact with an endosteal implant and may approximate more than 85% BIC (Figure 32-16). D2 bone, after initial healing, usually has 65% to 75% BIC. D3 bone typically has 40% to 50% BIC after initial healing (Figure 32-17). The sparse trabeculae of the bone often found in the posterior maxilla (D4) offer fewer areas of contact with the body of the implant. With a machined-surface implant, this may approximate less than 30% BIC and is most related to the implant design and surface condition (Figure 32-18).

Consequently, greater implant surface area is required to obtain a similar amount of BIC in soft bone compared with a denser bone quality.[6] As a result, many anterior mandibles with more dense bone have less importance of implant number, size, implant design, or progressive loading compared with posterior maxillae with less dense bone.

Bone Density and Stress Transfer

Crestal bone loss after loading may occur from excess stress at the implant–bone interface.[32,33,57] A range of marginal bone loss has been observed in implants in different bone densities with similar load conditions. In the study by Manz, the loss of central bone around an implant loaded for 6 months after stage II uncovery was directly related to the density of the bone. D1 bone lost the least marginal bone and D4 bone lost the most during the 6-month period.[58] Misch and Bidez noted in 1990 that part of this phenomenon may be explained by the evaluation of finite element analysis (FEA) stress contours in the different volumes of bone for each bone density.[59]

Early implant failure may also be related to the difference in stress transfer between different bone densities. Misch and Bidez performed a three-dimensional finite stress element analysis on patients with bone volumes of division A, B, and C minus width.[59] Each volume of bone consisted of cortical and trabecular models with four macroscopic bone densities

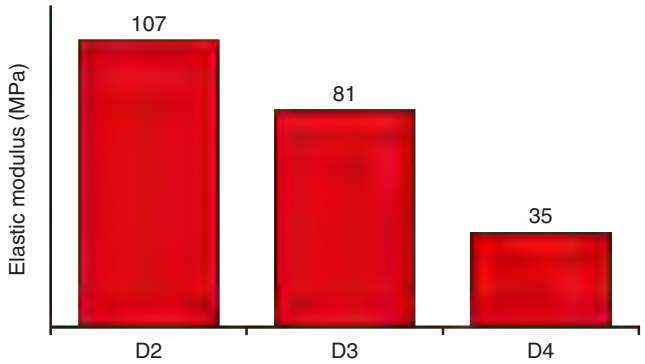


FIGURE 32-14. The elastic modulus of the trabecular bone is different for each bone density. D2 trabeculae are more stiff than D4 bone trabeculae.

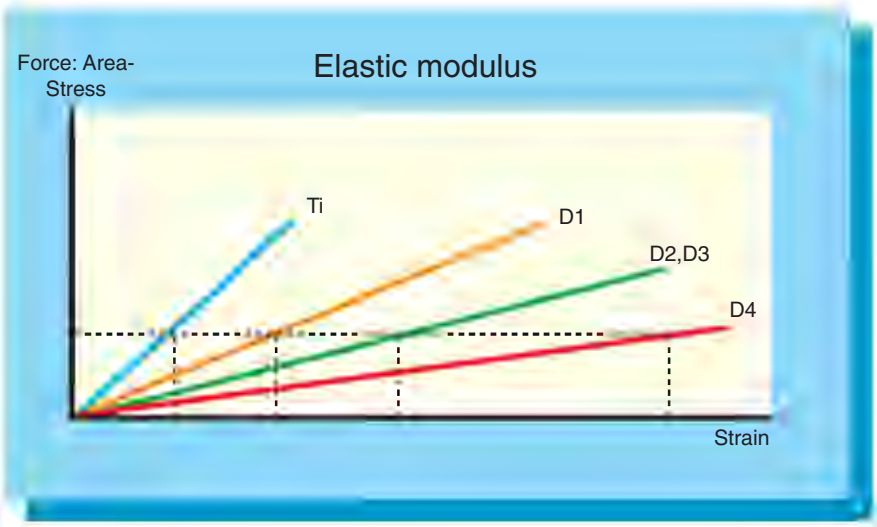


FIGURE 32-15. The biomechanical mismatch of titanium to bone is different for each bone density. The smallest difference is for D1 bone, and the greatest difference is for D4 bone.

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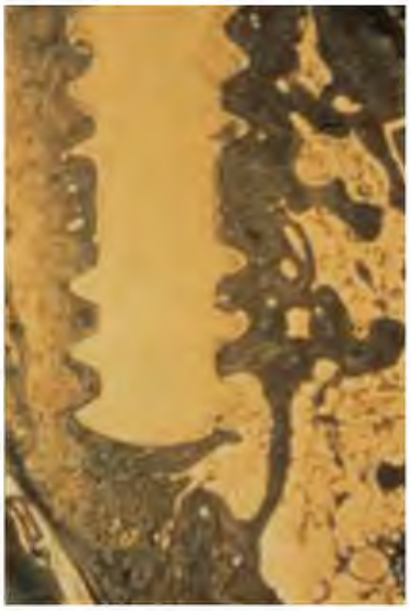


FIGURE 32-16. The bone–implant contact for D1 bone is highest.



FIGURE 32-17. The bone–implant contact for D2 bone is usually 65% to 75% after healing.

corresponding to D1 (100%), D2 (75%), D3 (50%), and D4 (25%). The authors observed a correlation between bone volume strength and density. Clinical failure was mathematically predictable in all D4 bone models and two of the D3 densities, depending on the bone volume.

Other studies using FEA models with various implant designs and bone quality have also evaluated the stress–strain distribution in the bone around the implants.[60,61] For example, Tada et al. evaluated the three-dimensional changes around different length implants in different bone qualities[62] (Figure 32-19). The type 3 and 4 bone categories had four to six times more strain around all implants, with the highest strains around the shortest implants.

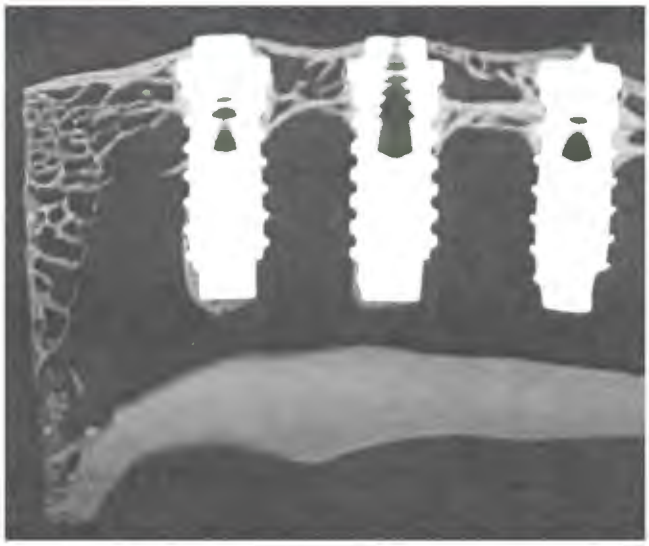


FIGURE 32-18. The bone–implant contact for D4 bone is less than 30% after initial healing.

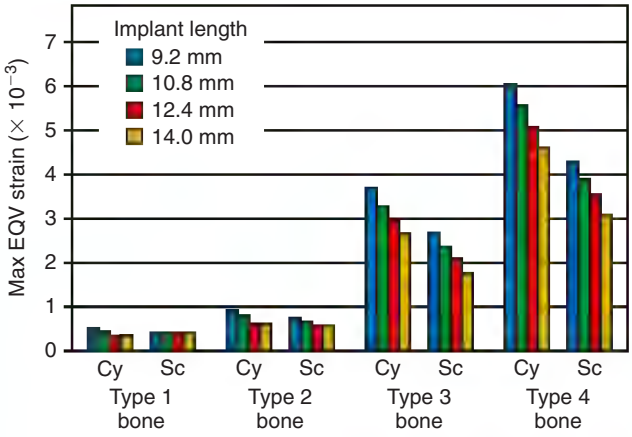


FIGURE 32-19. The density of bone affects the strain conditions around an implant. Types 3 and 4 bone have four to six times more strain than type 1 or type 2 bone, regardless of implant length.[62] *Cy*, Cylinder implant design; *EQV*, equivalent; *Sc*, screw implant design.

As a result of the correlation of bone density to the elastic modulus and BIC percent, when a load is placed on an implant, the stress contours in the bone are different for each bone density.[63] In D1 bone, the highest strains are concentrated around the implant near the crest, and the stress in the region is of lesser magnitude. D2 bone, with the same load, sustains a slightly greater crestal strain, and the intensity of the stress extends farther apically along the implant body. D4 bone exhibits the greatest crestal strains, and the magnitude of the stress on the implant proceeds farthest apically along the implant body.

Hence, dental literature review of failures, orthopedic literature of bone remodeling, literature regarding bone mechanics of the jaws, and FEA suggest the softer bone types have higher risk of implant failure.[64] As a consequence of different elastic modulus, BIC, strain regions found around implants with different bone densities, and strength of bone related to density, the magnitude of a prosthetic load may remain similar and yet give one of the following three different clinical situations at the bone–implant interface based on the bone density around

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the implant: (1) physiologic bone loads in the adapted window zone and no marginal bone loss, (2) mild overload to pathologic overload bone loads and crestal bone loss, or (3) generalized pathologic overload and implant failure. Therefore, to obtain a similar clinical result in each implant prosthesis, the variables in each patient must be either eliminated, reduced, or accounted for in the treatment plan.

Because the myriad of variables cannot be eliminated relative to bone density, the treatment plans (including implant number, size, and design) should be modified. Progressive bone loading for the softest bone types also increases bone density and its associated mechanical factors of strength, modulus of elasticity, BIC, and stress transfer.

Rationale for Progressive Loading

Bone Physiology

Cortical and trabecular bone throughout the body are constantly modified by either modeling or remodeling.[65] Modeling has independent sites of formation and resorption and results in the change of the shape or size of bone. Remodeling is a process of resorption and formation at the same site that replaces previously existing bone and primarily affects the internal turnover of bone, including the region where teeth are lost or the bone next to an endosteal implant. These adaptive phenomena have been associated with the alteration of the mechanical stress and strain environment within the host bone.[66]

Bone responds to hormonal and biomechanical regulation.[67] However, even in instances in which the demand for calcium is great (the primary objective for hormonal regulation), functional loading can compete and maintain bone mass.[68] Most women are aware of increased risk of osteoporosis after menopause and hormonal changes, yet bone loss (or gain) is more controlled by mechanical factors than hormones. Even in an animal with calcium levels in the blood so low that death may occur, when the limbs are exercised, the bone takes the calcium from the blood to increase its strength, and the animal dies. In other words, the mechanical stimulation of bone can cause cellular events that can even override life.[69]

Stress is determined by the magnitude of force divided by the functional area over which it is applied. *Strain* is defined as the change in length of a material divided by the original length. The greater the magnitude of stress applied to the bone, the greater the strain observed in the bone.[70] Bone modeling and remodeling are primarily controlled, in part or whole, by the mechanical environment of strain. Overall, the density of trabecular bone evolves as a result of mechanical deformation from microstrain. The deformation of the alveolar bone by mechanical forces even is related to the thickness of the bony plate.

Clinical evaluation confirms an increase in the amount of trabecular bone and cortical plate thickness in patients with natural teeth exhibiting parafunction. A dentist can observe these bone density changes when attempting to extract teeth. In a severely parafunctional patient, the tooth usually fractures when attempting to remove it because the surrounding bone is stronger than the tooth. In a maxillary posterior second molar unopposed by any mandibular tooth, the bone is so soft that the complete tuberosity and surrounding bone fractures and the tooth and attached surrounding bone are removed as one piece.

Frost proposed that bone mass is a direct result of the mechanical usage of the skeleton.[52,71–73] He redeveloped a mechanical adaptation chart relating trivial loading, physiologic loading, overloading, and pathologic loading zones to ranges of microstrain. His studies demonstrated increases in cortical bone mass related to strains applied to the bone (Figure 32-20). These categories also may be used to describe the trabecular bone response next to a dental implant in the jaws.[56,74,75]

The actual strain perceived by the bone tissue initiates a chain reaction of events that result in a biological response. Cowin and Hegedus proposed potential mechanisms by which bone cells sense mechanical load.[76,77] They suggested that cell-level strains were almost 10 times greater than tissue-level strains. The proposed cellular mechanisms include membrane deformation, intracellular action, and extracellular action.

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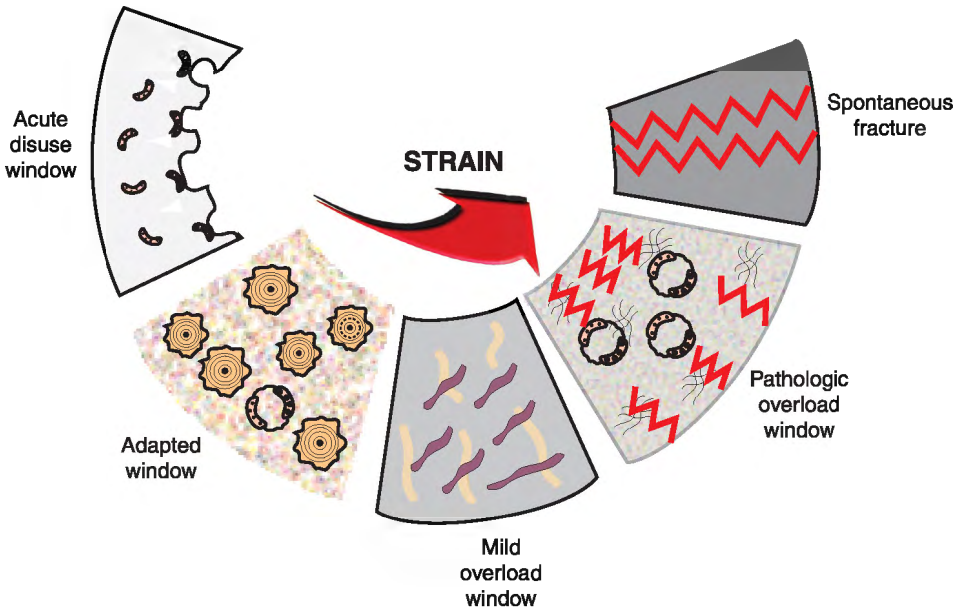


FIGURE 32-20. The microstrain conditions applied to bone determine the cellular events. The ideal loading zone is the adapted window. The pathologic overload zone causes bone resorption.

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Bone cells and the extracellular matrix comprise the strain-sensitive population, and each plays a vital role in the mediation of the interface. A review of the literature of in vivo and in vitro studies has shown that dynamic or cyclic loading is necessary to cause a significant metabolic change in the bone cell population.[78–84] The greater the rate of change of applied strain in bone, the more bone formation is increased.[85] The effect of applied strains on bone is dictated not only by the rate of the applied load but also by the magnitude and duration.

In other words, the prosthetic loading of the dental implant changes the number and density of bone cells. Cyclic loading is necessary to cause a significant metabolic change in bone cell population. Lower magnitude loads applied for many cycles can cause the same anabolic effects of larger loads applied for a limited number of cycles.[80] Therefore, a range of clinical conditions may equate to an increase in bone density, with prosthetic loading a logical condition for a dental implant.

Clinical Studies Supporting Progressive Loading

The biomechanical environment plays an intricate role in the quality and compositional outcome of the new implant-to-bone interface. Under loading, bone behaves as a structure with material and architectural properties and as a biological system.[86] Functional loading of the implant brings additional biomechanical influences, which greatly affect its maturation. Computer-aided assessment of fixated implants through digital subtraction radiographic image analysis and an interactive image-analysis system demonstrate an increase in density of periimplant bone structures over a 6-month to a 4-year period after the implant was placed.[87,88] The major changes of bone condensation around the implants occurred after the first 2 years they were loaded (Figure 32-21). Bone density increase is primarily reflective of the local stress factors, and endosteal implants are the major method to alter the strain and increase bone density in the edentulous jaws.[89] Continuously loaded implants remain stable within the bone with bone formation in areas under compression and the orientation of trabeculae corresponding to lines of stress.[89]

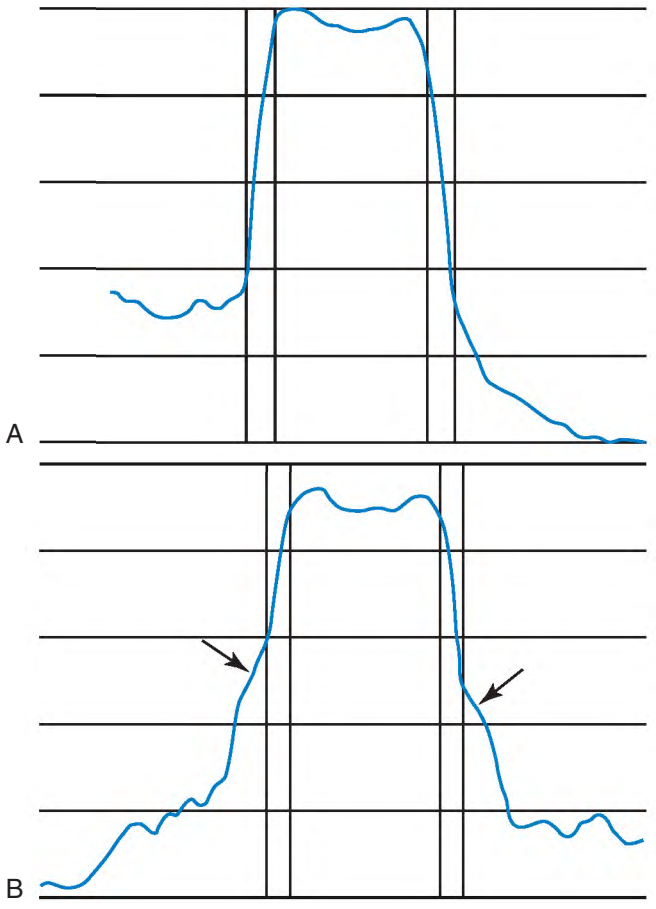


FIGURE 32-21. **A,** An implant interface after initial healing is weaker than the day of surgery because woven bone is primarily present next to the implant. **B,** After loading, the implant–bone interface is stronger than the original bone condition because the bone remodels in relation to the local strain condition.[87]

As bone responds to physiologic forces, a gradual increase in loads during prosthetic fabrication stimulates an increase in density. Pierazzini et al. has demonstrated the development of denser trabeculae around progressively loaded implants in animals.[90] Piattelli et al. performed histologic and histomorphometric study of bone reaction to unloaded and loaded nonsubmerged single implants in monkeys.[91] The bone interfaces of six implants, three loaded and three nonloaded, were evaluated after 15 months. Thicker regions of lamellar cortical bone appeared around the loaded implants compared with unloaded implants (Figure 32-22). The major bone increase in density and amount was observed in the crestal region around the loaded implants. Orthopedic implants causing a change in the loading environment elicited trabecular growth and realignment within the marrow space.[92,93]

The author evaluated clinical assessment of progressive loading guidelines for 250 implants over a 2-year period using a Periotest.[94] This instrument evaluates the dampening effect of implants, prostheses, and teeth, which is related directly to mobility. The Periotest values can range from −8 to +99. A range of −8 to + 9 Periotest value is applicable to a structure with an absence of clinical mobility. At uncovery, Periotest readings for implants in division D1 bone ranged from −8 to −3, with most in the −7 to −5 range. The implants in D2 bone registered Periotest values in the ranges of −5 to 0, with most recordings as −4 to −2 readings. The Periotest values for implants in D3 bone were measured from −3 to +1, and −1 was the most common Periotest value. For implants in D4 bone, Periotest values ranged from −2 to +6, with the most frequent readings between 0 and +2. As a general rule, the implants often recorded a more positive number when first uncovered, and the number became more negative with time. Almost all implants presented a more negative number after they had been in function for 1 year. After the first year of function, the Periotest values remained similar during the following year (Table 32-3).

The implants in D1 bone, after progressive loading, did not improve statistically, although a −7 Periotest value was recorded more often. The implants in D2 bone exhibited a mean decrease of 1 Periotest value. The implants in D3 bone had a slightly greater than 2 Periotest value decrease after progressive loading. The greatest change was seen in D4 bone. After progressive loading, the mean decrease in Periotest value was almost 4 units, with end Periotest values similar to many implants in D2 or D3 bone. Therefore, the poorer the bone density (D3 and D4), the more dramatic the decrease in Periotest values (which relates to mobility and density of bone around the implant). No strict linear relationship exists between load or time, a decrease in Periotest value, and an increase in bone density.

Rotter et al. compared the progressive loading protocol with extended healing periods.[95] Eight patients received 26 root-form

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FIGURE 32-22. **A,** An implant after initial healing may have fine trabecular bone in contact with the implant. **B,** After loading, the density of bone increases, especially in the crestal bone region.[91]

implants from various manufacturers. Fifteen implants were progressively loaded, and 11 implants were uncovered and remained with the permucosal extension (PME) until the final restoration was delivered. Periotest measurements were made on these 26 implants. The authors calculated the change in Periotest value readings from the time of stage II surgery until delivery of the final restoration (Table 32-4). The mean change for nonloaded (but extended healing time) group was a 0.27 Periotest value compared with a 1.51 Periotest value for the progressively loaded group. The progressively loaded D2 bone implants had Periotest score decreases of 1 point and the implant in D3 bone had Periotest score decreases of 2 points compared with a 0.3 Periotest value decrease for the longer healing period implants. Progressive loading improved readings

TABLE 32-3
Changes in Periotest Values during Progressive Bone Loading

	Periotest Values		Percentage of Implants
DI Implant			
Uncovery	−8 to −3	−8	20
		−7 to −5	60
		−4 to −3	20
After progressive loading	8 to −4		
Average PTV decrease	<1		
D2 Implant	−5 to 0	−5	14
Uncovery		−4 to −2	65
		−1 to 0	21
After progressive loading	−8 to 0		
Average PTV decrease	1		
D3 Implant			
Uncovery	−3 to +1	−3 to −2	15.5
		−2 to −1	26.5
		−1 to 0	51.5
		0 to +1	6.5
After progressive loading	−5 to 0		
Average PTV decrease	2		
D4 Implant			
Uncovery	−2 to +6	−2 to 0	30
		0 to +1	42
		+2 to +6	28
After progressive loading	−4 to +2		
Average PTV decrease	4		

PTV, Periotest value.

TABLE 32-4
Progressive Loading versus Longer Healing

Bone	Initial Periotest	Value	Change
Progressive Loading			
	D2	−3.15	−0.95
	D3	−0.45	−1.99
Nonprogressive Loading			
	D2	−2.71	−0.25
	D3	−0.83	−0.33

From Rotter et al.[95]

regardless of implant design, coating, or length (see Table 32-4). Hence, waiting longer before final loading does have some value, but the greatest component is when the implant interface is gradually loaded during the extended healing period.

Appleton et al. evaluated the periimplant bone changes in response to progressive osseous loading.[96] A randomized controlled clinical trial was designed to determine the effectiveness of progressive loading on maxillary single premolar implant crowns. In a pilot study, 13 hydroxyapatite-coated, cylindric implants were placed in 10 patients. The control group was restored immediately after 6 months of submerged healing with

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a metal–ceramic crown. The experimental group was loaded progressively with an acrylic crown. The time of gradual loading (by increasing the occlusal contact amount with acrylic at each time frame) was in three 2-month periods. Digital image analysis and digital subtraction radiology measured changes in crestal bone loss and bone density around the implant (Figure 32-23). The mean crestal bone loss for the progressively loaded implants was 0.13 ± 0.05 mm at 2 months, 0.18 ± 0.10 mm at 4 months, 0.24 ± 0.12 mm at 6 months, and 0.32 ± 0.16 mm at 12 months. The control group had 0.31 ± 0.08 mm at 2 months, 0.35 ± 0.13 mm at 4 months, 0.41 ± 0.22 mm at 6 months, and 0.47 ± 0.47 mm at 12 months.

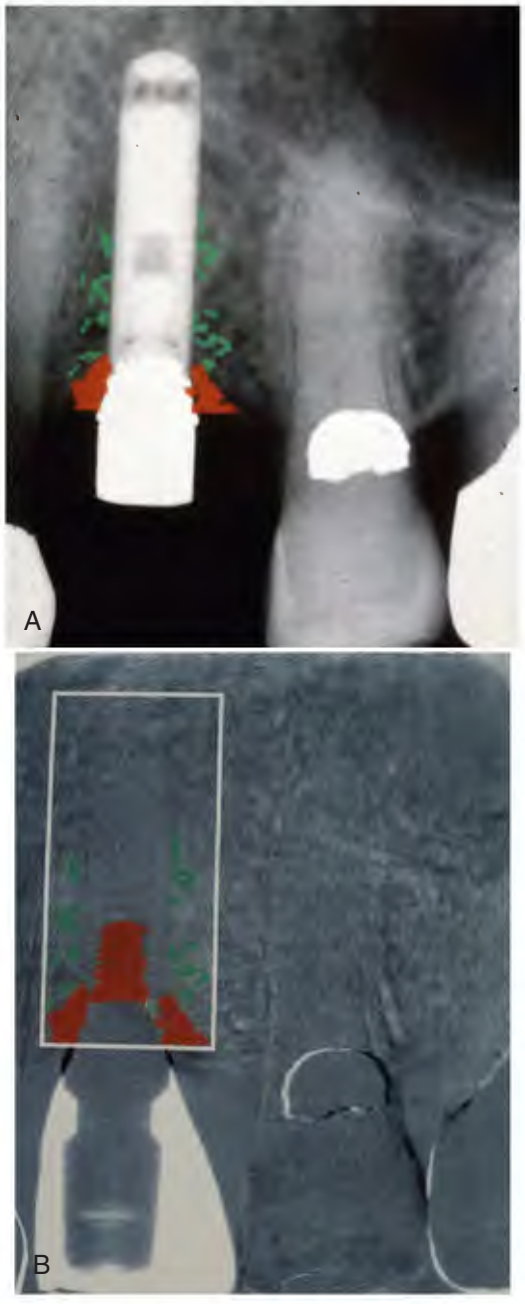


FIGURE 32-23. **A,** Pseudo color-enhanced digital subtraction image of a maxillary first premolar implant. *Green* indicates bone density increase, and *red* indicates bone loss.[91] **B,** Less crestal bone loss was observed in implant progressively loaded compared with the control group.[96]

In other words, there was less bone loss in progressively loaded implants of all four stages of bone loading during the first year of this pilot study. This report observed the loss of crestal bone is reduced by progressively loading implants. This report confirms the report by Manz that demonstrated a direct correlation between bone density and bone loss the first 6 months after loading[58] (Figure 32-24).

The implementation of progressive loading is more critical for lesser bone densities because they are several times weaker than those with significant cortical bone. Parafunction, cantilevers, and other stress magnifiers can increase the forces applied to the prosthesis and their shear components and cause bone microfracture or microstrains in the pathologic zone around the implant.[97–99] Progressive bone loading aims at increasing the density of bone, decreasing the risk of implant–bone failure, and decreasing crestal bone loss.

Progressive Loading Protocol

Full-arch prostheses with little or no cantilever and adequate implant number, position, and size rarely require progressive loading unless the bone density is poor. The favorable biomechanics of an arch are even compatible with immediate occlusal load applications.[100] However, the fewer the number of implants or the softer the bone types, the more progressive loading is suggested.

Cantilevers, patient force factors, and implant position may influence the risk factors in implant dentistry. Poor bone density may compromise implant success even when key implant position and number are satisfactory. In addition, crestal bone loss may be reduced with progressive loading.

The concept of progressive loading is to allow the bone to adapt to increasing amounts of biomechanical stress. Hence, rather than immediately loading the bone–implant interface, methods to slowly increase the stress over time are a benefit. The progressive loading protocol uses a cement-retained prosthesis when implants are splinted together. Because a screw-retained splinted restoration is not completely passive and a torque force applied to a screw is greater than a bite force, a traditional screw-retained restoration cannot use progressive loading to gradually load the bone.

As a general rule, the higher the risk factors, the more progressive loading is recommended. The principles of gradual loading are demonstrated best in a cement-retained prosthesis and are least applicable for the screw-retained bar of a mandibular removable prosthesis type 5 (RP-5) restoration. In addition, gradually loading a removable RP-4 or RP-5 prosthesis with a screw-retained superstructure bar is difficult because the transitional prosthesis often remains removable during the prosthesis fabrication. In addition, most of the forces placed onto the implants for a screw-retained bar or prosthesis are generated at the delivery from nonpassive superstructures. As a result, screw-retained prostheses do not use a progressive loading protocol.

A longer healing time between stage I and stage II is suggested when forces are greater or bone is softer. This time allows greater mineralization of bone and a more mature lamellar bone interface to form next to the implants before the load of the screws is applied to the implant bodies.

The progressive loading protocol has six different methods to gradually load the bone or to increase the bone density around the implant (Box 32-3). These elements help the dentist evaluate the gradual loading progress.

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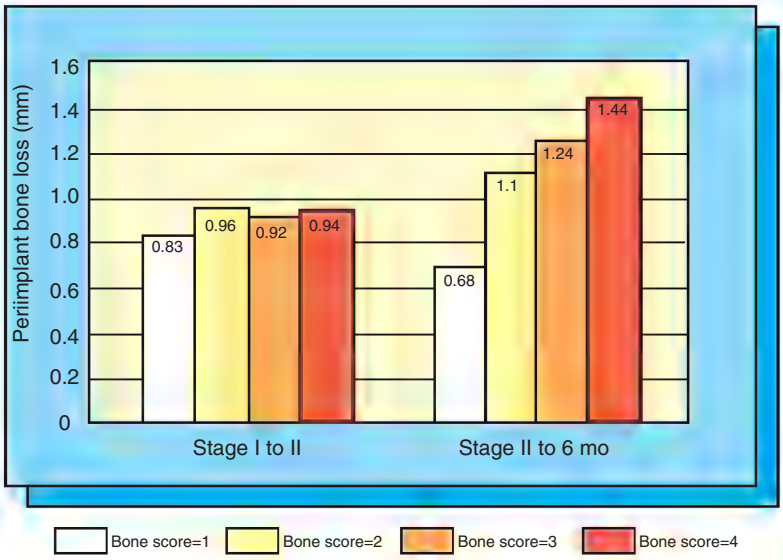


FIGURE 32-24. Bone loss was compared between implants in type D1 bone *(white)*, D2 bone *(yellow)*, D3 bone *(orange)*, and D4 bone *(red)*. From stage II uncovery surgery to the first 6 months of loading, the bone loss was in direct correlation to the density of bone.[58]

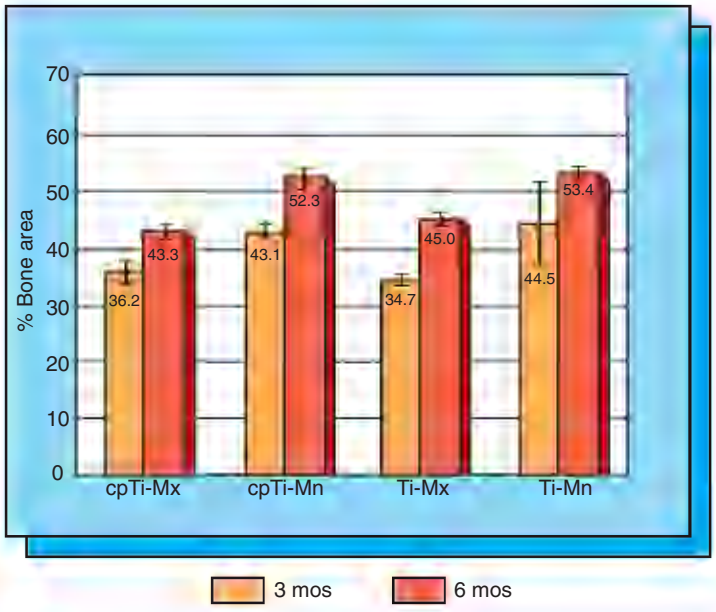


FIGURE 32-25. The percentage bone area is greater at 6 months compared with 3 months in both the maxilla and mandible.

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BOX 32-3 Elements of Progressive Loading

- Time interval
- Diet
- Occlusal material
- Occlusal contacts
- Prosthesis design

Time

Initial Healing

The histologic type of bone in contact with the implant varies and can affect the amount of stress the bone can sustain within physiologic limits. The ideal bone for implant prosthetic support is lamellar bone.[56] Lamellar bone is highly organized but takes about 1 year to mineralize completely after the trauma induced by implant placement.[34] Woven bone is the fastest and first type of bone to form around the implant interface; however, it is mineralized only partly and demonstrates an unorganized structure less able to withstand full-scale stresses. At 16 weeks, the surrounding bone is only 70% mineralized and still exhibits woven bone as a component. Computer-aided radiographic densitometry studies confirm that the bone–implant interface decreases the first several months after surgical insertion of an implant.[88] The percentage of bone mineralization and the type of supporting bone influence whether a load to the bone–implant interface is within its physiologic limits.

It has been reported that the BIC is related to the bone density and the healing time. For example, in a study by Carr et al., the BIC was greater in the mandible than the maxilla (the mandible is usually more dense).[101] In addition, the BIC was greater at 6 months compared with 3 months in both jaws. An increase in bone–implant contact occurred in both the maxilla and mandible between 3 and 6 months and ranged from a 7% to 9% increase[101] (Figure 32-25); thus, the healing time before implant loading may be related to the density of bone because the strength of bone increases and the BIC increases with a longer time period. Hence, 3 to 4 months of healing for D1 and

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D2 bone and 5 to 6 months for D3 and D4 bone have less risk than a shorter time period for all bone types. The time period between surgical placement and full occlusal loading is variable, depending on the bone density.

The macroscopic coarse trabecular bone heals about 50% faster than dense cortical bone. Although it heals more slowly, D1 bone has the greatest strength and greater lamellar bone contact. The suggested healing time between the initial and second-stage surgeries is kept similar for D1 and D2 bone and is 3 to 4 months. A longer time is suggested for the initial healing phase of D3 and D4 bone (5 and 6 months, respectively) because of the lesser bone contact and decreased amount of cortical bone to allow for the maturation of the interface and the development of some lamellar bone. In very immature bone, the healing time may be as long as 8 months.

The D4 implant–bone interface typically found in posterior regions of the maxilla exhibits minimum initial bone contact, with little to no cortical bone at the crest or apex. An implant surgery initially may trigger an increase in the amount of bone in the region. For example, bone has been shown to grow in contact with a submerged titanium screw inserted into an open marrow chamber of the femur.[102] The initial increase of bone cell activity most likely results from the surgical trauma and the regional acceleratory phenomenon.[103] The longer initial healing time is most beneficial to the poorest bone density types.

Hence, in softer bone, a longer period of time of initial healing and gradual loading is suggested. As a general rule, D1 bone uses a 3 or more month period before loading, D2 bone a 4 or more month period, D3 bone a 5 or more month initial healing period, and D4 bone uses a 6 or more month period.

The combined observations of the macroscopic amount of bone in contact with a nonloaded implant and the microscopic type of bone at the stage II surgery of the implant demonstrates a wide difference in D1 to D4 bone densities. However, the major improvement in bone density and strength long term occurs as a consequence of loading the implant.

Four prosthodontic steps are suggested for the reconstruction of a partially or completely edentulous patient, with endosteal implants supporting a cemented prosthesis. Each of the four major prosthodontic appointments also are separated by a period of time related to the bone density observed at the initial time of surgery. In addition, the dentist attempts to gradually increase the load to the implant at each prosthetic step.

The four prosthetic steps are (1) abutment insertion, preparation, final impression and temporary (of the esthetic zone); (2) a metal try-in and new bite registration; (3) initial delivery of the prosthesis; and (4) final evaluation of the restoration and hygiene appointment.

In simple restorative cases, the prosthetic appointments may be reduced to three appointments: (1) abutment selection, preparation, final impression, opposing impression, and closed-mouth bite registration; (2) initial delivery of the restoration; and (3) final evaluation stage (accompanied by a hygiene appointment).

Type D1 bone benefits from the greatest amount of lamellar bone contact at the beginning of the restoration process. As a result, gradual loading of the implant interface through spacing of the prosthodontic appointments is least important, and the restorative appointments can be separated by as little as 1 week. Type D2 bone responds favorably to physiologic loads. The four prosthetic appointments during which the implant body is loaded sequentially are separated by 2 weeks or more. As a result, the initial 4 months of healing after surgery and 2 months for prosthesis fabrication make the overall treatment time 5.5 months.

The prosthodontic appointments for D3 bone are separated by at least 3 weeks, and overall treatment takes about 7 months to complete, including the 5 months of initial healing. During this time, the bone contact percentage can increase, and the fine woven bone trabeculae can mature into coarser lamellar trabeculae, with an increase in mineral content. The progressive loading process is more critical for D3 bone than for D2 or D1 bone because of its weakness and less initial bone contact.

In D4 bone, the progressive bone loading protocol is most critical. The scheduling of restorative appointments err on the side of safety, separated by at least 4 weeks. As a consequence, the overall treatment time for D4 bone is twice that of D1 or D2 bone and at least 9 months (including 6 months of initial healing). This schedule allows sufficient time for mature lamellar, mineralized bone to develop at the interface and increases the numbers of trabeculae in direct contact and within the network region of the implant (Table 32-5).

When the dentist uses multiple implants, the weakest bone area determines the gradual load protocol. Hence, if the anterior maxilla and posterior maxilla are restored together, the posterior maxilla would determine the initial healing period and the time period between each prosthetic appointment.

Diet

The dentist controls the diet of the patient to prevent overloading during the early phases of the restorative process. During the initial healing phase, the dentist instructs the patient to avoid chewing in the area, especially when the implants are placed in a one-stage approach, with an exposed healing abutment. After being uncovered, the implant connected to an abutment for cement retention is at greater risk of loading during mastication. The patient is limited to a soft diet such as pasta and fish, from the final impression stage until the initial delivery of the final prosthesis. The masticatory force for this type of food is about 10 psi. This diet not only minimizes the

TABLE 32-5
Treatment Times for Progressive Bone Loading for Cement-Retained Prostheses

Bone Density	Initial Healing (months)	Interval Between Appointments (weeks)	Reconstruction (weeks)	Total Time (months)
D1	3	1	3	4
D2	4	2	6	5.5
D3	5	3	9	7
D4	6	4	12	9

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masticatory force on the implants but also decreases the risk of temporary restoration fracture or partially uncemented restoration. Either of these consequences can overload an implant and cause unwanted complications.

The diet should not be overlooked during the restorative phase of treatment. Most dentists have observed the fracture of an acrylic prosthesis with harder foods and greater occurrence of uncemented restorations when they ignore the type of diet during the transitional prosthesis stages.

After the initial delivery of the final prosthesis, the patient may include meat in the diet, which requires about 21 psi in bite force. The final restoration can bear the greater force without risk of fracture or uncementation.

After the final evaluation appointment, the patient may include raw vegetables, which require an average 27 psi of force. A normal diet is permitted only after evaluation of the final prosthesis function, occlusion, and proper cementation.

It should be noted that the most damaging forces to a transitional (or final) restoration is parafunction, not the function of eating. Hence, after the prosthesis is placed into occlusion, the evaluation of parafunction and methods to reduce its negative side effects are critical to the loading process.

Occlusal Material

The occlusal material may be varied to gradually load the bone–implant interface. During the initial steps, the implant has no occlusal contact and thus in essence has no material over it. At subsequent appointments, the dentist uses acrylic as the occlusal material, with the benefit of a lower impact force than metal or porcelain. Either metal or porcelain can be used as the final occlusal material.

If parafunction or cantilever length causes concern relative to the amount of force on the early implant–bone interface, the dentist may extend the softer diet and acrylic restoration phase several months. In this way, the bone has a longer time to mineralize and organize to accommodate the higher forces.

Occlusion

The dentist gradually intensifies the occlusal contacts during prosthesis fabrication. No occlusal contacts are permitted during initial healing (step 1). The first transitional prosthesis is left out of occlusion in partially edentulous patients (step 2). The occlusal contacts then are similar to those of the final restoration for areas supported by implants. However, no occlusal contacts are made on cantilevers or offset loads (step 3). The occlusal contacts of the final restoration follow the implant-protective occlusion concepts (described in Chapter 31).[103]

Prosthesis Design

There are four potential prostheses designs in a restorative process. During initial healing, the dentist attempts to avoid any load on the implants, including soft tissue loads. Hence, in a completely edentulous patient, relief and a soft tissue conditioner (also relieved) may be used. The first transitional acrylic restoration in partially edentulous patients has no occlusal contact and no cantilevers. Its purpose is to splint the implants together and reduce stress by the mechanical advantage and to have implants sustain masticatory forces solely from chewing. The second acrylic transitional restoration has occlusal contacts placed over the implants with occlusal tables similar to the final restoration but with no cantilevers in nonesthetic regions. The final restoration has narrow occlusal tables and cantilevers designed with occlusal contacts following implant-protective occlusion guidelines.[103]

Progressive Loading Phases

After the surgical stage II uncovery procedure or one-stage implant healing, the surgeon evaluates clinical mobility, bone loss (horizontal and vertical), proper placement in reference to prosthetic design and angulation to load, zones of attached gingiva, and gingival thickness. The surgeon usually attaches a low-profile PME to the implant body at the end of this appointment. This component extends through the tissue about 2 mm and is protected from early loading (Figure 32-26).

In selected cases, often when the surgeon and restoring dentist are the same person, one may obtain the preliminary impression during this appointment if the soft tissues are outside the esthetic areas and if no bone recontouring or grafting has been performed or a one-stage surgical approach was used during initial healing. The dentist instructs the patient with a posterior implant in a partially edentulous arch not to wear any removable restoration. If anterior teeth are part of the removable prosthesis, a 7-mm-diameter hole is placed completely through the partial denture framework around each PME so it will not load the implant. In completely edentulous patients, the tissue surface of the denture is relieved at least 5 mm over and around the implants and replaced by a tissue conditioner. The conditioner also is relieved a few millimeters. The patient returns in 2 weeks for suture removal and to replace the tissue conditioner with a soft liner.

The procedures for a partially edentulous Kennedy class I or II patient are first presented. The progressive bone-loading appointment sequence for cement-retained prostheses is as follows (Table 32-6):

1. Initial abutment selection, final impression, and transitional prosthesis I
2. Metal superstructure try-in and transitional prosthesis II
3. Initial insertion of final prosthesis
4. Final evaluation and hygiene



FIGURE 32-26. A permucosal extension was placed by the surgeon at the implant insertion or at stage II uncovery. Ideally, the soft tissue is healed before prosthetic reconstruction.

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TABLE 32-6
Progressive Loading Appointments for a Cement-Retained Prosthesis

Step	Procedure	Diet	Occlusal Material	Occlusal Contacts
1	Final abutments Final impression Transitional prosthesis	Soft	Acrylic	1*; none 2*; no cantilever
2	Transitional prosthesis II Metal try-in Bite registration	Soft	Acrylic	1 and 2*; contacts only on implant; no contacts on cantilevers or pontics; occlusal table same as final prosthesis
3	Final prosthesis Adjust occlusion	Harder	Metal or porcelain	Occlusion follows implant-protective occlusion guidelines; narrow occlusal table
4	Final evaluation Hygiene	Normal	Metal or porcelain	Same as above

First Appointment

Initial Abutment Selection, Final Impression, and First Transitional Prosthesis

The goal of this first prosthetic appointment is to assess the implant and soft tissues and make sure that all the prosthetic components and details of the prosthetic appointment are addressed. The occlusion of the patient is also observed so the appointment may use a closed-mouth centric registration. When the doctor performs the surgery and prosthesis placement, this appointment may occur during the suture removal appointment after stage II surgery or during the uncovery procedure.

Final Impression and Transitional Prosthesis I

The dentist removes the PMEs from the implant bodies and selects the appropriate or two-piece abutment for cement retention. The dentist threads the abutment by hand into position with about a 10–N-cm force (Figure 32-27). The dentist verifies complete seating of the abutment with a radiograph. When the abutment fully engages the antirotational hex, the countertorque system and torque wrench preloads the abutment screw at a force of 20 to 35 N-cm, depending on screw material and design. The countertorque is often a hemostat that holds the abutment while the torque wrench stretches the screw with a tensile or shear load. This prevents the torque from being applied to the implant body (Figure 32-28).

The dentist performs final abutment preparation at this appointment for the direct technique. The dentist selects the occlusal material before the final abutment preparation and evaluates the amount of retention on the abutments. When a subgingival margin is indicated, the dentist may place a retraction cord in the sulcus. The dentist also may fabricate (or reline the premade transitional prosthesis) to foster soft tissue healing and create an improved emergence profile. The dentist obtains a final impression, records the centric occlusal registration with a closed-mouth centric position when centric relation is harmonious with centric occlusion, or makes a face-bow record along with protrusive and check bites when required. The dentist lutes the first transitional prosthesis with a noneugenol zinc oxide cement, and occlusal contacts are totally absent (Figure 32-29).

The dentist notifies the patient that the implants and bone are exactly "what you wish them to be at the present time." However, the bone is immature and weak, just as a broken arm is weak after a fracture and the cast is first removed. If too much force is placed on the implant too early, the implant may become loose or bone may be lost around the implant. Either situation will require additional time and expense to treat. Therefore, the dentist instructs the patient to avoid this region of the mouth while eating. The diet should consist of soft food such as pasta or fish. The patient should not chew sticky foods or gum and should avoid aggressive chewing or oral habits that may cause the temporary prosthesis to loosen or break. The dentist also informs the patient that complications created by the improper use of the temporary prosthesis will add



FIGURE 32-27. An abutment for cement retention is inserted and torqued into the implant bodies.



FIGURE 32-28. The final abutment for cement retention is torqued into position after a radiograph confirms its position.

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FIGURE 32-29. The first transitional restoration is cemented with temporary cement. It is completely out of occlusion.



FIGURE 32-30. The laboratory technician fabricates a precious metal framework that splints the abutments together.

additional surgeries, prosthetic appointments, and costs to the treatment.

Laboratory Phase I

The laboratory technician pours the final impressions with die stone, mounts the models following prosthodontic principles, and makes a full-contour wax-up and cutdown of 2 mm in regions of porcelain for the prosthesis framework. The technician then fabricates a precious metal superstructure (Figure 32-30) and uses an occlusal acrylic index to indicate the occlusal registration recorded for the implant-supported prostheses.

Indirect Prosthetic Appointment I

An alternate technique is to use a direct or indirect impression transfer coping for the implant body. The long fixation screw should exit the occlusal of the impression tray for the open-tray technique. After the impression material is set, the screw is unthreaded, and the impression may be removed from the mouth with the direct impression coping in the impression. The dentist attaches implant body analogs into the corresponding positions within the impression. The dentist reinserts the low-profile permucosal healing caps into the implant bodies and makes an occlusal bite registration in centric relation occlusion. A face-bow transfer is then made of the maxilla. The dentist dismisses the patient with instructions not to chew in the region and to brush the PMEs gently with chlorhexidine.



FIGURE 32-31. A metal try-in evaluates the casting.

Laboratory Phase I

The laboratory technician pours the impression with dental stone and, when necessary, attaches analogs and then separates the model and mounts it to the opposing arch with the bite registration and face-bow transfer. The laboratory technician inserts the abutments into the implant body analog and prepares the implant abutments for height, parallelism, and position within the prosthesis contours.

The technician then may fabricate a transitional acrylic prosthesis. Ideally, for partially edentulous patients, the first transitional restoration is completely out of occlusion. Its primary purpose is to splint the implants together rigidly. If a cantilever is present, no occlusal contact on the cantilevered portion exists.

Second Prosthetic Appointment

Metal Try-in

The patient returns in 1 to 4 weeks (or more) depending on the bone density. The dentist removes the first transitional restoration and evaluates its retention to help select the proper luting agent for the final restoration. The metal superstructure is tried in (Figure 32-31). Because the patient is not anesthetized and the mouth has been open only a few minutes, this is an ideal opportunity for the dentist to verify the centric relation. If the patient bites into the laboratory occlusal acrylic index, the previous occlusal record was accurately registered. If the patient occludes in a different position, the dentist evaluates and corrects the occlusion on the casting as indicated and records a closed-mouth centric occlusal registration using a rigid addition silicone material on top of the casting (Figure 32-32).

The dentist delivers the second transitional prosthesis (Figure 32-33). This may be a new transitional prosthesis or more often the first transitional prosthesis with a modified occlusal table through the addition of acrylic on the occlusal contact areas. Monomer is first applied to the occlusal aspect of the temporary prosthesis, and petroleum jelly is applied over the opposing teeth. The dentist adds acrylic on the occluding surfaces of the temporary restoration, and the patient occludes into the material and moves in all excursions. The dentist eliminates the nonworking and working occlusal contacts and can bring the pontic areas and angled abutments into light centric occlusion. Heavier contacts are developed on the implants in ideal position. No cantilevers are present in the restoration unless needed for esthetics. The occlusal scheme is similar to that of the final prosthesis. The dentist evaluates the occlusion using a heavy bite force occlusal adjustment. Occlusal contacts are limited to

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FIGURE 32-32. A closed-mouth centric recording is made over the metal framework.



FIGURE 32-34. The laboratory technician completes the final restoration.



FIGURE 32-33. The original transitional restoration is modified by adding acrylic on the occlusal surface, and a heavy bite force occlusal adjustment is made.



FIGURE 32-35. The final restoration is evaluated in the mouth.



FIGURE 32-36. A heavy bite force evaluation of the occlusion is made.

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those directly over implant bodies. The diet remains soft with pasta, fish, or softer food types.

Laboratory Phase II

The laboratory technician completes the prosthesis with an occlusal scheme that follows implant-protective occlusal guidelines (Figure 32-34). The dentist notes angled implant bodies so that the occlusal contacts may be modified to be in the long axis of the implant body or reduced in intensity.

Third Prosthetic Appointment: Initial Prosthesis Delivery

The next appointment follows 1 to 4 weeks later, depending on the bone density. The dentist removes the transitional prosthesis and evaluates its retention to help select the cement used in the final prosthesis. If retention is satisfactory, the dentist uses a similar cement at the initial delivery of the final restoration. However, eugenol-based cements may be used as desired because a metal rather than acrylic restoration is cemented.

The dentist inserts the final restoration and evaluates it carefully relative to occlusal contacts (Figure 32-35). After using a light bite force to equilibrate the occlusal contacts, the dentist makes a heavy bite force occlusal adjustment with no lateral contacts in excursions (Figure 32-36). After cementation, the dentist obtains a radiograph to use as a baseline for future radiographic evaluation for crestal bone loss and implant health (Figure 32-37). If the dentist observes crestal bone loss compared with the stage II uncovery appointment, the dentist should suspect parafunction and fabricate night guards to control stresses.

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FIGURE 32-37. A radiograph is made for baseline evaluation of the prosthesis.



FIGURE 32-38. A clear template (0.008 inch) is made over the patient's denture and trimmed to the soft tissue borders. This template will become a customized impression tray to convey the vertical occlusal dimension and incisal edge position to the laboratory.



FIGURE 32-39. A two-piece transfer coping engages the hexagon of the implant body. A closed-tray impression is made with the customized impression tray over these implant body transfers.

The bone has benefited from the additional time and is now more mineralized and exhibits improved load-bearing capability compared with the first transitional prosthesis delivery. In addition, the stronger final restoration (compared with transitional) can sustain greater masticatory loads. Therefore, the diet of the patient now may include harder foods, such as meat.

Fourth Prosthetic Appointment: Final Evaluation and Hygiene

The patient returns in about 4 weeks. This appointment is usually with the hygienist for a maintenance appointment. The dentist first evaluates retention of the prosthesis. If retention is adequate, the dentist does not remove the restoration and uses the soft access cement for the definitive restoration. If the dentist can remove the prosthesis with finger pressure, the dentist cements the restoration with a stronger cement. The dentist evaluates the soft tissues and home care and performs a final occlusal equilibration. The diet of the patient may now include raw vegetables and harder foods. The patient is scheduled for another maintenance appointment in 3 to 4 months.

Completely Edentulous Patient Protocol

Some modifications to the previously discussed protocol are included with fabrication of full-arch restorations. A full-arch restoration often uses an indirect (laboratory) approach to select or prepare (or fabricate) the abutments. Because no natural teeth are present, the implants are loaded when the initial transitional prosthesis is delivered. The dentist should adhere to the following protocol emphasizing the differences compared with the previous Kennedy class I or II patients.

First Prosthetic Appointment

Initial Abutment Selection and Preliminary Impression

Before or during surgical phases, the dentist may fabricate a treatment prosthesis that restores the patient to the proper occlusal vertical dimension (OVD) and determines the correct tooth position for the final prosthesis. The dentist fabricates a clear template over the removable prosthesis and trims it to the surrounding soft tissue border (Figure 32-38). The dentist positions the denture and clear template (0.008 inch) in the mouth and records a bite registration to the opposing arch. The dentist removes the denture from the template, which then acts as a customized impression tray indexed to the opposing occlusion.

The dentist inserts a two-piece straight abutment for cement retention into the implant bodies (Figure 32-39). The dentist positions the template and bite registration over the straight abutments for cement. This serves as a custom impression tray for a closed-tray impression. In the maxilla, the dentist first may place putty impression material in the palate region of the clear template to account for the thickness of the palate portion of the complete denture. The dentist evaluates the length of the abutments and may perform corrections intraorally. The dentist evaluates the clear prosthetic template after it is properly seated for vertical centric occlusion and then fills the clear prosthetic template with an addition silicone and reinserts it. The patient closes into the previous occlusal recording. The dentist removes the template impression and bite registration, which serve as a preliminary impression and initial OVD record to be mounted in the laboratory to the opposing arch impression (Figure 32-40).

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FIGURE 32-40. **A** and **B,** The customized impression tray with the occlusal bite registration in centric relation occlusion.

If a prosthetic template or custom tray was not fabricated beforehand, the dentist places a roll of addition silicone putty onto the abutments for cement and guides the mandible to centric relation occlusion at the approximate vertical dimension. The dentist then makes a preliminary impression of the abutments for cement and of the opposing arch.

The dentist removes the abutments for cement, attaches them to the implant body analogs, and seats them into the impression. The dentist reinserts the stage II PMEs into the implant bodies and relieves the soft liner over the PMEs. The patient is instructed to limit mastication to very soft foods and to remove the denture at night to prevent nocturnal parafunction. Parafunction during this time is a major concern of overload for a completely edentulous patient because the implants are independent and do not have the biomechanical advantage of splinting. The patient returns in 1 to 2 weeks for the next prosthetic appointment.

Laboratory Phase I

Laboratory steps after the first prosthetic appointment include pouring the preliminary impression with the implant abutment and implant body analogs in dental stone. The laboratory technician mounts the casts on an articulator using the prosthetic template or custom tray and occlusal registration before it is separated from the cast (Figure 32-41). The technician may adjust the abutments in length, angulation, and proper clearance for crown contours using the clear overlay template of the wax-up or denture as a guide (Figures 32-42 and 32-43). A wax-up using denture teeth elaborates the proposed form of the final prosthesis. The technician fabricates a clear template over this wax-up.

The technician then fabricates a transitional acrylic prosthesis on the study cast using the clear prosthetic template that was used to evaluate the abutments. No posterior cantilever should



FIGURE 32-41. The impression transfer copings are attached to the implant bodies, poured, and mounted to the opposing arch with the customized impression tray.



FIGURE 32-42. The customized impression tray is removed from the working cast.



FIGURE 32-43. The final abutments are selected and prepared for parallelism and tooth position.

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be present on this first transitional restoration unless required for esthetics (Figures 32-44 and 32-45). Pontics also should be left out of occlusion. Ideally, only implants that can be loaded with axial forces within 20 degrees should exhibit occlusal contacts at this early loading stage. No posterior contacts are present during excursions if adequate anterior teeth or implants are present, especially when the restoration opposes a fixed or natural dentition.

The first transitional restoration is designed to completely fill in the interproximal areas of the implants in the premaxilla. Difficulty in speech is a common complication reported when dentists are restoring a completely edentulous maxillary arch with a fixed prosthesis. The patient must accommodate the absence of the palate on the prosthesis, and air often escapes through the embrasures between the implants. The more bulky temporary restoration can ease the transition from denture to fixed restoration and facilitate speech accommodation.

The technician fabricates a second clear prosthetic template from the wax-up of the final prosthesis in case the dentist desires a different transitional restoration at the next clinical appointment. The clear template also can be used by the dentist to evaluate abutment preparation intraorally.

The technician fabricates a modified baseplate and wax rim over the abutments (Figure 32-46). With a technique similar to that of complete denture fabrication, the wax rim is used to record the incisal edge position, OVD, midline, high lip line, and centric relation occlusion. The technician also may fabricate a custom impression tray on this working model.

Second Prosthetic Appointment

Final Impression and Transitional Prosthesis I

The dentist removes the PMEs and inserts the final abutments for cement (Figure 32-47). The dentist places the clear template of the final prosthesis wax-up into position, evaluates the abutments for ideal placement and height (at least 1 to 2 mm less than the occlusal plane, depending on the occlusal material), and recontours them as required.

The dentist inserts the first transitional prosthesis (Figure 32-48). A most important step for the provisional prosthesis is the evaluation of incisal edge position for esthetics and phonetics. The dentist should establish this position before fabricating the superstructure to ensure ideal support of porcelain or acrylic in the final restoration. This position also greatly influences posterior occlusal relationships in any excursive position. The dentist can measure the thickness of the acrylic provisional prosthesis facial to the abutments for cement retention to ensure adequate space for metal and porcelain on the final restoration. If the transitional prosthesis is not ideal relative to incisal edge, OVD, esthetics, and midline, the dentist inserts the modified baseplate and wax rim and uses them to establish these criteria similar to the methods for a maxillary complete denture. The dentist then obtains centric relation occlusal



FIGURE 32-44. A transitional restoration is made over the prepared implant abutments.



FIGURE 32-46. A baseplate and wax rim is fabricated on the working model for the occlusal vertical dimension and centric bite registration at the next prosthetic appointment.



FIGURE 32-45. The transitional prosthesis does not have a cantilever.

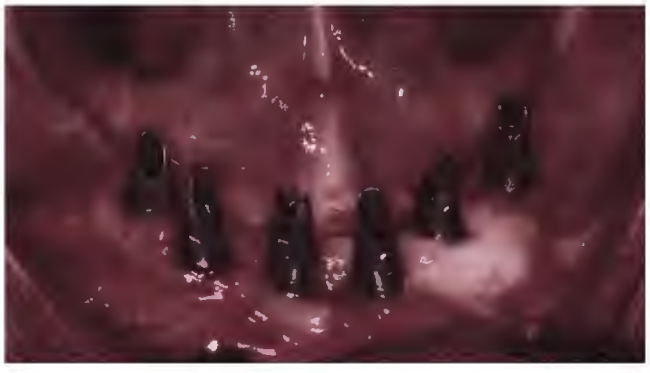


FIGURE 32-47. The laboratory-prepared abutments are positioned over the antirotation component of the implant body and are secured with an abutment screw at 30 N-cm of torque.

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FIGURE 32-48. The first transitional restoration, without cantilever, is delivered. The patient is instructed to limit the diet to only soft food.



FIGURE 32-49. At the metal try-in appointment, the framework of the prosthesis is evaluated. White wax is used to evaluate the incisal edge position. Acrylic posterior indexes are used to evaluate the occlusal vertical dimension and centric occlusal registration.

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records on the baseplate and wax rim or with a positioning jig at the appropriate OVD. The dentist reevaluates these relationships and criteria on the metal framework at the next prosthetic appointment.

The dentist makes a final impression and occlusal registration when the transitional prosthesis has the correct incisal edge, vertical dimension, and necessary prosthetic guidelines. Anterior tooth shape and arrangement may be selected using a denture mold guide or using the study cast of the treatment prosthesis to assist in the personalization of the final esthetic result. The dentist makes a face-bow transfer of the maxillary arch to permit correct horizontal mounting of the cast on the articulator and cements the transitional prosthesis with a zinc oxide noneugenol temporary "soft access" cement. Modifier or petroleum jelly often is added to the soft access cement for multiple abutments to facilitate the retrieval of the transitional prosthesis without complication.

The dentist carefully evaluates the occlusal contacts. In centric relation occlusion, the implants ideally should be loaded with only axial loads. When possible, no offset loads or cantilevers should be present. In addition, the first transitional prosthesis has no contact on long-span pontics. The occlusal scheme is similar to that of the final restoration.

This is the first time the patient has worn a fixed prosthesis since the denture. The diet of the patient at this time is still very soft (e.g., pasta and fish). The dentist would be wise to explain to the patient the need to remain on this very soft diet. A force that is too aggressive may cause implant overload or break the cement seal of the provisional restoration, which will cause cantilever and moment loads on the remaining implants. The dentist warns the patient that any implant or bone loss from this point may require implant removal, bone graft, implant replacement, and long healing times.

Laboratory Phase II

The laboratory technician first mounts the master cast on an articulator using a face-bow and centric registration, removes it, and then mounts the cast of the provisional restoration with the separate bite registration recording or inserts the modified baseplate and wax rim on the master cast. The technician makes an index of the incisal edge and facial tooth position of the temporary, or wax rim, in the proper position and replaces the master cast on the articulator. The technician makes a wax-up of the final restoration and then cuts back 2 mm for porcelain thickness in the appropriate regions. The technician then fabricates the metal framework with precious metal.

The technician may use white wax for the shape and size of the six anterior teeth on the metal superstructure, which allows clinical evaluation of the incisal edge, esthetics, and speech on the actual casting. The technician fabricates acrylic occlusal indexes on the posterior regions at the recorded OVD to verify its accuracy at the metal try-in appointment.

Third Appointment: Metal Try-in and Transitional Prosthesis II

The dentist evaluates the transitional prosthesis retention and then removes the prosthesis. If the prosthesis is not loose, the dentist will use the same cement at the conclusion of this appointment. The dentist tries in the metal framework (Figure 32-49). The casting should not be tapped into position if too tight. Instead, the dentist can modify the abutment for cement retention with a coarse diamond. When the dentist deems the casting fit acceptable, he or she uses the posterior occlusal acrylic indexes to check centric occlusion and OVD (Figure 32-50). The patient is not anesthetized; has been wearing a transitional prosthesis with no interferences; has been opening the mouth only for a short time; and has a rigid, stable structure in place. As a result, the dentist can evaluate or obtain an accurate jaw relationship record. If the dentist notes any variance from the original occlusal registrations, a new recording is indicated. The dentist adjusts the posterior acrylic indexes (and metal occlusals) to the proper OVD and evaluates the white wax on the anterior teeth for lip position, phonetics, and esthetics. The dentist determines the high lip line and scores it in the cervical region of the wax. The dentist may make the final decision relative to fixed prosthesis type 2 or 3 restorations at this time.

When fixed prostheses are opposing natural teeth or fixed restorations, no posterior contacts occur during mandibular excursions in any lateral or protrusive jaw position. Anterior guidance is primarily responsible for the separation of the posterior teeth. Therefore, after the OVD and incisal edge are determined, the protrusive and lateral excursions of the mandible can be evaluated. The dentist confirms the final crown contour

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FIGURE 32-50. The accuracy of the prior centric occlusion recording is verified and repeated as necessary.



FIGURE 32-51. The secondary transitional device is delivered at the conclusion of the third appointment.



FIGURE 32-52. The final restoration is delivered to the patient. This restoration is a fixed prosthesis type 2, with porcelain fused to metal.

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(taken from a denture mold chart) and shade selection for the gingiva and teeth during this session.

The dentist then modifies the first transitional restoration (or fabricates a second temporary prosthesis). The dentist adds monomer to the occlusal aspect and places petroleum jelly over the opposing teeth. The dentist adds acrylic on the occluding surfaces of the temporary restoration, and the patient occludes into the material and moves in all excursions. The dentist eliminates the nonworking and working occlusal contacts and can bring the pontic areas and angled abutments into light centric occlusion. Heavier contacts are developed on the implants in ideal position. No cantilevers are present in the restoration unless needed for esthetics. The occlusal scheme is similar to that of the final prosthesis. Posterior embrasures of the temporary may now be opened to improve interproximal hygiene.

The dentist cements the temporary restoration with a soft access cement (Figure 32-51). If the transitional prosthesis was too difficult to remove at the beginning of this appointment, the dentist may use a softer cement and vice versa.

The patient continues with the softer diet of pasta and fish until the next appointment, still avoiding harder foods (e.g., meats, raw carrots). Patients exhibiting parafunction may remain at this stage with an acrylic transitional restoration for as long as 4 months. A laboratory-processed restoration usually is indicated for this extended period. If the patient generates excessive forces and the restoration has more than two pontics, a composite fixed bridge with metal substructure may be indicated during the extended transition period.

Fourth Appointment: Initial Delivery

The fourth restorative appointment (2–4 weeks later) marks the initial delivery of the final restoration (Figure 32-52). After it is seated, the dentist adjusts the final occlusion as indicated. The occlusion is designed to load the implants axially wherever possible. After cementations, the dentist may take radiographs and vertical bitewings to establish the baseline values of crestal bone for future comparison and compare them with the bone level at implant uncovery surgery.

The dentist uses a soft access cement in the restoration and reinforces, demonstrates, and stresses oral hygiene regimens. The diet of the patient still does not include hard foods, but patients can enjoy most foods and may add meat to the diet. No raw vegetables or hard, crunchy foods are yet in the diet at this time.

Fifth Prosthetic Appointment: Final Evaluation and Hygiene

At the fifth prosthetic appointment (about 4 weeks later), the dentist evaluates the final restorative result and improves difficult access areas for hygiene. The dentist scrutinizes the patient's soft tissue health and hygiene regimen. Periimplant probing is indicated to establish soft tissue baseline measurements at this appointment. The dentist refines occlusion. No posterior contacts are present during excursions when opposing natural dentition or a fixed prosthesis. A soft access cement is preferred, but a partially unretained restoration places considerable risk on the remaining cemented units. Therefore, zinc oxide eugenol with 2-ethoxybenzoic acid often is used if no cantilevers are present. The dentist may use a harder cement (e.g., zinc phosphate) on

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the most distal and anterior abutments when cantilevers are present because tensile forces are more likely on these positions.

The diet of the patient is normal at this time. The use of an acrylic night guard for bruxism or a soft occlusal appliance for clenching is usually prescribed for a full-arch prosthesis. The dentist asks the patient to return every 3 to 4 months during the first year so that the dentist may evaluate bone changes and occlusal patterns. Maintenance hygiene appointments often are scheduled every 4 to 6 months after the first year when ideal patient conditions are present.

Summary

Maintenance of rigid fixation during the first year of prosthesis construction and function with minimum bone loss is related to the bone remodeling process. The progressive bone loading approach provides the environment favorable for the development of load-bearing bone at the implant interface in two ways: the development of an extended time period before the introduction of full-magnitude functional forces and the limitation of these forces to vertical forces as the dominant component. In addition, a gradual increase in loads permits the adaptation of the bone. The increase in bone density, which may be evidenced by radiography, Periotest measurements (decreased Periotest values), mobility, and improved crestal bone conditions around the implant compared with a more sudden loading protocol results in increased implant survival and less crestal bone loss.

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CHAPTER **33**

A Maxillary Denture with Modified Occlusal Concepts Opposing an Implant Prosthesis

Carl E. Misch

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Eighteen million Americans are completely edentulous, representing 10.5% of the adult population. In addition, 12 million (7% of the adult population) have no maxillary teeth opposing some mandibular natural teeth. Hence, 17% of the U.S. adult population is wearing a maxillary complete denture. Yet the average dentist spends less than 1% to 5% of his or her time treating edentulous patients.

Lack of stability and retention are the most frequent complaints related to complete removable prostheses. However, patients often think that the retention and stability of maxillary dentures are acceptable and that the mandibular denture presents more problems. As a result, a common treatment plan for edentulous patients includes implants to support the mandibular restoration and a traditional soft tissue–supported maxillary denture[1–3] (Figure 33-1). A maxillary complete denture may function as a satisfactory replacement for missing teeth for many completely edentulous patients. However, after a mandibular implant-supported restoration is fabricated, the patient becomes more aware of the lack of stability, support, and retention of the removable maxillary prosthesis.[4,5]

In many ways, the combination of a complete maxillary denture against a lower mandibular implant-supported prosthesis resembles a single complete maxillary denture opposing mandibular natural dentition. The rigid mandibular teeth make the maxillary prosthesis the least stable member of the dentition. In addition, the occlusal plane of the mandibular dentition is often variable and not ideal. This makes it even more difficult to obtain an ideal occlusal scheme to help stabilize the maxillary denture.

One may anticipate postinsertion complications of the removable maxillary restoration opposing a more rigid mandibular overdenture or fixed prosthesis. The patient complains of soft tissue sore spots and maxillary denture instability. The sore spots under the maxillary denture result in part because patients with rigidly fixated implant prostheses are able to generate masticatory forces approaching that of natural teeth, but wearers of complete dentures have been shown to exert less than 25% of this force.[6] The occlusal forces are also directed in a more consistent direction and location and even may lead to midline fracture of the denture.[7] In addition, more recent reports indicate that a combination syndrome effect of the maxillary arch may be developing with associated alveolar bone resorption and soft tissue inflammation.[8,9]

Maxillary denture instability also becomes more noticeable to the patient because of the improved occlusal awareness and stability of the mandibular counterpart.[7] Mandibular implant overdentures enhance proprioception and improve the consistency of mandibular closure position. A conventional soft tissue–borne complete removable mandibular prosthesis moves up to 10 mm during function, which may accommodate any

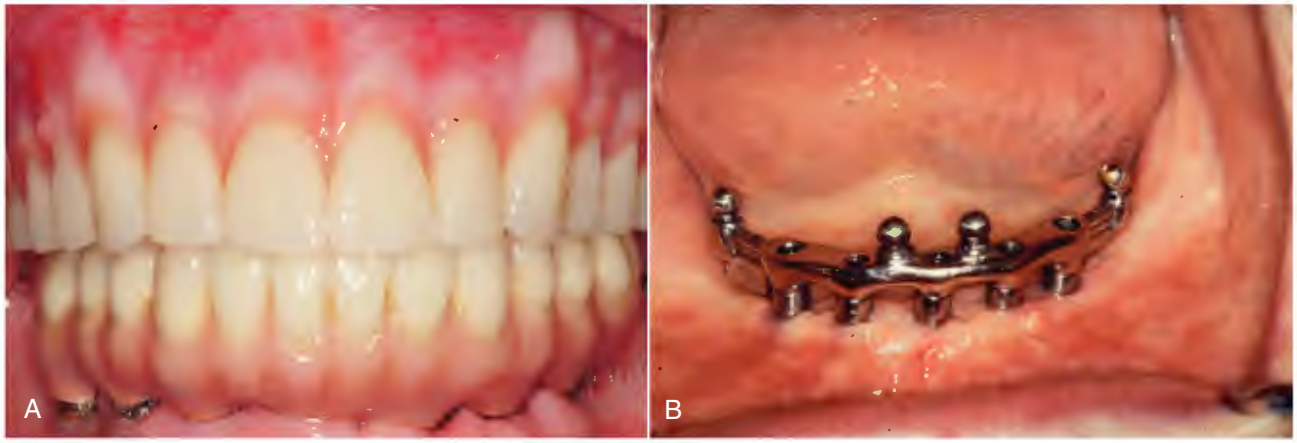


FIGURE 33-1. **A** and **B,** A common treatment plan for a completely edentulous patient is a maxillary denture opposing a mandibular implant prosthesis. The mandibular prosthesis may be fixed (**A**) or an overdenture (**B**).

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prematurities or inaccuracies of occlusion.[10] The patient is accustomed to the mandibular denture lifting up from the posterior ridge during mandibular excursions. The changes of making the mandibular implant prosthesis more stable predispose to the patient's awareness of maxillary denture instability (Box 33-1).

Several modalities are available to improve the prognosis of the restoration on a compromised support area. Varied soft tissue impression techniques, altered occlusal schemes, and a broad range of removable prosthetic concepts show improvement of the final restoration when opposing a stable implant-supported prosthesis. Unfortunately, many patients rely solely on denture adhesive to improve retention of the prosthesis. The inconsistent fit, need for recurrent applications, and poor taste are often consequences (Figure 33-2).

Many textbooks have been written describing the steps and fabrication of a maxillary denture, and complete guidelines are beyond the scope of this chapter. However, specific elements are discussed.

To minimize maxillary denture complications when opposing a mandibular implant restoration, the dentist can implement several concepts. These concepts include preprosthetic surgery to improve the maxillary ridge anatomy and prosthetic approaches specifically tailored to address these problems, raising the posterior occlusal plane (compared with conventional denture concepts), restoring the occlusal vertical dimension (OVD), placing the maxillary and mandibular posterior teeth more medial, and establishing bilateral balanced occlusion in the final restoration[11–14] (Box 33-2). The purpose of this chapter is to highlight these areas of special concern when fabricating a maxillary denture opposing an implant-supported restoration.



FIGURE 33-2. Denture adhesive is often used as the primary way to improve retention when a maxillary denture opposes an implant prosthesis.

BOX 33-1 Maxillary Denture Complications Opposing Implant Prostheses

1. Soft tissue sore spots
2. Accelerated premaxillary bone loss
3. Denture instability

Maxillary Soft Tissue Evaluation

A successful restoration with a soft tissue–supported removable prosthesis depends on several conditions. However, the anatomy of the edentulous arch foundation is the primary criterion for prosthesis support and stability.

The dentist may evaluate dentures for support, stability, retention, esthetics, masticatory efficiency, speech, extension, and occlusion. *Support* of a maxillary denture is determined from the resistance of the denture to a vertical force direction applied to the denture. The crest of the residual ridge and the overlying tissue is the region most responsible for support.[15,16]

The foundation of the maxillary denture is bone, the overlying submucosa, and the mucosa. The blood vessels and nerves are located in the submucosa and bony architecture. Denture support for a maxillary denture primarily corresponds to the regions where fibrous connective tissue is attached firmly to bone, namely, the edentulous ridge.[16] The dentist rarely can exploit the concept of placing teeth over the residual crest to improve support in the anterior region because the resorption process has brought the ridge palatal to the ideal denture tooth position.

Contrary to popular belief, the palate of the maxilla is not a primary support region for a maxillary denture or implant overdenture.[16] Whereas the tissues over the midpalatal suture are usually thin and nonmobile, the surrounding mucosa can be displaced under minimal pressure. The denture base can be relieved selectively in this region to prevent it from acting as a fulcrum, with resultant instability and soreness when vertical forces are transmitted through the maxillary prosthesis. The maxillary denture opposing an implant-supported restoration is subjected to greater forces, and the dentist should consider generous relief of this area to prevent soft tissue trauma. The midpalatal area is a relief zone because the overlying tissues are thin compared with the rest of the maxilla.

The dentist also should provide denture relief to the incisive papilla region to prevent compression of the associated blood vessels and nerves during function. This may eliminate a burning sensation during function from compression of this tissue, especially under the increased bite forces from a mandibular implant prosthesis.

The posterior aspect of the hard palate is an area of secondary retention, not support.[15,16] The submucosa is rich in mucous glands and blood vessels, granting greater resiliency under vertical forces. This region is loaded in a lesser amount by the denture compared with the crest of the ridge or premaxilla (Figure 33-3).

Retention is determined as resistance to a vertical incisal or occlusal force direction or pulling force applied to a denture. The valve seal of the periphery of the denture and the close approximation of the intaglio aspect of the denture are the

BOX 33-2 Maxillary Denture Opposing Implant Prostheses

1. Prosthetic surgery of maxillary arch
2. Raise posterior plane of occlusion
3. Restore occlusal vertical dimension
4. Position posterior teeth in medial-positioned lingualized occlusion
5. Bilateral balanced occlusion

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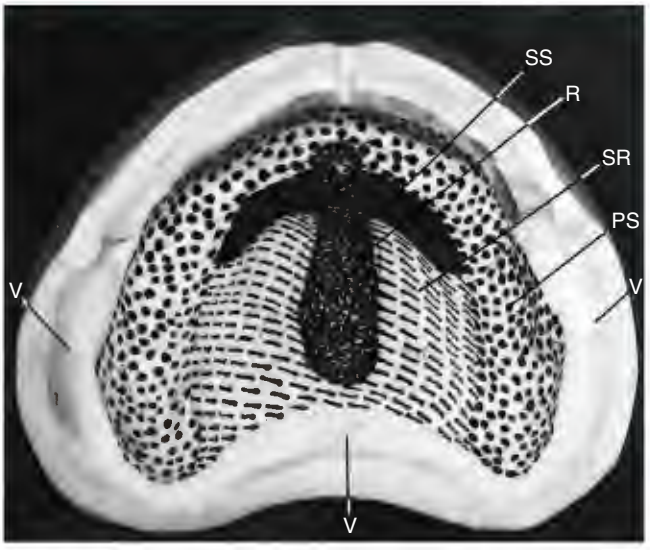


FIGURE 33-3. The primary support region for a maxillary denture is the firm, keratinized mucosa of the edentulous ridge. The secondary support area is the palatal aspect of the premaxilla, which resists the movement of the denture in all lateral excursions. The incisive papilla and midpalatal suture region is a relief zone for the denture, and the hard palate is a secondary relief area. (From Zarb GA, Bolender CL, Hickey JC, et al: *Boucher's prosthodontic treatment for edentulous patients*, ed 10, St Louis, 1990, Mosby.)

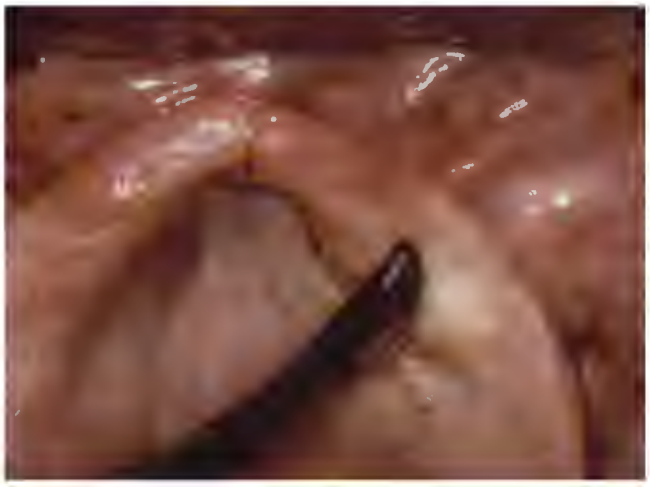


FIGURE 33-4. Mobile keratinized mucosa serves as poor soft tissue support for a denture and should be corrected before the fabrication of a denture.

important considerations for retention. Anatomical features that contribute to the performance of the maxillary denture may vary greatly, but the ability to maintain a border seal during function is much greater than with a mandibular denture and often compensates for other limiting retention factors.[17,18]

The maxillary tuberosities should be firm and located several millimeters superior to the plane of occlusion. Surgical removal of hyperplastic tissue is indicated. The hamular notch is located halfway between the maxillary tuberosity and the hamulus of the medial pterygoid plate. The posterior palatal seal is positioned through this area of loose connective tissue to improve tissue contact and retention. The pterygomandibular raphe attaches from the hamulus to the retromolar pad and should not be impinged on. The posterior limit of the prosthesis is correlated with the soft palate vibrating line, which is more an area than a definite line.[15,16]

Stability of the denture is the resistance of movement to a lateral force applied to the denture. The vertical component of the residual ridge from the hard palate is primarily responsible for improving stability. The premaxillary segment of the edentulous maxilla is a most important structure to ensure stability of the prosthesis. The denture stability is compromised severely without a vertical component to the premaxilla.[17] In addition, the rugae area of the premaxilla is the secondary stress-bearing region.[15,16] This region also helps resist the forward movement of the denture during excursive mandibular movements. It is important to make the patient aware of the continued bone loss in the premaxilla under a denture. Unless implants are inserted to stimulate the bone, the bone loss is continuous, and the denture will become less stable.

The type and movement of the supporting tissue are also important parameters to consider in edentulous ridge correction. The soft tissues of the maxillary ridge should be firm to lateral forces to limit denture movement during occlusion. The amount of tissue movement over the bone can affect denture stability directly and cause soft tissue abrasions. If one observes excessive mobility of the anterior or posterior ridges, the dentist should consider soft tissue preprosthetic surgery. If the tissue is mobile, the denture cannot have stability to any lateral force.

The oral mucosa classically has been described as a movable, unattached, nonkeratinized mucosa or as a nonmobile, attached, keratinized mucosa. These two categories are oversimplified for denture support. Attached keratinized mucosa has been recognized to increase in thickness as a result of bone resorption, primarily in the anterior maxilla. This tissue thickness often exceeds several millimeters and becomes highly mobile. Although classified as attached gingiva, the tissue serves as a poor denture base (Figure 33-4). Likewise, unattached, nonkeratinized tissue may become thick and nonmobile tissue by interposing hydroxyapatite (HA) between the bone and periosteum. This tissue then can serve as an adequate denture-supporting base. Therefore, clinically relevant qualities of tissue for denture support relate to thickness and mobility, not necessarily to the histologic surface condition.

Hard Tissue Evaluation

Surgical techniques that can improve the support of a prosthesis in the maxilla include alveolar ridge augmentation. Autogenous bone grafts for ridge augmentation is a viable alternative in the atrophic maxilla if implants are placed shortly after the graft surgery. If the autogenous graft is used only for improved soft tissue support, as much as 90% of the grafted bone may resorb within 3 to 5 years after augmentation surgery.[19] During the rapid resorption process, the soft tissue–supported denture needs repeated relining and rebasing procedures to maintain ridge contact. The resultant soft tissues become highly mobile and unsupported by the resorbing ridge. The patient often complains of recurrent soft tissue abrasions and of mobile, unstable, and poorly retentive prostheses. Hence, implants must be used to maintain the bone formed after a bone graft.

Dense nonresorbable HA used as a ridge augmentation material to enhance the denture support area has proved an adjunct in preprosthetic surgery in which implant placement is not part of the immediate future treatment plan.[20] HA ridge

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augmentation can slow down the rate of ridge resorption. The dense material can bond to the cortical bone and increase the amount of denture support. Clinical experience demonstrates longer periods between relining the maxillary prosthesis after HA augmentations.[21,22]

The maxilla can be divided into three regions: the left and right posterior segments and the anterior segment. The posterior maxilla rarely requires ridge augmentation for improved ridge shape or contour. The tuberosity region usually maintains ridge form. The posterior palatal seal area of the denture does not depend primarily on the posterior ridge form. The posterior region is usually adequate to give lateral stability in the posterior region regardless of posterior ridge contour.

The bone anatomy of the premaxilla is primarily responsible for the varying degree of stability of maxillary dentures. After the loss of teeth, the bone first resorbs in width, and the incisive papilla eventually becomes the most anterior part of the edentulous ridge. The anterior limit of the papilla is usually 7 to 9 mm behind the incisal edge of the central incisors, and the anterior edentulous ridge is considerably diminished. The maxillary anterior teeth positions are dictated by esthetic and functional requirements. The more anterior and incisal position of the denture teeth from the underlying bone results in less denture stability during function.

The vertical component of the anterior maxilla is also the primary element that prevents anterior rotation of a complete removable maxillary prosthesis and loss of posterior value seal. Anterior forces commonly are generated against maxillary prostheses during mandibular excursions, especially during the anterior incision of food. During chewing, the bolus of food acts as a fulcrum for denture rotation (Figure 33-5). Therefore, the primary role of the premaxilla under function is to oppose denture dislodgment and improve the stability of the removable prosthesis.

Hydroxyapatite Indications

The maxillary bone division A ridge usually has the height and width of bone to support, retain, and stabilize the prosthesis. On occasion, labial undercuts may compromise retention and increase soft tissue abrasions. As a result, the dentist may fill in labial undercut areas with HA to improve the ridge contour. The division B and C–w anterior ridges or class I and II ridges from the Kent et al. classification are suited ideally for HA ridge augmentation[22] (Figure 33-6). The dentist may perform a vestibuloplasty in the same procedure to increase the height of the anterior ridge and further improve stability and retention (Figure 33-7). The patient wears a surgical stent for 10 to 14 days to support the graft and maintain the dimension gained with the vestibuloplasty.

The division D and C–h ridges are least suited for HA augmentation. Although these ridges are in greater need, the poor ridge form provides insufficient structure to resist future migration of the HA in the labial fold and may compromise long-term success.[14]

Hydroxyapatite ridge augmentation rarely is indicated for the mandibular arch. The mandibular denture moves up to 10 mm during function compared with about 2 mm of movement for the complete maxillary denture.[10] Ridge augmentation alone does not provide enough improvement for successful mandibular denture support. In addition, sore spots are more common on the thinner, nonmobile tissues; migration of the augmentation material is of greater occurrence (especially in

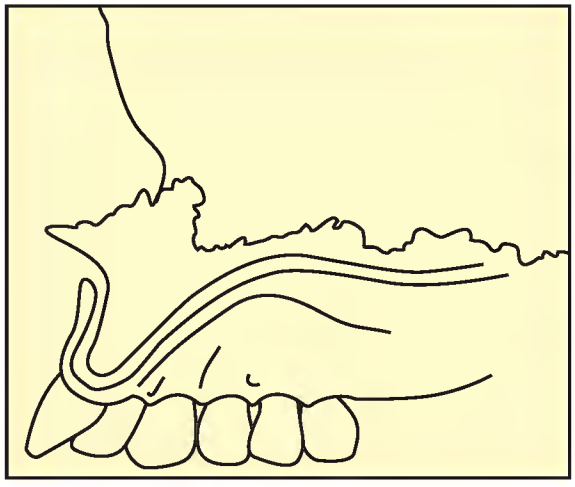


FIGURE 33-5. An important point is to maintain the height of the premaxilla for a denture wearer so as to stop the denture from rotating up in the front and down in the back during excursive movements that cause a break in the posterior valve seal and loss of retention. (Redrawn from Misch CE: *Contemporary implant dentistry,* ed 2, Mosby, 1999, St Louis.)

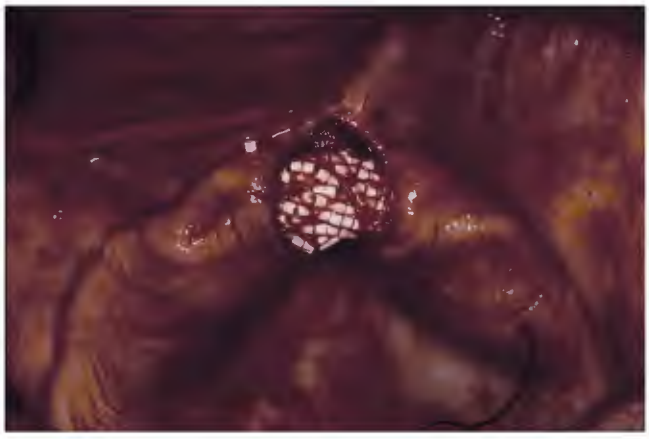


FIGURE 33-6. A hydroxyapatite graft may be used to convert mobile tissue into a firmer support and to square off the ridge form of division B to C minus width maxillary ridges.



FIGURE 33-7. The augmented ridge from Figures 33-4 and 33-6 is firm and has parallel walls for improved denture support, retention, and stability.

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moderate to severely atrophic ridges) along with paresthesia of the mental nerve.[23] Endosteal implants provide much greater support, retention, and stability for the mandibular denture. However, the maxillary edentulous arch and complete denture often can benefit from HA ridge augmentation.

Ridge Shape

In many instances, the incorrect assumption has been made that the larger the alveolar ridge, the better the retention and stability of the denture. The anatomical element most likely to change after HA augmentation is the ridge shape or form. As a result, many alveolar HA ridge augmentations have resulted in greatly increased ridge size but decreased retention and stability. One must appreciate the shape of the ridge in developing the relationships among retention, stability, and support criteria for a maxillary removable prosthesis.

Alveolar ridge shape may be classified related to retention. The ideal ridge form for retention has high, broad parallel walls that also improve lateral stability even if vertical displacement occurs. Therefore, retention and stability are affected by the lateral aspect of the ridge contour (Figure 33-8, *A*). A flat, atrophic ridge provides poor stability but improved support for a maxillary denture. The least stable ridge shape is the V-shaped ridge at an angle to the opposing force. This ridge shape is also poorest for retention and support (Figure 33-8, *B*).

The V-shaped ridge is a common ridge form resulting from HA ridge augmentation surgery, which oversizes the ridge at its base with the particulate HA. The ideal ridge is flat at the crest (and under the teeth) for support and has parallel walls on the ridge sides for retention and stability.[15,16] Hence, ridge shape affects retention, support, and stability, and ridge form correction should be designed to provide an ideal ridge form (Figure 33-9).

The primary long-term goal of premaxillary HA augmentation is to achieve a square ridge shape that can sustain the increased masticatory forces developed by the opposing arch. Other benefits are a reduction of soft tissue movement, a decrease in the rate of bone resorption, and maintenance of the vertical component of the anterior ridge.

Maxillary Denture Impressions

Four methods may be used to improve the retention of a maxillary denture: (1) a valve seal that completely fills the vestibular border, (2) the extension of the posterior limit of the denture, (3) the accuracy of the intaglio aspect of the prosthesis, and (4) the design of the post dam.

The final impression tray should be 2 to 3 mm short of the peripheral vestibular tissues to provide space for border molding. Existing dentures should not be used as an impression tray because they are usually overextended in the labial vestibule because bone resorption has occurred since their initial delivery. Impression trays designed for teeth are overextended for complete denture impressions. Therefore, they should not be used even for preliminary impression to design the custom tray (Figure 33-10). The dentist may perform border molding procedures on the custom tray using polyether or compound, and each has some advantages (Figure 33-11). The peripheral seal designed from the border molding should completely fill the vestibular space to improve retention and decrease food impaction under the denture (Figure 33-12). Regardless, when the border molding procedure is completed, the maxillary custom tray should have good valve seal retention (before the final impression is made) (Figure 33-13). If not, the dentist should consider extending the posterior palatal seal position in the final impression and the denture. When the denture impression is poured in stone, it should be boxed so the peripheral border is reflected in the cast (Figure 33-14).

The literature gives many methods to determine the extent of posterior palatal seal, and each one gives a slightly different position (Figure 33-15). One method has the patient hold the nose, close the mouth, and attempt to force air out at the same time. The palatal drape is pushed down from the hard palate and results in a posterior line for the extension of the denture. This technique results in a position farther anterior than the other methods. As such, this technique provides the least retention for the final prosthesis and is therefore limited to patients complaining of a gag reflex when the denture extends posteriorly too far.

Another option to determine the posterior extent of the denture is to extend the palatal seal to the fovea palatinae. This results in an intermediate denture extension (Figure 33-16). In addition, these small openings off the midline are usually difficult to observe and therefore cannot be used routinely in a clinical setting.



FIGURE 33-8. **A,** The ideal ridge form has high, broad, parallel walls that provide excellent retention, stability, and support. **B,** The least favorable ridge form is a V-shape ridge that provides reduced stability and support for the denture. A hydroxyapatite graft may square off the ridge form *(dotted line)* on the palatal aspect to improve the condition. (Redrawn from Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, Mosby, 1999.)

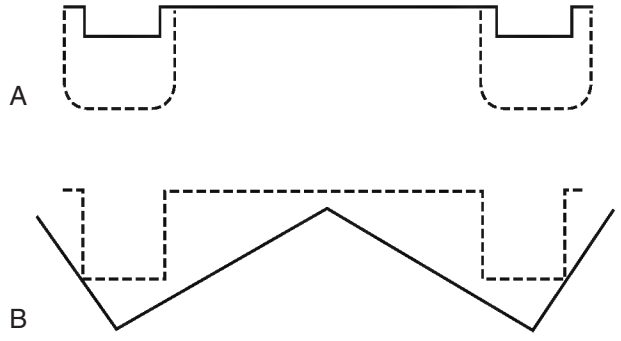


FIGURE 33-9. **A,** An atrophic ridge with a flat palate provides excellent prosthesis support and retention for a denture *(solid line)*. **B,** A hydroxyapatite (HA) augmentation often converts this ridge form to a V-shape ridge *(solid line)* with reduced stability, support, and retention. The ideal HA graft should convert the ridge form to a broad, flat crest with parallel sides *(dotted lines)*. (Redrawn from Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, Mosby, 1999.)

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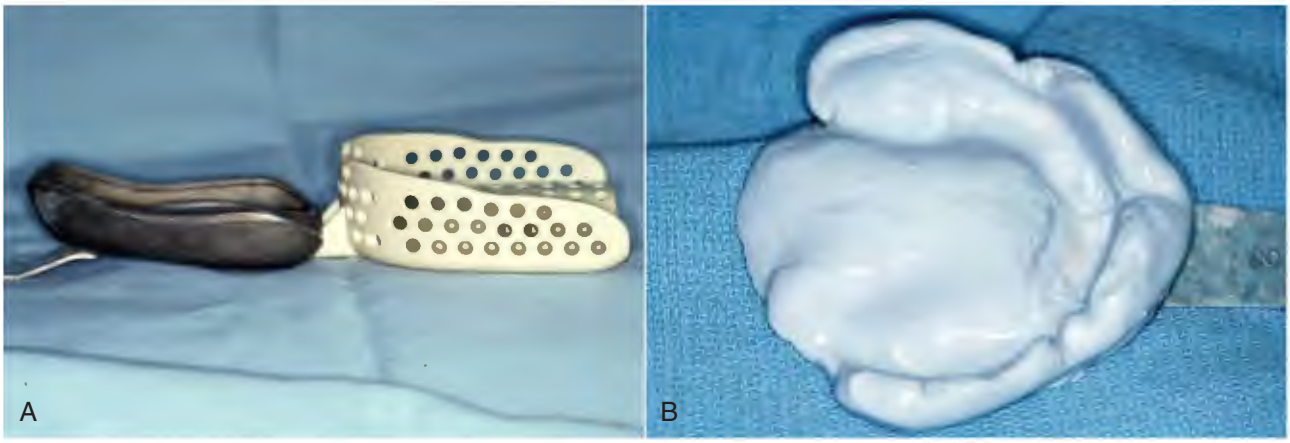


FIGURE 33-10. **A,** An impression tray made for edentulous arches should be used for the preliminary impression *(left)*. Impression trays designed for teeth *(right)* will overextend the peripheral borders of the impression. **B,** The alginate impression with an impression tray designed for edentulous maxillae will not overextend the borders.



FIGURE 33-11. Border molding with polyether impression material injected into the vestibule ensures a complete capture of the region, which increases retention of the restoration.

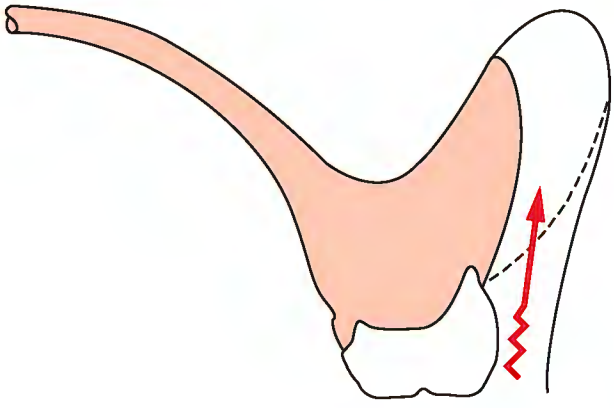


FIGURE 33-12. The periphery of the denture should fill the vestibule area completely to increase retention and decrease food impaction under the denture.

A third technique to determine the posterior extent of a denture is to ask the patient to say, "Ah." The "vibrating line" between the mobile soft tissue and the palate results in the most posterior position (Figure 33-15, position C). As such, this is the technique most often used to determine the posterior limits of the denture.

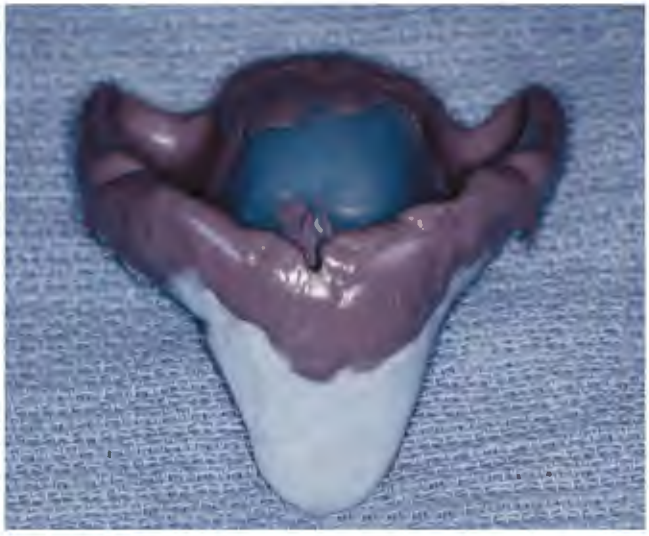


FIGURE 33-13. The border-molded impression should have good retention before the making of the final impression. If not, the dentist should consider extending the posterior palatal seal position of the denture.

Some patients do not mind when the posterior limit of the denture extends beyond the vibrating line (Figure 33-15, position D). When valve seals are poor, the posterior extension of the maxillary denture may compensate and improve the overall retention. Hence, when resorption is moderate to advanced and other treatment modalities such as an implant overdenture are not considered, extension of the posterior limit of the denture beyond the vibrating line improves the retention of the prosthesis.

The third method to improve retention of a maxillary denture is related to the intaglio adaption of the denture. To improve the accuracy of fit for the intaglio aspect of the dentures and to protect the underlying bone, the tissue thickness should be at full thickness when the impressions are made. Kydd et al. demonstrated that maxillary soft tissues loaded for 10 minutes may be compressed to 60% of their original thickness and remain at 65% to 85% for extended periods, with 4 hours necessary for complete recovery.[24] In an older patient, the recovery of tissue

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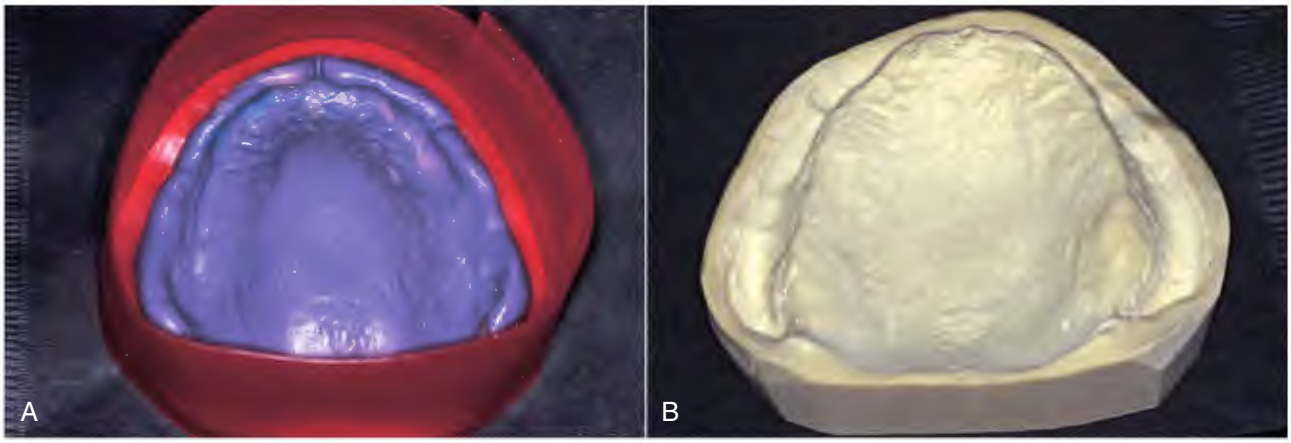


FIGURE 33-14. **A,** The final denture impression is boxed so the peripheral border is captured in the cast. **B,** The model of the final impression includes the anatomy and thickness of the peripheral border.

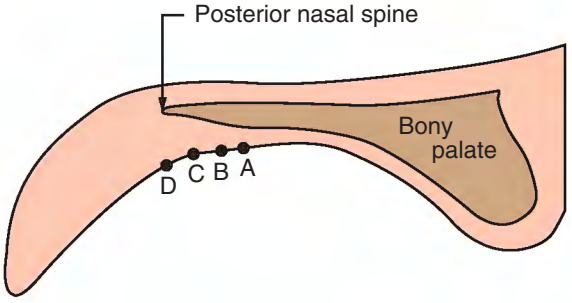


FIGURE 33-15. Many methods exist to determine the posterior palatal extension of a denture, and each gives a slightly different position (**A** to **D**). The farther posterior the extension, the better the retention. When the retention of the prosthesis is poor because of inadequate anatomy, saliva, and so on, the posterior extension may be placed beyond the traditional guidelines.



FIGURE 33-16. The positions of the fovea palatinae are usually difficult to identify and give an intermediate position of the posterior extent of a denture. The held-nose and forced-air technique gives the least extension of the denture *(line across the palate)*.

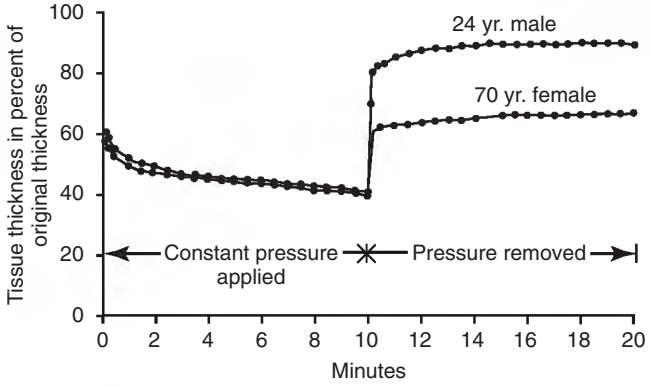


FIGURE 33-17. The tissue thickness should be in a full state when making the final impression (or when delivering the denture). When the tissue under a denture is compressed, it decreases in thickness by 40% to 50% when held in this position for 10 minutes; it may take more than 2 hours in an elderly patient to return to normal.[26]

thickness after 10 minutes of compression may be 2 or more hours (Figure 33-17). Therefore, final denture impression and delivery follow certain guidelines.

A tissue conditioner can improve the tissue health and help obtain the final tissue thickness while the prosthesis is worn before making the final impression. The denture should be removed at least 4 hours before the final impression. This often means the appointment for the final impression should be in the early morning before the patient eats, and the patient should leave the prosthesis out the night before the appointment. As important, a similar routine is repeated on the day the denture is delivered. Otherwise, the soft tissue may be compressed, and the retention at initial delivery may prove to be less than ideal.

The adaption of the intaglio surface of the denture may also be improved by decreasing the amount of acrylic shrinkage during processing of the denture. The use of an injection-molded processing technique to minimize acrylic shrinkage and improve the fit and retention of the final denture is of benefit. The retention may also be improved by a post dam along the posterior limit of the prosthesis. The post dam is used to compensate for the shrinkage of acrylic during the processing of a denture.

The fourth aspect to improve maxillary denture retention is the post dam design. A common post dam design forms a hill, with the greatest height (depth to tissue) in the middle, and sloping posteriorly and anteriorly.[15,16] This contour does not adequately reflect the anatomy of the soft tissue above the vibrating line. When the limit of the denture is established by saying, "Ah," the anatomy of the soft palate directs the design

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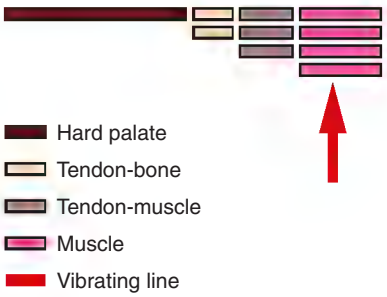


FIGURE 33-18. In the posterior palatal seal region, the muscle layer corresponds to the vibrating line and is the most posterior and most mobile depressible layer. Anterior to this muscle is the muscle-to-tendon attachment (which moves less), then the tendon-to-bone attachment (which moves even less), and then bone of the hard palate (which does not move).

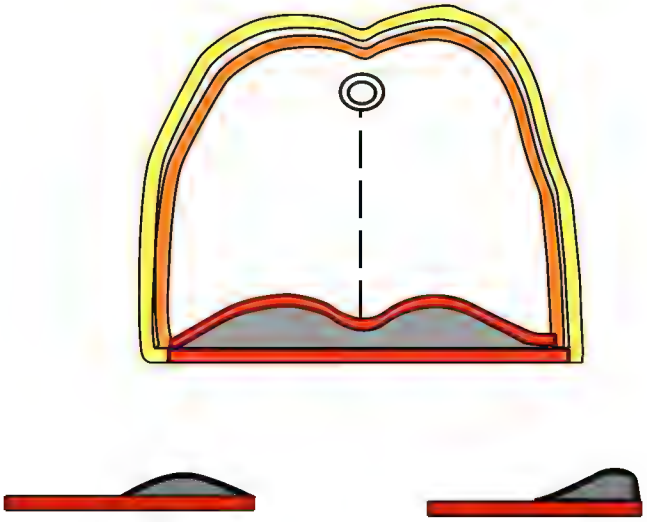


FIGURE 33-19. The post dam in the denture often is made highest in the center and slopes down anteriorly and posteriorly *(left bottom)*. An anatomically designed post dam is highest in the most posterior region and slopes forward *(right bottom)*.

of the post dam. Directly above the vibrating line is a muscle, which has the most flexibility. The muscle is attached to a tendon (with slightly less movement) that attaches to a hard palate covered by soft tissue that has the least movement (Figure 33-18). Therefore, the depth of the post dam should be greatest in the posterior area and then slant toward the tissue of the hard palate (Figure 33-19). The initial depth varies for each patient and is determined by depressing the area in the mouth with a mirror or blunt object.[25]

Maxillary Anterior Tooth Position

Several texts on denture fabrication state that the first step in the reconstruction is determining the OVD followed by the position of the lower anterior teeth.[15,16,25,26] However, the maxillary anterior horizontal and vertical tooth positions should be evaluated before any other segment of the reconstruction, including the OVD.[14] If the maxillary incisor edge is modified in either the horizontal or vertical plane, all other elements of the maxillary and mandibular prosthesis may also need to be changed. No other region of the mouth should be restored until this position is obtained because it negatively influences the proper position of every other segment (e.g., OVD, mandibular anterior tooth position, and posterior planes of occlusion).

BOX 33-3 Sequence of Treatment for a Maxillary Denture

1. Labial position of maxillary anterior teeth
2. Vertical position of maxillary anterior teeth
3. Maxillary occlusal plane
4. Occlusal vertical dimension
5. Mandibular anterior teeth
6. Mandibular posterior teeth
7. Maxillary posterior teeth

The patient's existing maxillary complete denture often has the maxillary anterior tooth position incorrect. The resorption of the premaxilla causes the denture to shift apically and posteriorly following the bone loss pattern. A base plate and wax rim first evaluates the position of the maxillary anterior teeth. At this point, the evaluation is not for the cosmetic aspects of tooth color or shape, but tooth position is scrutinized. After this is determined, the maxillary occlusal plane, OVD, mandibular incisive edge position, posterior mandibular teeth, and last the maxillary posterior teeth are determined (Box 33-3). Arch relationships are often affected by resorption patterns in edentulous ridges. The anterior and posterior edentulous maxilla resorbs toward the palate after tooth loss.[27] The width of the alveolar ridge decreases 40% within a few years, primarily at the expense of the labial plate. This results in a cantilevered force on the denture teeth. The maxilla is affected more often than the mandible because the incisal edge position in the esthetic zones cannot be modified and is dictated by esthetics, speech, lip position, and occlusion.

The anterior location of the occlusal plane is determined by the maxillary incisal edge position. The farther forward the maxillary anterior denture teeth, the more leverage off the anterior bone and the more likely the maxillary anterior teeth will tip up and the posterior palatal seal will fail, with the upper denture dropping from the ridge. Yet many dentists attempt to do plastic surgery with plastic, hoping to eliminate vertical facial lines in the lip by bulking up the labial flange and positioning the teeth forward from the ridge (Figure 33-20).

The dentist inserts the base plate and wax rim into the patient's mouth and first determines the labial contour of the maxillary lip because modification at a later step may alter all other measurements. Most often the facial surfaces of the central incisors are 12.5 mm from the most posterior aspect of the incisive papilla or 7 to 9 mm from its anterior limit[28] (Figure 33-21). Hence, the dentist initially positions the wax rim this far forward at the midtooth position. The philtrum of the lip should be a visible depression in the midline under the nose. If the philtrum is flattened, the lip is extended too far, and wax should be removed from the labial of the wax rim. In addition, in 92% of cases, the line drawn from the tip of the canines has been shown to bisect the incisive papilla[29] (Figure 33-22).

The labial position of the maxillary anterior teeth is then evaluated with the patient at a relaxed vertical dimension. This is primarily to evaluate the overall support of the maxillary lip and its relationship to the balance of the face, especially in relation to the nose and presence or absence of a philtrum in the midline. A perpendicular line from the Frankfort plane (plane

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passing through the lowest point in the floor of the left orbit and the highest point of each external auditory meatus of the skull) that touches the lower lip should most often find the maxillary lip 1 to 2 mm in front of this line and the chin 1 to 2 mm behind this line (at the correct OVD)[30] (Figure 33-23).

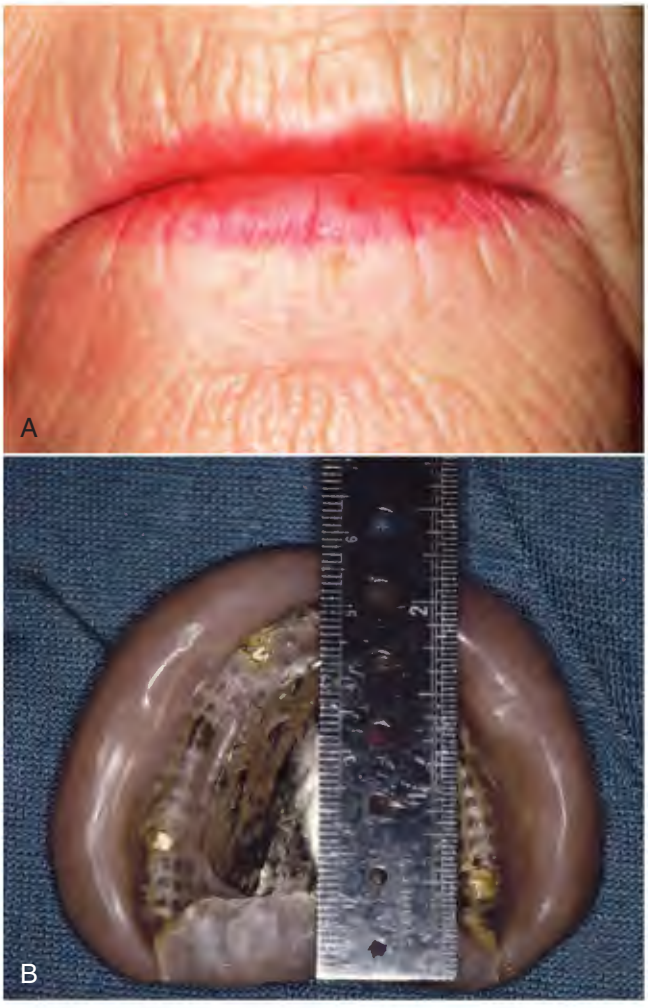


FIGURE 33-20. **A,** Many dentists attempt to remove vertical lines in the maxillary lip by overcontouring the border and placing the teeth more labial. **B,** This denture has the anterior teeth cantilevered forward 15 mm from the incisive papilla.

The vertical position of the maxillary incisal edge is then evaluated. This position primarily reflects esthetic requirements. Most dentists determine the vertical positions of the maxillary teeth by the central incisors related to the maxillary lip at rest. A significant decrease of maxillary central incisor tooth length exposure with the lip in repose is relative to age, especially between 30 and 40 years. According to Vig and Brundo, a 30-year-old person exposes more than 3 mm of the maxillary central incisor when the maxillary lip is at rest or repose.[31] A 40-year-old person shows 1.5 mm of maxillary central incisors; a 50-year-old person about 1 mm; a 60-year-old person 0.5 mm of tooth; and at 80 years old, the lip is observed level with the teeth. The reverse is observed with the lower teeth, with 0.5 mm for a 20-year-old person, 1 mm for a 40-year-old person, 2 mm for a 50-year-old person, 2.5 mm for a 60-year-old person, and 3 mm for an 80-year-old person.

The length of the central aspect of the maxillary lip from the base of the nose to its inferior border is a determining factor for the exposure of the central incisors. The maxillary lip is on average 20 to 22 mm and 22 to 24 mm for a 20-year-old woman and man, respectively (Figure 33-24). As a consequence, the base plate and wax rim usually is fabricated with a 22-mm dimension (Figure 33-25). In the case of lip discrepancy, the resting lip line is also affected. For example, short upper lips expose more incisal edge and vice versa (Figure 33-26).



FIGURE 33-21. The labial position of the maxillary teeth is usually 12.5 mm anterior from the posterior aspect of the incisive papilla.

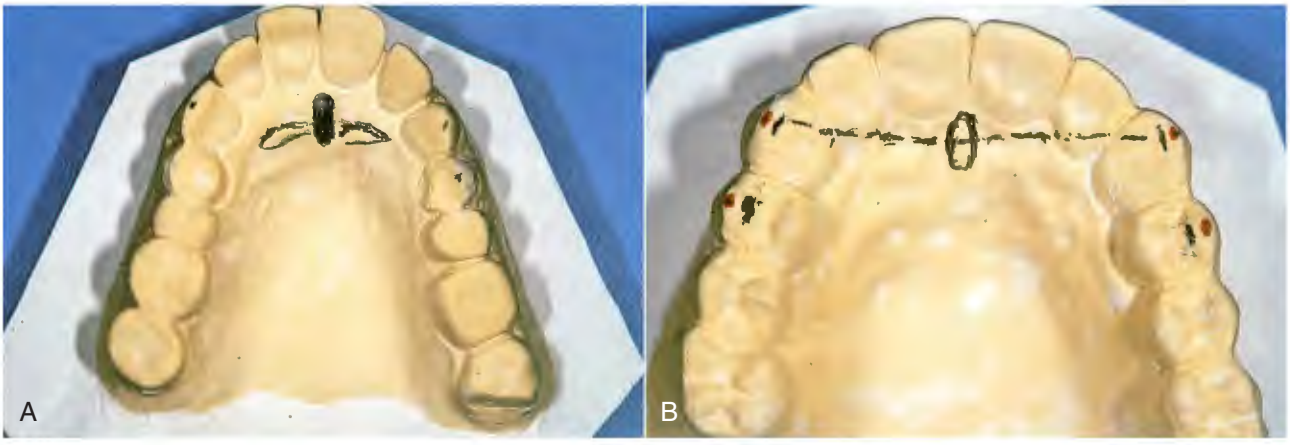


FIGURE 33-22. A line joining the midcanine position is perpendicular to a line joining the midline and bisects the center of the incisive papilla in a tapered dentate arch form **(A)** and an ovoid dentate arch form **(B)**.

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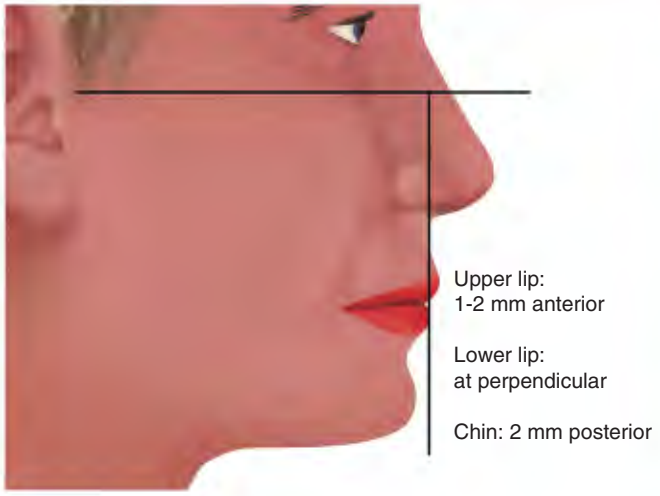


FIGURE 33-23. A vertical line to the Frankfort plane usually touches the lower lip, with the chin recessed 2 mm and the maxillary lip 1 to 2 mm anterior.



FIGURE 33-26. This female patient has a short upper lip, which measures approximately 14 mm. As a consequence, she exposes 6 mm of her central incisors. Note that the canine only shows 1 mm.

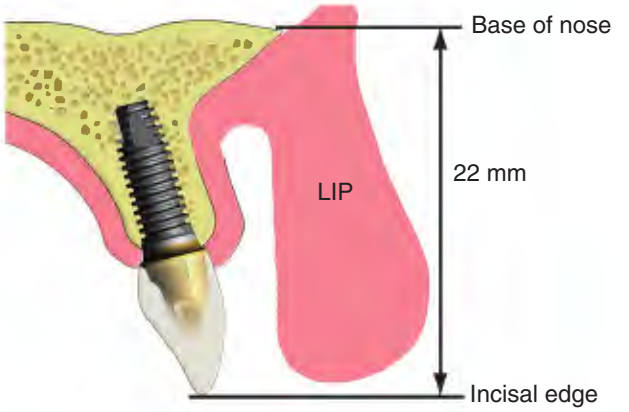


FIGURE 33-24. The length of the lip is often 22 mm.

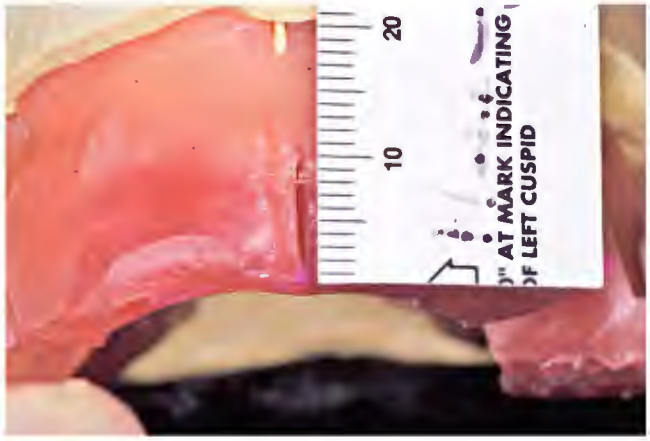


FIGURE 33-25. The maxillary base plate and wax rim are usually fabricated with 22 mm from the periphery to the incisal edge.

However, Misch reported that the range of central incisal exposure with the lip in repose was 2 mm to +8 mm regardless of the age.[32] The statistical average exposure of central incisors represents less than 15% of the population, especially in women. In addition, at age 60 years, patients often have natural teeth shorter than the relaxed maxillary lip because of loss of facial muscle tonicity. Yet even 80-year-old edentulous patients often desire to have maxillary central incisors below the lip at rest.

At maxillary lip rest, the central incisor portion of the incisal edge exposed varies greatly in women because of a wide range of lip bow contour. As a general rule, lip bow is more pronounced in young people and less in old people and is greater in women than men. The higher the lip bow contour, the more central incisor edge is shown when the lip is at rest.

The author has noted that the canine position is more consistent and less affected by age.[32] In general, the canine tip is lateral to the lip bow and is usually ±1 mm than the maxillary lip in repose (say, "Emma" and relax) at any age (Figure 33-27). Even with a short upper lip, the canine position is similar to the resting lip line because it is more lateral to the short maxillary lip in the midline (see Figure 33-26). The canine is usually 1 to 2 mm shorter than the central incisors in a horizontal line to the horizon. Therefore, the dentist may use the canine to more accurately determine the vertical position of the anterior teeth.

After the dentist determines the resting lip position to anterior teeth position, speech may then be evaluated. The dentist makes the anterior incisal width of the wax rim similar to that of the final teeth. The dentist evaluates length and labiolingual position with "F" and "V" sounds.[33] When the patient says "F," the maxillary incisal edges should lightly touch the wet–dry border of the lower lip, similar to lower lip position during a broad smile position. When the patient says "E," 50% to 70% of the space between the maxillary and mandibular lip should be occupied by the maxillary central incisors. If less than 50% of the space is occupied, the teeth usually can be lengthened, but if more than 70% of a space is occupied by maxillary centrals, lengthening the teeth usually is not indicated.[34]

The farther away the incisor edge is off the bone (the greater the crown height), the greater the moment force applied to the denture teeth and less stability of the denture during function. A conventional denture on a division D maxilla may require the incisal edge position slightly superior or inward, closer to the edentulous ridge, to improve anterior stability.

When the teeth (wax rim) are positioned more labial, the vertical position of the lip is elevated. An alternative to

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FIGURE 33-27. The canine tip position of the natural teeth in relation to the resting maxillary lip is less variable than the central incisor position. Between the ages of 20 and 80 years, the canine tip is usually level with the maxillary lip ±1 mm. **A,** A young woman. **B,** An old man.

increasing the length of the anterior teeth so more teeth are visible with the lip in repose may be to increase the thickness of the premaxillary denture flange. This extra thickness brings out the lip and also raises the vermillion border. As a result, the teeth are not longer, but the border of the lip is higher. The fuller maxillary lip may also look younger because vertical age lines may also be reduced. Likewise, the thinner the labial flange and a more palatal position of the maxillary anterior teeth results in a more inferior or extended position of the lip.

Posterior Maxillary Plane of Occlusion

Occlusal Plane

After the maxillary anterior teeth positions are deemed acceptable, the horizontal occlusal plane is determined in the posterior regions of the mouth. The occlusal plane is defined in three dimensions: occlusal gingival, anteroposterior (A-P), and buccolingual.[35] The dentist obtains the maxillary anterior occlusal gingival position of the incisal edge position relative to esthetics and phonetics. This dimension also determines the position of teeth relative to the residual crest of the anterior ridge. The posterior occlusal gingival plane has a variety of positions and will be modified to help stabilize a maxillary denture. The buccolingual dimension (horizontal plane) of the occlusal plane is parallel with the horizontal horizon, which usually corresponds to a line drawn through the pupils of the eyes (but follows a compensating curve). One side of the arch should be parallel to the other. The A-P dimension is established by the anterior incisal edge and the position of the posterior occlusal plane.



FIGURE 33-28. The anatomic landmark approach for the occlusal plane uses the retromolar pad for the posterior reference.

In complete denture techniques, the mandibular occlusal plane is determined after the OVD is established. The maxillary occlusal plane therefore follows the mandibular plane. In the occlusal–gingival position of the mandibular posterior occlusal plane (which determines the crown height space [CHS]), guidelines range from keeping the occlusal plane closer to the arch with less favorable ridge size and contour, thus favoring the mandibular arch[15,17]; putting the occlusal plane midway between the two arches[36]; using anatomical landmarks to place it in its natural location[37,38]; or terminating the occlusal plane posteriorly at the distal half of the retromolar pad.[15,17,39]

The most common mandibular posterior occlusal plane technique uses an anatomic landmark. However, the anatomical landmark approach for occlusal plane also has fueled controversy because several planes and lines have been suggested. A review of the literature highlights the controversy within the profession with suggested guidelines by Lundquist and Luther using the tips of mandibular cuspids and lower half of the retromolar pad.[39] Ismail and Bowman recommended joining the upper third of the retromolar pad to the mandibular incisal edge.[40] Others have suggested a line passing through the junction between the middle and superior third of the retromolar pad as a guideline[41] (Figure 33-28).

Most of the anatomic landmark approaches have a horizontal plane below Camper's plane. In a study by Misch, the posterior position of the anatomical plane in complete denture fabrication (half the retromolar pad) is parallel to line from the alar of the nose to the bottom of the ear. In other words, it is well below Camper's plane (Figure 33-29).

One reason for the controversy of the occlusal plane is that most authors use the posterior occlusal plane position to benefit lower denture stability rather than comparing the plane with the natural teeth. When the occlusal plane is oriented lower than the one observed with natural teeth, the stability of a lower denture is improved by decreasing the crown height and moments of force and allowing the tongue to rest above the posterior teeth, which helps stabilize the lower denture. However, when the mandibular restoration is implant supported, this occlusal plane location is not indicated because it positions the posterior maxillary teeth lower (and increases the posterior crown height) than the original tooth position. The increase in CHS decreases esthetics during smiling because more gingival denture material is displayed above the posterior

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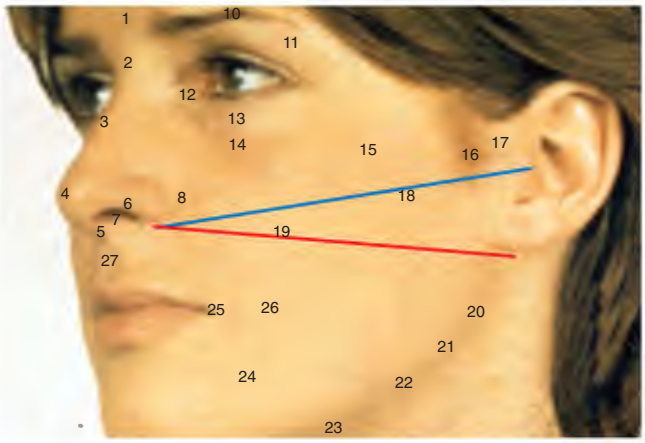


FIGURE 33-29. Camper's plane is positioned from the alar of the nose to the midtragus of the ear. The anatomic mandibular plane that uses the retromolar pad as a reference is a plane from the alar of the nose to the bottom of the ear. As a result, the maxillary denture is less stable and often exposes the gingival region above the posterior teeth when smiling.



FIGURE 33-30. In this patient, the maxillary denture occlusal plane is half up on the retromolar pad and built with flat posterior teeth. A gingival display above the posterior teeth is not usual with this setup.

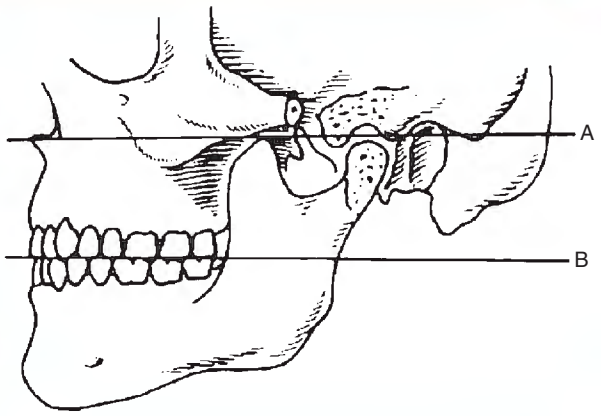


FIGURE 33-31. Camper's plane is determined by a line from the inferior aspect of the nose (alar process) to the auditory meatus or midtragus of the ear.

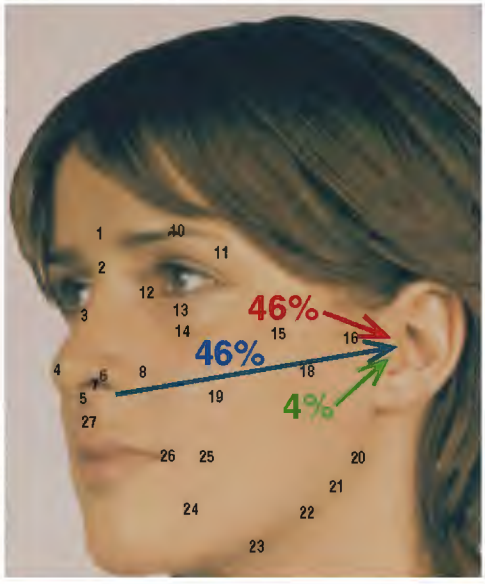


FIGURE 33-32. Misch evaluated Camper's line and the occlusal plane in 50 patients with natural teeth. In only 4%, the occlusal plane was below the midtragus (which is close to the half retromolar pad position). In half of the patients, the occlusal plane was parallel to the top third of the tragus (which would help stabilize a maxillary denture).

teeth (especially in the premolar area) and decreases denture stability (Figure 33-30).

Camper's plane has classically been described to correspond with the occlusal plane of the maxillary teeth. Ideally, the maxillary posterior occlusal plane should be parallel to the Camper's plane, which places the denture teeth closer to the maxillary supporting bone. Following Camper's plane is a logical position, although confusion exists as to the actual position of Camper's plane. A consistent landmark for this position is the inferior alar process of the nose, but the posterior landmark varies from the superior to the middle point of the tragus[15,16] (Figure 33-31).

Misch evaluated the existing maxillary occlusal plane from the maxillary canine to first molar in 50 patients with natural maxillary and mandibular teeth.[14] The anterior reference point was the inferior ala process position. In half of the patients, the parallel posterior reference point was located in the upper third of the tragus; in 46%, it was parallel to the midtragus; and in 4%, it was below the midtragus. Therefore, the author suggests that the posterior plane of occlusion with natural teeth varies, with 96% of the patients following a line passing through the middle to superior third of the tragus position (Figure 33-32).

The tragus position was different on the contralateral side in almost 25% of the patients. This was a result of one ear position higher on one side than the other. Hence, an ear bow transfer for maxillary arch position to the articulator is not parallel to the horizontal plane in one of four patients.

For a type I, division A or type I, division B maxilla with good retentive form, the maxillary wax rim is oriented toward the midtragus position. A Frank Fox plane is placed on the maxillary wax-in to evaluate this position (Figure 33-33). The posterior reference point is raised to a position near the upper third of the tragus, slightly raising the occlusal plane, to stabilize the denture for the less favorable division C or D maxillary arch. Thus, the dentist can vary the A-P orientation of the occlusal plane in relation to the length and support of the maxillary lip,

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FIGURE 33-33. A Frank Fox plane is positioned on the maxillary wax rim to evaluate Camper's plane.

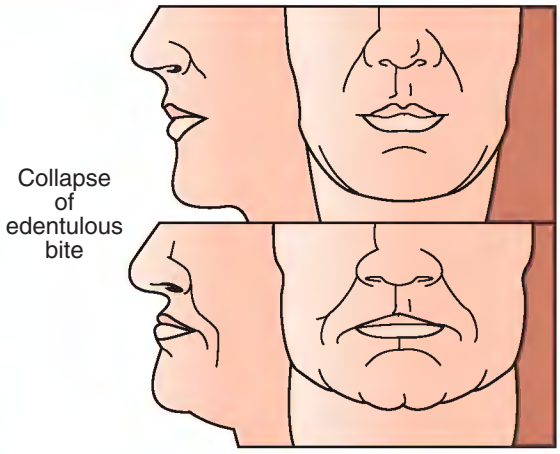


FIGURE 33-35. As the occlusal vertical dimension is decreased, the mandible rotates forward and up upon closing. The chin is more dominant, and the anterior teeth occlude farther forward and modify incisal guidance and function.



FIGURE 33-34. The same patient as in Figure 33-30, with the same dentures and same six anterior teeth. Only the posterior teeth and plane of occlusion were modified. (Unfortunately, the camera angle was changed, too.)

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ridge shape, height, and position. Raising the posterior occlusal plane for a maxillary denture makes the prosthesis more stable because the crown height is reduced. It also makes the prosthesis more esthetic in relation to the high lip position during smiling (Figure 33-34).

Occlusal Vertical Dimension

To determine the anterior position and the CHS of the mandible, the overall issue of OVD must be addressed. The OVD is defined as the distance between two points (one in the maxilla and the other directly below in the mandible) when the occluding members are in contact.[35] This dimension requires clinical evaluation of the patient and cannot be evaluated solely on the diagnostic casts.

The determination of the OVD is not a precise process because a range of dimensions is possible without clinical symptoms.[26] At one time, it was believed OVD was very specific and remained stable throughout a patient's life. However, this position is not necessarily stable when the teeth are present and definitely is decreased after the teeth are lost. Long-term studies have shown this is not a constant dimension and often decreases over time without clinical consequence in dentate or partially or completely edentulous patients.[42] A completely edentulous patient often wears the same denture for more than 10 years, during which time the OVD may be reduced 10 mm or more without symptoms or even patient awareness.

The OVD may be altered without the symptoms of pain or dysfunction, especially when the condylar disc assembly is healthy. However, this is not to say that altering the OVD has no consequences. A change in OVD affects the esthetics of the chin-to-face position and the mandibular CHS. As such, it may affect the biomechanics of the support system of a prosthesis. Any change in the OVD will modify the horizontal dimensional relationship of the maxilla to the mandible. Therefore, a change in OVD will modify the anterior guidance, range of function, and facial esthetics.[43]

The most important effect of OVD on tooth (implant) loading may be the effect on the biomechanics applied to the premaxilla of the denture. The more closed the OVD, the farther forward the mandible rotates and the more skeletal class III the chin appears. In an edentulous patient who wears the same denture over many years, the mandibular bone loss in height results with the mandibular anterior teeth occluding with the maxillary anterior denture teeth prematurely and dislodging the maxillary denture. Hence, restoring the OVD and incisal guidance is paramount to any oral reconstruction.

The maxillary anterior tooth position is determined first and is most important for the esthetic criteria of the reconstruction. However, esthetics is also influenced by OVD because of the relationship to the maxillomandibular positions. The smaller the OVD, the more Angle's skeletal class III the jaw relationship becomes; the greater the OVD, the more Angle's skeletal class II the relationship becomes. Alteration of the OVD for esthetics primarily affects the mandibular tooth position. For example, the OVD position may be influenced by the need to soften the chin for a patient with a large mental protuberance by increasing the OVD (Figure 33-35).

The OVD is almost never too large in an edentulous patient, and unless some manufactured interference has been created, it is within clinical guidelines or collapsed. Therefore, the restoring dentist most often should determine whether the OVD needs to be increased. In other words, the existing OVD in a patient without symptoms of the temporomandibular joint is

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a position to start the evaluation, not one that necessarily must be maintained.

Methods to Evaluate Occlusal Vertical Dimension

In traditional prosthodontics, a range of techniques has been described to establish the OVD.[44] Whereas objective methods use facial dimension measurements, subjective methods rely on esthetics, resting arch position, and closest speaking space. There is no consensus on the ideal method to obtain the OVD. Therefore, this dimension is part art form and part science.

Niswonger proposed the use of the interocclusal distance ("freeway space"), which assumes that the patient relaxes the mandible into the same constant physiologic rest position.[44] The practitioner then subtracts 3 mm from the measurement to determine the OVD. Two observations conflict with this approach. First, the amount of freeway space is highly variable in the same patient, depending on factors such as head posture, emotional state, presence or absence of teeth, parafunction, and time of recording (greater in the morning). Second, interocclusal distance at rest varies 3 to 10 mm from one patient to another. As a result, the distance to subtract from the freeway space is unknown for a specific patient. Therefore, the physiologic rest position should not be the primary method to evaluate OVD. However, it should be evaluated after the OVD is established to ensure a freeway space exists when the mandible is at rest.

Silverman stated that approximately 1 mm should exist between the teeth when making an "S" sound.[45] Pound further developed this concept for the establishment of centric and vertical jaw relationship records for complete dentures.[46] Although this concept is acceptable, it does not correlate to the original OVD of the patient. Denture patients often wear the same prosthesis for more than 14 years and during this time lose 10 mm or more of their original OVD. Yet all of these patients are able to say "Mississippi" with their existing prosthesis. If speech were related to the original OVD, these patients would not be able to pronounce the "S" sound because their teeth would be more than 11 mm apart. But to say the letter "S" with the correct sound, the teeth must be approximately 1 mm apart (regardless of the OVD). Therefore, the speaking space should not be used as the only method to establish OVD. However, after the OVD has been determined, the speaking space should be observed, and the teeth should not touch during sibilant sounds. On occasion, a short adjustment period of a few weeks may be required to establish this criterion.

After the position of the maxillary incisor edge is determined, the OVD influences the esthetics of the face in general. Facial dimensions are objective (because they are measured) and directly related to the ideal facial esthetics of an individual. They can be easily assessed regardless of the clinician's experience. This objective evaluation is usually the method of choice to initially evaluate the existing OVD or establish a different OVD during prosthetic reconstruction. In addition, it may be performed without the need for additional diagnostic tests.[43]

Facial measurements can be traced back to antiquity, when sculptors and mathematicians followed the *golden ratio* for body and facial proportions as described by Plato and Pythagorus.[47] The golden ratio relates to the length and widths of objects in nature as 1 to 0.618.[48] It was observed that biologic features follow this ratio.[49] Architectural proportions often follow the golden ratio, because it is considered the most esthetically appealing to the human eye. Leonardo da Vinci later contributed several observations and drawings on facial proportions, which he called *divine proportions*.[50] He observed the distance between the chin and the bottom of the nose (i.e., OVD) was a similar dimension as (1) the hairline to the eyebrows, (2) the height of the ear, and (3) the eyebrows to the bottom of the nose—and each of these dimensions equaled one third of the face (Figure 33-36).



FIGURE 33-36. Leonardo da Vinci used measurements to aid in drawing a face. The occlusal vertical dimension was similar to the hairline to eyebrow length and the height of the ear.

Many professionals, including plastic surgeons, oral surgeons, artists, orthodontists, and morticians, use facial measurements to determine OVD.[51,52] Misch reviewed the literature and found that many different sources reveal many correlations of features that correspond to the OVD[14,43,53]:

1. The horizontal distance between the pupils[54]
2. The horizontal distance from the outer canthus of one eye to the inner canthus of the other eye
3. Twice the horizontal length of one eye
4. Twice the horizontal distance from the inner canthus of one eye to the inner canthus of the other eye
5. The horizontal distance from the outer canthus of the eye to the ear
6. The horizontal distance from one corner of the lip to the other following the curvature of the mouth (cheilion to cheilion)[54]
7. The vertical distance from the external corner of the eye (outer canthus) to the corner of the mouth
8. The vertical height of the eyebrow to the ala of the nose[50]
9. The vertical length of the nose at the midline (from the nasal spine [subnasion] to the glabella point)[51]
10. The vertical distance from the hairline to the eyebrow line[50]
11. The vertical height of the ear[50]
12. The distance between the tip of the thumb and the tip of the index finger when the hand lays flat with the fingers next to each other (Figure 33-37).

All of these measurements do not correspond exactly to each other but usually do not vary by more than a few millimeters (with the exception of the vertical height of the ear and the length of the index finger) when facial features appear in balance. An average of several of these measurements may be used to assess the existing OVD. In a clinical study by Misch, the OVD was often slightly larger than the facial measurements listed (more in men than women) but was rarely a smaller dimension.[53]

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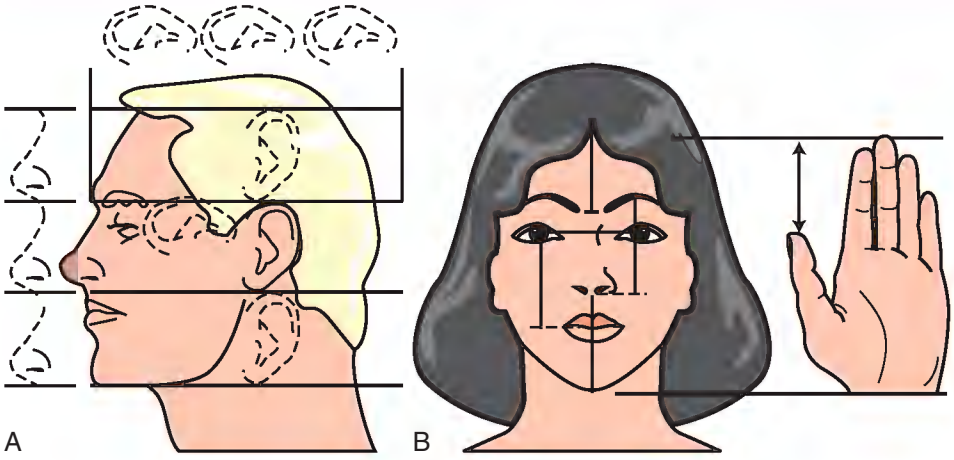


FIGURE 33-37. Leonardo da Vinci described "divine proportions" in the following way: **A,** "The distance between the chin and the nose, and hairline and the eyebrows are equal to the height of the ear and to one-third of the face height." **B,** In addition, the facial height (from the chin to hairline) is often equal to the length of the hand, and the distance from the chin to the bottom of the nose is the same length as the distance between the tip of the thumb and the tip of the index finger. (From Misch CE: *Contemporary implant dentistry,* ed 2, Mosby, 1999, St Louis.)

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FIGURE 33-38. The superior two thirds of the face is first evaluated to see if it is in facial balance.

To determine facial measurements and their relationship to the desired OVD, the dentist first should evaluate the superior two thirds of the face and establish the face in general as facial balance (Figure 33-38). For example, when the horizontal distance between the pupils of the eyes is within 2 mm of the vertical distance from the outer canthus of the eye to the corner of the mouth, the midface is within facial balance. When the eyebrow to ala of the nose is similar to the hair line (in women) to eyebrow, the superior third of the face has balance. When these measurements are similar, the rest of the measurements are usually similar, including the bottom of the nose to the bottom of the chin (i.e., OVD). Therefore, the position by facial measurement is an objective starting point. Most often a male patient has an OVD that is slightly larger than the other facial dimensions. The subjective criteria of pleasing esthetics may then be considered after the facial dimensions are within balance with each other.

Facial measurements as a start to determine OVD offer significant prosthetic advantages. These are objective measurements rather than subjective criteria (e.g., resting jaw position or swallowing). After the dentist has determined the initial OVD, the dentist may use the wax rim to evaluate speech, swallowing, and resting jaw position. In addition, the esthetic requirements may mandate slightly decreasing the OVD and making the patient appear more Angle's class III or slightly increasing the OVD and making the jaw relationship more Angle's class II.

An anterior cantilever on implants in the edentulous mandibular arch may correct an Angle's skeletal class II, division I jaw relationship. The maxillary anterior teeth support the lower lip at rest in both Angle's skeletal class I and class II relationships. A traditional complete mandibular denture cannot extend beyond the anatomical support or neutral zone of the lips without decreasing stability of the prosthesis. However, with implants, the mandibular denture teeth may be set in a more ideal esthetic and functional position.[14]

The anterior cantilever in the Angle's skeletal class II mandible depends on an adequate implant number and A-P distance between the splinted implants. To counteract the anterior cantilever effect, the treatment plan should provide increased implant support by increasing the surface area by number, size, design, or A-P implant position. In these cases, a removable type 4 (RP-4) prosthesis, designed to prevent food impaction, may facilitate daily care compared with a fixed type 3 (FP-3) prosthesis.

Because no absolute method exists to determine OVD that can be used assuredly for all individuals, the facial measurements for balance are attractive because they require no radiographs or other special measuring devices. The maxillary and mandibular wax rims are evaluated at the OVD position (Figure 33-39). A closed-mouth centric relation bite registration is then made. Because the mandibular prosthesis is implant supported, the bite registration is usually more easily obtained compared with a soft tissue–supported mandibular denture.

Mandibular Incisor Edge Position

After the maxillary incisal edge, the posterior plane of occlusion and the OVD are deemed clinically acceptable, the position of the lower anterior teeth is evaluated. Because the maxillary

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FIGURE 33-39. A maxillary base plate and wax rim opposing a mandibular base plate and wax rim verification jig. The maxillary midfacial line, high lip line, canine position, and occlusal vertical dimension are evaluated before obtaining a closed-mouth bite registration record.



FIGURE 33-40. The maxillary anterior teeth are first positioned in the wax rim. The mandibular anterior teeth do not occlude with the maxillary teeth. A horizontal overjet of approximately 2 mm is sufficient.

anterior teeth are first set in the wax rim, the mandibular teeth positions are set in relation to these teeth. In a maxillary denture, no anterior contact in centric relation occlusion is designed with the mandibular implant prosthesis.[55,56] Centric stops or pressure from the tongue and muscle positions usually prevent continued extrusion of mandibular anterior natural teeth. However, this is not necessary when the anterior teeth are supported by implants or are part of a denture.

The occlusal position of complete maxillary and mandibular dentures during function is often anterior to the recorded centric relation occlusion.[15] As a result, the anterior teeth occlude before the posterior teeth. When the mandibular implant prosthesis is more secure than the maxillary denture, the maxillary prosthesis loses the valve seal retention and may be dislodged during mandibular excursions in the absence of posterior contacts, which occurs not only during the incision of food but also during parafunction. Inadequate valve seal and instability of the maxillary denture also can contribute to gagging.

Maxillary anterior prosthetic teeth most always are positioned facially off the anterior supporting bone to satisfy phonetic and esthetic requirements. The moment forces created by the mandibular anterior teeth of the implant prosthesis may cause instability of the maxillary prosthesis, and therefore the anterior teeth should not come in contact with the maxillary denture. Most often, the horizontal overjet of the anterior teeth is about 2 mm. This overjet permits functional movements of the mandibular overdenture or fixed prosthesis without immediate anterior tooth contacts that may dislodge the maxillary denture and protects the premaxilla from excess forces (Figure 33-40).

A vertical overbite of 2 mm with the maxillary anterior teeth often is used to position the mandibular anterior teeth. During mandibular excursions, the maxillary and mandibular anterior teeth contact because the mandible moves down and forward (the condyle slides along the glenoid fossa). In this way, the patient still is able to bite through a sandwich or piece of meat. The resulting anterior guidance is about 15 degrees, which is less than the ideal with natural teeth, where incisal guidance is desired. This position is compatible with the use of a bilateral balanced occlusion scheme when using posterior anatomic teeth. Hence, the maxillary anterior teeth are positioned first primarily by esthetics and secondarily speech. The mandibular anterior teeth are then positioned (after the OVD is established) primarily related to occlusion and function.

The tips of the maxillary canines align with the center of the incisive papilla and are closer to the resorbed residual ridge compared with the maxillary anterior incisors. Therefore, anterior contacts in centric occlusion may be present at the distal aspect of the maxillary canine.

After the maxillary and mandibular anterior teeth are set on the wax rims, the dentist determines the amount of incisal guidance, which determines the steepness of the compensating curve for a balanced occlusion. The greater the anterior guidance, the greater the posterior compensating curve. To establish anterior guidance with a minimal curve is easier to develop bilateral balance. Therefore, setting a shallow incisal guide for phonetics, esthetics, and function of the anterior teeth offers significant advantages.

Posterior Tooth Form

The form of the posterior teeth may be classified as anatomical (30-degree cusp angle), semianatomical (10- to 20-degree cusp angle), or nonanatomical (flat). In most complete denture designs, the posterior tooth form is determined by the resorption process of the posterior mandible. When abundant bone is present, an anatomic tooth form is used. When severe atrophy is present, a flat tooth form is used[57,58] (Figure 33-41).

The anatomical tooth form presents considerable esthetic advantages for the maxillary denture, especially in the premolar positions. In addition, the steeper cusp forms are more efficient at penetrating the bolus of food compared with anatomical forms.[59] In addition, the use of maxillary posterior anatomical teeth allows the creation of a vertical overbite in the anterior region of the mouth for improved esthetics and bilateral balance of occlusion. The cusp angles on the posterior teeth allow posterior occlusal contact in protrusion. When flat, nonanatomical teeth are used in the posterior regions, the dentist must eliminate the vertical overbite in cases in which the jaw relationship does not provide an adequate horizontal overjet.[60] Therefore, the maxillary posterior denture teeth should have relatively steep cusp angles.

When a maxillary denture opposes an implant prosthesis, the maxillary posterior teeth should use a 20- to 33-degree cusp

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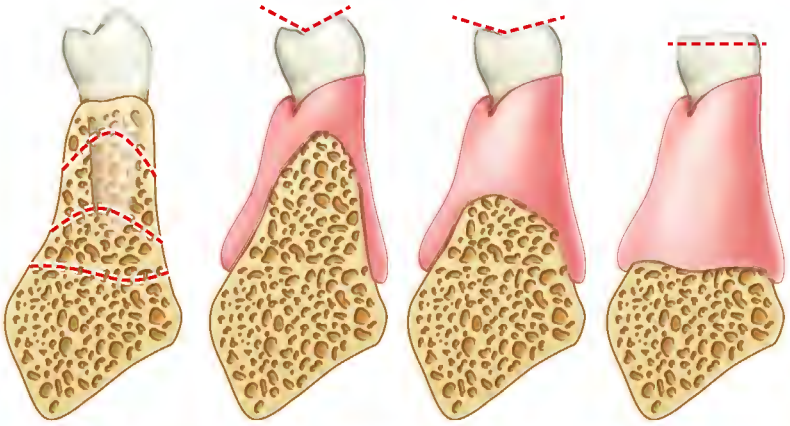


FIGURE 33-41. The posterior mandibular bone volume often determines the posterior tooth form in complete dentures. The more abundant the bone *(left)*, the more anatomic the tooth form. The less bone present *(right)*, the flatter the tooth form.



FIGURE 33-42. The maxillary posterior teeth use an anatomic tooth form for esthetics and function. The mandibular posterior teeth should use a more nonanatomical tooth form.

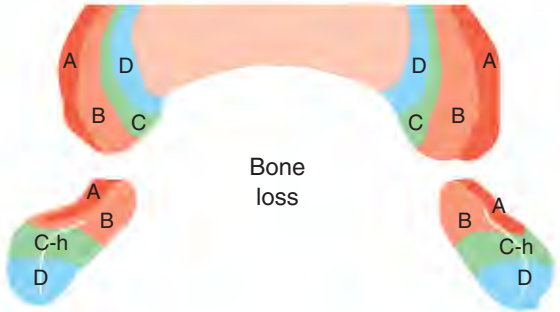


FIGURE 33-43. The mandible resorbs first to the lingual and then to the facial. The maxilla resorbs toward the midline.

angle for improved esthetics and function. The mandibular posterior teeth should be 10 to 20 degrees (less than the maxillary teeth). This will enhance the occlusal setup suggested by the author (medial-positioned, lingualized occlusion) (Figure 33-42). Steep cusp angles in the mandible may cause destabilizing horizontal forces, as summarized by Ortman in his statement "the flatter the ridge, the flatter the cusp angles."[61] However, cusp angles are not a consideration for mandibular implant overdentures or fixed prosthesis because the attachment system overrides the functional concerns of tooth form.

Posterior Tooth Position

The mandibular edentulous posterior ridge resorbs in a medial direction as it transforms from division A to B bone volume but then resorbs laterally from division B to C and then to D[27] (see Figure 33-42). In complete dentures, the dentist often first determines the position of the mandibular posterior teeth. Occlusal concepts aiming at denture stability often position the mandibular teeth perpendicular to the edentulous ridge.[15,16] This positions the central fossa of the posterior mandibular teeth more medial than that of the natural teeth predecessors in division B bone but more facial in division C and even more facial in division D compared with the natural tooth position. Mandibular dentures in the neutral zone record the tongue position and result in a more buccal position of the denture teeth in resorbed arches.[62] The maxillary denture teeth then are positioned farther facially than the original natural teeth if the dentist maintains a normal cusp–fossa relation.

Under ideal circumstances, the maxillary residual ridge is the primary stress-bearing region for a maxillary denture.[15] The denture teeth are set closer to this structure than to any other supporting region. Placement of the denture teeth directly over the edentulous posterior crest reduces moments of force and improves support under vertical forces. In division A bone of the premolar and molar regions, the dentist often can place teeth over the crest of the ridge.

The maxillary edentulous posterior ridge resorbs in a medial direction as it transforms from division A to B, division B to C, and division C to D (Figure 33-43). In most complete denture concepts, the maxillary teeth are usually positioned to follow the mandibular teeth (which are positioned more buccal as the residual ridge resorbs) and increasingly are cantilevered off the maxillary bone support. Consequently, when the mandibular teeth are positioned over bony support (or when neutral muscular zones are used), maxillary denture teeth are always lateral of the resorbing bony support, and the condition is compounded in cases of advanced maxillary atrophy (division C or D bone) (Figure 33-44). The maxillary posterior teeth are also involved in esthetics, especially the premolar region. The more lateral tooth placement eliminates the buccal space during

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FIGURE 33-44. In this maxillary denture, the posterior teeth were set in relationship to the mandibular teeth, which were set over the existing division D bone. The posterior teeth are cantilevered buccally, off the bony base of the maxilla, which causes instability and poor esthetic appearance of the denture.

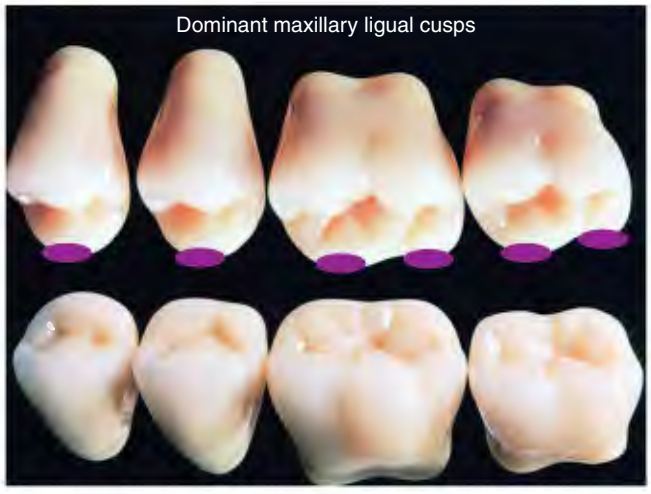


FIGURE 33-45. The posterior maxillary anatomic teeth occlude the lingual cusp with the central fossa of the mandibular non-anatomic tooth.

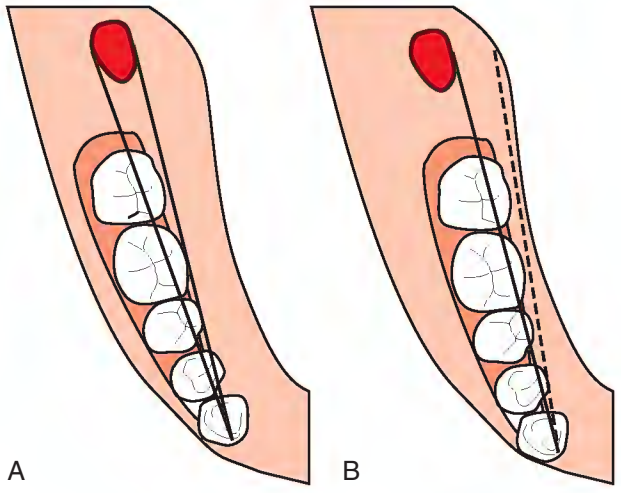


FIGURE 33-46. **A,** Pound's triangle is created by drawing two lines from the mesial aspects of the canine to each side of the retromolar pad. The lingual aspects of the mandibular teeth then are positioned within this triangle. **B,** Misch proposed drawing a line from the distal aspect of the canine to the medial aspect of the retromolar pad. The central fossae of the mandibular posterior teeth are then positioned just buccal to this line, and the lingual surfaces are lingual of this line. (Redrawn from Misch CE: *Contemporary implant dentistry,* ed 2, St Louis, 1999, Mosby.)

smiling and negatively affects esthetics compared with the position of the natural teeth.

Gysi first introduced the basic concept of lingualized occlusion.[63] Later Payne reported on a modified posterior setup of Farmer and suggested that the maxillary buccal cusps of posterior teeth should be reduced so only the lingual cusps would be in contact.[64] Pound and Murrell discussed a similar concept but reduced the buccal cusp of the mandible rather than the maxilla, so the maxillary teeth remain more esthetic and introduced the term *lingualized occlusion*.[57,58]

Consistent in the philosophy of Payne and Pound was the belief that the palatal cusp should be the only area of maxillary tooth contact. This lingualized occlusion has since been renamed *lingual contact occlusion*.[65] These occlusal schemes were designed to narrow the occlusal table and improve mastication, reduce forces to the underlying mandibular bone, simplify the denture teeth setup, prevent cheek biting, and help stabilize a lower denture (Figure 33-45).

Mandibular implant overdentures or fixed prostheses gain stabilization and retention through the implant support system. They are not tissue supported, so the occlusal scheme and tooth position may differ from traditional denture techniques. The author has suggested that the technique of Payne and Pound be modified further when one fabricates a maxillary denture opposing a stable implant-retained prosthesis.[12–14] Because the mandibular prosthesis is stable, the dentist may then position the teeth in the most favorable manner for upper denture stability and support.

Pound placed the lingual cusp of the mandibular posterior teeth between two lines drawn from the canine to the buccal and lingual sides of the retromolar pad (Pound's triangle)[57,58] (Figure 33-46, *A*). The tooth position originally suggested by Pound helps stabilize a mandibular denture. However, an implant-supported mandibular prosthesis does not require such a tooth position to enhance lower denture stability. Misch evaluated the position of the lingual cusps of mandibular molars in 30 patients and skulls with proper jaw relationship and occlusion compared with the lingual cusp position referred to by Pound[14] (Figure 33-47). In all patients, the position of the posterior lingual cusps extended medial to a line drawn from the canine to the medial aspect of the retromolar pad. In other words, it is more medial than Pound's position and more medial than the underlying mandibular bone. In the majority of patients, the lingual cusps extended 2 mm more lingual beyond the line, but in about 10%, they extended to 3 mm, and another third were 1 mm more lingual to the line. Therefore, Misch has suggested that for mandibular implant prostheses, denture teeth may be set medial to the retromolar pad in a position similar to natural teeth (Figure 33-46, *B*).

The more medial the posterior denture teeth, the more vertical the occlusal forces generated over the maxillary bone, thus

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FIGURE 33-47. The lingual position of the mandibular posterior teeth was evaluated in 30 patients and skulls with natural teeth. In all patients, the lingual contours of the mandibular teeth were 1 to 3 mm lingual of Pound's most medial line.



FIGURE 33-48. **A,** Only the lingual cusps of the maxillary anatomical posterior teeth occlude with the mandibular teeth. This brings the occlusal contact closer to the crestal bone support and helps stabilize the denture. **B,** The mandibular teeth have occlusal contact in the central fossa: the buccal cusps are reduced in height, with no occlusal contact in centric occlusion.

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reducing tipping and enhancing the upper denture stability during function. Therefore, the central fossa of the mandibular posterior teeth is suggested to be positioned on a line drawn from the tip of the mandibular canine to the lingual aspect of the retromolar pad. The mandibular posterior teeth are placed so that the central fossa is over this line and the lingual cusps extend medial to the line.[66] Although this position places the denture tooth more medial than previous denture tooth position techniques, the lingual cusps in both arches are in similar location to that of the original teeth.

The maxillary posterior teeth are then positioned so the mandibular buccal cusp occludes with the maxillary central fossa, with a horizontal overjet of the maxillary buccal cusps. This positions the maxillary posterior teeth closer to the natural tooth position because they follow the more naturally positioned mandibular teeth.

The occlusal centric contacts follow the guidelines of lingualized occlusion described by Payne, Pound, and Murrell.[64,57,58,] Only the lingual cusps of the maxillary posterior teeth are in contact during centric occlusion (Figure 33-48). Because the primary occlusal contact is the lingual cusp of the maxillary teeth rather than the buccal cusp of the mandibular teeth, this acts as an additional stabilizing factor for the maxillary denture, directing forces closer to the maxillary residual ridge. In addition, the narrower occlusal table (because only one cusp occludes) decreases the force required to penetrate food and simplifies the occlusal adjustment process.

Bilateral balance occlusion has fallen out of favor in many denture philosophies because the occlusal concept is difficult to obtain, and is not practical during function—"enter bolus, exit balance."[67] However, the maxillary and mandibular teeth are set in bilateral balance occlusion. This concept further stabilizes the maxillary denture during parafunction. It also helps protect the premaxilla from the maxillary denture rotating up and loss of posterior seal. Because the anterior teeth do not occlude in centric occlusion, this also protects the premaxillary bone.

When the maxillary denture opposes an implant prosthesis and is set with incisal guidance, only the anterior teeth occlude in protrusive or mandibular excursions (Figure 33-49). When this concept is used with complete dentures, the mandibular denture goes up in the back and down in the front. Because the patient is used to an unstable lower denture, it is not a major concern. However, when the restoration is a maxillary denture opposing an implant-supported mandibular prosthesis, the maxillary denture falls from the back and up in the front. The valve seal is lost, and the denture has no retention. As a consequence, bilateral balance is the occlusal concept necessary to avoid this complication (Figure 33-50).

As the crown height increases, an increasing moment force is applied to the maxillary teeth when set facial to the residual ridge. This increased moment force is difficult to avoid in the anterior maxilla because specific tooth position is required for proper esthetics and phonetics. However, setting the teeth and the occlusal contacts in the posterior regions toward the midline and raising the posterior plane of occlusion minimize these forces and instability. The maxillary second molar may even be set in crossbite to improve further the vertical force component over the severely atrophic division D posterior maxilla. Raising the posterior occlusal plane to the upper third of the tragus, medial position of the teeth, lingual contact occlusion, and bilateral balance occlusion help stabilize the weakest member of the removable prostheses, the maxillary denture (Figure 33-51).

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FIGURE 33-49. When only the anterior teeth occlude in mandibular functional movements, the mandibular implant prosthesis is stable. Therefore, the maxillary denture will rotate up in the anterior and down in the posterior. The valve seal will separate and the maxillary denture will lose retention.



FIGURE 33-50. The maxillary denture has bilateral balance to keep the prosthesis stable during function. This picture illustrates opposing prostheses during a mandibular right excursion with occlusal contacts of the anterior and posterior teeth.

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FIGURE 33-51. **A,** A maxillary denture wax-up opposing a mandibular implant fixed prosthesis. Only the lingual cusps of the maxillary denture occlude into the central fossae of the mandibular teeth. **B,** A right excursion of the mandible has bilateral balance occlusion. **C,** The final maxillary denture and mandibular fixed prosthesis in the mouth.

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Functionally Generated Path Technique for Maxillary Removable Prostheses

The functionally generated path (FGP) technique enables the restoring dentist accurately to capture the mandibular eccentric movements of a patient without the use of complicated or expensive instrumentation.[55,56,68] The eccentric movements are recorded after the dentist establishes the OVD and anterior guidance. The technique has been used for all types of occlusal schemes but is most useful for bilateral balanced occlusion, especially when the occlusal plane is not ideal. The dentist may use the FGP concept to fabricate the maxillary complete denture opposing natural dentition or to reset posterior teeth with rebasing or relining procedures.

The most common indication for the FGP in the implant practice is a maxillary complete or RP-5 overdenture opposing natural or previously restored fixed restorations (Figure 33-52). Bilateral balanced occlusion is especially difficult to establish when one of the arches presents natural dentition. Compounding the problem are patient treatments that do not permit complete occlusal rehabilitation of the natural arch. Implant dentistry often presents treatment options that combine the restoration of the maxillary arch with a traditional complete denture with an implant-supported fixed mandibular prosthesis.

The eccentric movements of the mandible are dictated by the condylar disc assembly paths and the anterior incisal guidance. Because the FGP technique first establishes the vertical and anterior guidance, all necessary information is already available for an accurate customized recording of mandibular movements.

An occlusal plane analyzer may be used on diagnostic casts to evaluate pretreatment conditions of the mandible and assist in intraoral occlusal plane correction. Occlusal analyzers may be fabricated in several sizes. The average size corresponds to a 4-inch sphere and provides a starting point for ideal curves of Wilson and Spee. Any discrepancy observed on the cast may be corrected in the mouth. Misch has designed a laboratory-assisted template with this intent.[14] In the laboratory, a vacuum or press fit of an acrylic shell is prepared over the cast. The occlusal plane analyzer is then used to evaluate and correct an improper occlusal plane. A handpiece is used to grind the acrylic shell and protruding occlusal cusps on the duplicate diagnostic cast. The clear acrylic shell is then taken intraorally and inserted over the teeth. Any cusp extending through the acrylic shell is recontoured to the level of the surrounding acrylic. As such, the occlusal plane is rapidly corrected to an ideal condition (Figure 33-53).



FIGURE 33-52. A maxillary denture occasionally is made to opposing natural teeth or an implant-supported fixed restoration without an ideal occlusal plane. Bilateral balance is difficult to achieve under these conditions.

The first step in the FGP technique for a maxillary removable prosthesis is the determination of maxillary anterior tooth position after fabrication of final impressions and stable base plate records. The dentist uses the guidelines previously discussed for esthetics, contour, and phonetics. The dentist then addresses the mandibular arch. If the mandibular arch is a RP-4 overdenture and the restoring dentist selects the position of the teeth, one determines the maxillary occlusal plane in the occlusogingival, buccolingual, and A-P directions. If the mandibular arch already is restored with a fixed prosthesis or natural teeth, the dentist also recontours the mandibular anterior teeth as necessary to eliminate irregularities in height or labial position. The dentist recontours the buccal contours of the mandibular posterior teeth to permit a more medial position of the occlusal contacts and often reduces the lingual cusp height to prevent lateral prematurities.

The dentist establishes the OVD using facial measurements. The dentist obtains a record of vertical centric occlusion relation after determining anterior teeth position and OVD. The dentist may or may not use a face-bow registration to mount the maxillary cast base plate with anterior teeth in final position. The dentist mounts the opposing cast of the natural fixed mandibular teeth with the centric registrations and uses a "verticulator" or articulator with condylar protrusive settings greater than 60 degrees as the articulator for FGP techniques (Figure 33-54).

After the maxillary anterior teeth and OVD are established, the maxillary posterior wax rim is designed to occlude with the opposing cast or denture teeth on the articulator. The dentist cuts a narrow slot into the maxillary posterior occlusal rim directly over the central fossa of the mandibular posterior teeth. This slot extends to the acrylic base plate and forms a 3-mm-wide groove. The dentist adds monomer to the base plate in the groove and fills in the area with acrylic. The dentist coats the opposing cast with petroleum jelly or separating medium and articulates the casts. The dentist then removes the remaining wax rim after the acrylic polymerizes. This procedure results in an acrylic fin occluding with the central fossa of the posterior cast at the recorded vertical occlusal dimension (Figure 33-55).

The dentist places the maxillary base plate in the patient's mouth and confirms the anterior tooth position and vertical occlusion (Figure 33-56). The dentist adds Iowa wax or soft wax around the posterior acrylic fin and then guides the patient first into centric occlusion and makes a record of the occlusal surfaces of the mandibular teeth with the wax. The dentist softens the wax in warm water and instructs the patient to bite in centric occlusion, and then the dentist guides the patient into a left lateral movement until the maxillary and mandibular canines are in the same plane. After the dentist registers the extent of the movement, the patient opens the mouth and occludes back into centric occlusion. This recording is repeated. The dentist removes the maxillary base plate and examines it (Figure 33-57). The posterior wax should not be unsupported at the base. If the wax extends wider on the occlusal table than on the base, the dentist adds wax below the occlusal registration table until it is supported.

The dentist reinserts the maxillary base plate and guides the patient into centric relation occlusion and guides the mandible

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FIGURE 33-53. **A,** A Misch occlusal analyzer with a 4-inch curve is placed on the mandibular cast to evaluate the curves of Wilson and Spee. **B,** A clear vacuum form is placed over the teeth, and the mandibular cusp is selectively recontoured to fit the occlusal analyzer. **C,** The modified cusps are marked on the cast. **D,** The clear template is placed in the mouth, and the appropriate cusps are modified.

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FIGURE 33-54. During the maxillary wax rim and try-in appointment, the position of the maxillary anterior teeth has been confirmed and the occlusal vertical dimension, and centric occlusion records have been obtained. The articulator reproduces this clinical situation, and the condylar settings on the articulator are selected greater than 60 degrees.



FIGURE 33-55. An acrylic fin on the maxillary base plate is made to occlude with the central fossa of the mandibular teeth at the occlusal vertical dimension position.

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FIGURE 33-56. The maxillary base plate and anterior teeth try-in are evaluated intraorally. The posterior fin occludes in the central fossa of the posterior teeth.



FIGURE 33-57. Iowa or soft wax is placed around the posterior fins of the base plate. The patient is guided through left and right border movements, keeping the jaws in contact.

into a right lateral border movement. The patient opens when the mandibular movement has aligned the maxillary and mandibular canine facial surfaces and closes back into centric occlusion. The movement is repeated. The dentist removes the maxillary base plate and examines it for accurate occlusal patterns and supported occlusal wax contour.

The dentist inserts the base plate again, this time guiding the patient into centric relation occlusion and asking the patient to make one protrusive movement until the maxillary and mandibular anterior teeth are aligned. The patient then opens the mouth, and the dentist removes the base plate. Protrusive movements are not border movements and may vary slightly with repeated records. Therefore the dentist records only one protrusive movement in the posterior occlusal wax.

The dentist places a moist, cold towel around the posterior wax to prevent distortion, boxes the region, and pours it with dental or die stone (Figure 33-58). The cold towel helps prevent



FIGURE 33-58. A moist, cold towel is positioned around the posterior soft wax regions of the base plate, and stone is poured onto the wax.

distortion of the wax when the stone generates heat during setting.

When the stone is set, the dentist repositions the maxillary base plate on the articulator, removes the mandibular cast of the teeth or dentures from the mandibular component, and joins the posterior stone patties to the mandibular articulator frame with plaster (Figure 33-59). The dentist then separates the mandibular occlusal casts from the maxillary base plate. The occlusal aspect of the mandibular cast does not appear as teeth; instead, the cast is the representation of the border and protrusive movements of the mandibular cusps (Figure 33-60).

The dentist increases the articulator vertical relation pin 1 mm, positions the maxillary posterior fully anatomical denture teeth in the maxillary base plate, and places the premolars for esthetics and function. The first molar is often more medial in position in divisions C and D bone, and the maxillary second molar may be set in crossbite if the posterior ridge has severe resorption. The posterior teeth are set 1 mm too high at the present step because the articulator vertical incisal pin was increased.

The dentist then repositions the vertical relation pin to the original vertical dimension. The articulator is used only in the vertical position. No excursions are made. Articulating paper marks the portions of the teeth in occlusion, and the dentist recontours these until obtaining the original vertical dimension (Figure 33-61). This procedure results in a bilateral balanced occlusal scheme.

The dentist tries the maxillary prosthesis with waxed-in teeth in the patient's mouth. The patient makes the left and right border movements along with a protrusive movement. The dentist evaluates occlusion and adjusts as needed. The dentist also evaluates esthetics and phonetics. The final denture then may be processed and delivered at the following appointment (Figure 33-62).

One may use an alternative technique for a FGP denture if the mandibular arch also may be restored. This technique first finishes the maxillary denture to ideal esthetics, contour,

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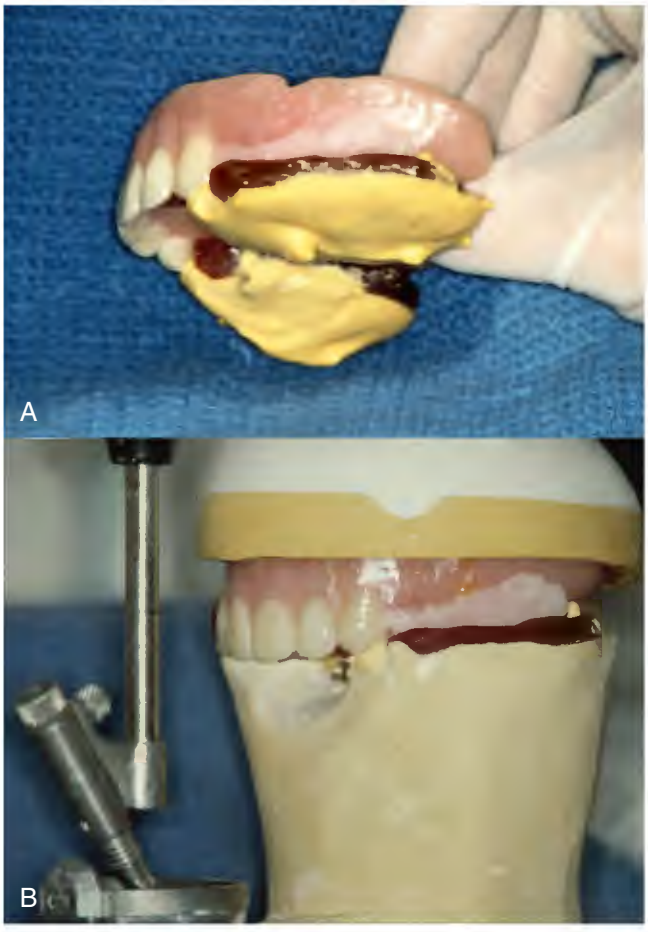


FIGURE 33-59. **A,** The maxillary wax try-in and occlusal patties of set stone. **B,** The mandibular cast is removed from the articulator and is replaced with the stone patties and joined to the mandibular articulator frame with plaster.



FIGURE 33-60. The stone patties do not appear as natural teeth. They are the representations of the mandibular teeth tracings during border and protrusive movements of the mandibular occlusal surfaces.



FIGURE 33-61. The incisal pin of the articulator is raised 1 mm, and the posterior teeth are set in the wax rim. The pin is returned to its original position, and the vertical movement of the articulator is used to equilibrate the maxillary teeth until the original occlusal vertical dimension is restored.



FIGURE 33-62. The maxillary denture is processed, and final delivery of the prosthesis is made. The patient is reminded about continued bone loss and the need to remove the prosthesis during sleep to slow the bone loss process until implants may be inserted.

comfort, and occlusal plane depending on the amount of maxillary ridge resorption. The mandibular arch is then restored to the final maxillary prosthesis.

The dentist positions the final maxillary denture in the patient's mouth, positioning the mandibular anterior teeth first and evaluating for esthetics and phonetics at the desired vertical dimension. Anterior contact in centric relation occlusion usually is not indicated for a maxillary removable prosthesis. The dentist places an incisal stop or index on the anterior teeth to record the vertical dimension at centric condylar position. A centric vertical occlusal recording permits the mounting of the maxillary denture cast and mandibular base plate on an articulator.

After the maxillary cast and mandibular occlusal records are mounted on an articulator, the dentist fabricates the acrylic fin connected to the mandibular base plate in a manner similar to the previous technique. During the next patient appointment, the dentist makes intraoral wax recordings similar to those of the previous procedure. The setting of the posterior teeth, occlusal grind-in procedure, and delivery of final prosthesis are also similar.

For a maxillary RP-4 overdenture opposing natural teeth, one should use mutually protected occlusion or canine guidance.

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The dentist also may use an FGP concept for this occlusal scheme. However, after processing, the dentist selectively removes occlusal nonworking contacts to eliminate all interferences.

Summary

The maxillary denture becomes a source of complaint when opposing natural teeth or a stable mandibular overdenture. Many removable denture concepts have been developed to make the mandibular prosthesis more stable. After implants are placed in the mandible and attached to a superstructure, the maxillary denture becomes the least retentive and stable member. Methods to improve maxillary denture stability include careful evaluation and treatment of the maxillary soft tissue, ridge HA augmentation and shape enhancement, raising of the posterior occlusal plane in relation to the bone support, and establishing a balanced "medial-positioned lingualized occlusion." The result is reduced moment forces and improved maxillary denture stability.

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CHAPTER 34

Maintenance of Dental Implants

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Implant dentistry has evolved into an evidence-based, clinical science with well-documented research to validate previously unsupported clinical practice procedures. Significant efforts that focus on the biology and biomechanics of implant dentistry helped develop and refine clinical techniques based on peer-reviewed findings. The evolution of research and understanding of biological concepts in implant dentistry has caused many areas of conflict and controversy. Innovative theories developed and techniques changed. In addition, sciences have spurred implant dentistry to new pinnacles of success.

The tremendous expansion of knowledge in this field has created new ideas and terminology that is redefined based on new principles.[1] In many instances, new research may contradict established paradigms. It may be confusing for clinicians to select correct protocols, procedures, instruments, and techniques. As materials and technique are further investigated, dogma may undergo criticism and controversy. Seasoned clinicians consistently update and modify techniques and instruments to maintain clinical excellence as technology and research advance.

One area of expansion of knowledge and conflict of views relates to the maintenance of dental implants. Early research explored techniques and instruments that were current for the methods and materials of that time. Although many of those implants still exist and are functional in patients, research and advances in technology have given us newer materials and advances in implant design and structure, minimizing previous challenges from a maintenance perspective.

An understanding of the mucoepithelial implant attachment is essential before commencing maintenance procedures. Controversies and parameters for probing and crestal bone loss are important for clinicians to recognize. There are anatomical and histologic differences between the attachment apparatus of teeth compared with implant osseointegration. The bacterial plaque biofilm challenges on these implant–tissue attachments may be significant to clinical success. This chapter explores the success and failure of implants and discusses the biological and engineering parameters that need to be considered when evaluating implants and periimplant tissues.

When the clinician understands the parameters of implants and teeth, specific maintenance plans may be established for the patient. Clinicians should inform patients of expectations and outcomes during treatment and demonstrate oral hygiene options appropriate during each stage. Patients need to recognize the importance of maintenance before the decision is made to commence implant therapy.[2] The ability of the patient to understand financial, time, and maintenance obligations is critical and should be made clear to the patient initially and during subsequent appointments. In addition to educating patients, clinicians should assess compliance to home care routines. Patients also should be competent to perform home maintenance procedures.[3] As the acceptance and demand for dental implants increase, the need to understand the importance of maintenance as it relates to long-term implant success also increases.[3] The role of the dental hygienist in implant maintenance and care is also increasing and becoming more defined[3] (Box 34-1).

Implants and associated prostheses are different from natural teeth and may require adjunctive procedures and instruments for professional and patient care.[4] Instruments must be effective at removing biofilms and accretions, and procedures performed by patients and clinicians should avoid damage to all components of the implant, abutment, restoration, and tissues.[5] Establishment and maintenance of the soft tissue seal around the transmucosal portion of the implant enhances the success of an implant. This barrier is fundamentally a result of appropriate wound healing and connection of epithelial attachments. The maintenance of healthy periimplant tissues may contribute to implant success. In addition, tissues free of inflammation and a biofilm-free implant sulcus will support the patient's general and oral health.

Plaque Biofilm and Dental Implants

The differences between teeth and implants suggest that dental implants may increase susceptibility to inflammation and bone loss in the presence of bacterial plaque biofilm accumulation.[6]

BOX 34-1 The Role of the Dental Hygienist in Implant Maintenance

- Identify potential implant patients
- Education and motivation throughout treatment
- Development, continual assessment, and modification of patient-specific oral hygiene procedures
- Evaluation of prosthesis (components, attachments, mobility, and retention)
- Evaluation of periimplant tissue
- Probing
- Exposing clinically acceptable radiographs
- Removal of biofilms, soft and hard accretions
- Recommendation of oral hygiene implements
- Determine a patient-specific recall interval
- Co-therapist to identify potential problems and complications
- Documentation of implant(s) status

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Plaque biofilm and inflammation are established etiologic factors of periodontal disease. Sticky masses of bacteria with a polysaccharide matrix colonize on hard and soft surfaces in the oral cavity but can be disrupted and removed with mechanical debridement or chemical inactivation. If undisturbed, plaque biofilm matures. Current chemotherapeutics do not penetrate thick biofilm.

Rough implant surfaces have been reported to retain more biofilm than smooth surfaces,[7] yet the rough surfaces result in greater bone–implant contact and are therefore favorable below the bone. Biofilm migrates and transitions from teeth to implants and from implant to implant.[8] Similar to teeth, clinical findings of failing implants include inflammation, pockets, and progressive bone loss.[9] Similarities of bacteria responsible for periodontitis, periimplant mucositis, and periimplantitis are now recognized.

When evaluating the periimplant microbiota, Lee et al. compared microbial changes between patients with a history of periodontal or periimplant infections and implants that have been in function for a period of time.[10] This study reported that patients with a history of periodontitis had a greater impact on enhancing periimplant microbiota than implant loading time. One of the major influences on periimplant microbiota may be the presence of specific microbiota on remaining teeth. Although all implants were successfully osseointegrated, *Porphyromonas gingivalis* and *Tannerella forsythia*, red complex periodontal pathogens may colonize contiguous implants. Thus, it is important to emphasize to patients about their responsibility to control plaque biofilm consistently and effectively, especially if the patient has a history of periodontal disease.

Plaque biofilm development and maturation have similarities for natural teeth and dental implants. The gingival sulcus in periodontal health and the permucosal attachment of a successful dental implant are similar.[7] In a study of biofilm from 18 edentulous patients with successful dental implants, facultative anaerobic cocci (52.8%) and facultative anaerobic rods (17.4%) were reported.[11] However, the pathogens *P. gingivalis* and spirochetes were absent, and minimal gram-negative rods (7.3%) were present.

Generally, pellicle, a naturally occurring glycoprotein in the saliva, first adheres to intraoral structures, including both teeth and implants. Gram-positive cocci bacteria are the first, "early colonizers" beginning with single cocci and progressing to streptococci forms (Box 34-2). Without adequate oral hygiene measures (i.e., brushing, flossing, and interdental cleaning), additional bacteria colonies, including gram-negative, rod-shaped bacteria, synergistically grow with the established gram-positive bacteria. The gram-negative bacteria are frequently facultative or strict anaerobic bacteria and are considered "late colonizers." Many, if not the majority, of these gram-negative bacteria are black pigmented and are classified under a number of genera (e.g., *Bacteroides, Prevotella, Porphyromonas, Fusobacterium* spp.).

Periimplant mucositis is an inflammatory change of the soft tissue surrounding an implant. Periimplant mucositis around an implant is similar to gingivitis around a tooth. There is no loss of attachment for teeth with gingivitis, and there is no loss of bone for implants with periimplant mucositis. The primary etiology is plaque biofilm. Similar to gingivitis, periimplant mucositis is reversible when the plaque biofilm is removed.[10] If allowed to progress, periimplantitis may result, which includes loss of bone and loss of osseointegration, similar to loss of attachment and bone with periodontitis.

BOX 34-2 Plaque Biofilm Development and Colonization

Acquired pellicle formation
↓
Bacterial adhesion
↓↓
Supragingival plaque biofilm colonization
Gram-positive streptococci, *Actinomyces* spp.
↓↓↓
Plaque biofilm maturation (gram-negative rods and filaments)
↓↓↓↓↓
Well-differentiated subgingival plaque biofilm (gram-negative anaerobes)

Periimplantitis exhibits similar microbial flora as adult periodontitis.[12] Changes involve both the hard and soft tissues surrounding an implant. The implant may exhibit all the signs of periimplant mucositis as well as exudate, increased pocket depth, and bone loss. If left untreated, significant bone loss, infection, and mobility could result, leading to the failure of an initially integrated implant.

Plaque biofilm reported to be associated with failing dental implants consists largely of gram-negative rods.[13] Clinically, failing dental implants are characterized by soft tissue inflammation, increased probing depths, increased mobility, and periimplant radiolucency. Specific pathogens in implant pockets greater than 6 mm include *Aggregatibacter (Actinobacillus) actinomycetemcomitans, Prevotella intermedia,* and *P. gingivalis* in more than one third of the sites, as confirmed by DNA analysis.[14]

More specific studies on plaque biofilm around dental implants suggest similarities between periodontal diseases and failing implants,[15] but differences have also been reported.[16,17] Spirochetes were not detected in plaque samples from well-maintained and clinically healthy implants.[15] Higher proportions of staphylococci (15.1%) were reported than generally found in gingivitis (0.06%) and periodontitis (1.2%) sites.[18] This finding suggests that staphylococci may be more significant in developing periimplantitis lesions than previously recognized.

Comparisons of plaque biofilms have been reported in a limited study of Brånemark and ITI (Straumann Institute) implants and are remarkably similar in controlled studies. Ten patients with Brånemark implants and 10 patients with ITI implants were evaluated, and the deepest pockets around the implants were sampled.[17,18] After 3 and 6 months, several periodontal pathogens were cultured and isolated, including *P. gingivalis, P. intermedia, Fusobacterium nucleatum,* and various spirochetes. None of the implants were colonized by *A. actinomycetemcomitans*. Longer investigations extended microflora reports on dental implants in 19 patients.[18] At 3 years, the osseointegrated implants were colonized predominantly by *P. gingivalis, P. intermedia,* and *A. actinomycetemcomitans*.

Natural dentitions with dental implants appear to increase the risk for implant infections compared with completely edentulous patients. This suggests that natural teeth may serve as a reservoir for periodontal pathogens, which may promote their colonization and growth to contiguous implants in the same oral cavity.[19] Quirynen and Listgarten reported that proportions

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of coccoid forms (65.8%), motile rods (2.3%), and spirochetes (2.1%) in implant pocket areas were similar to the microorganisms in natural teeth (55.6%, 4.9%, and 3.6%, respectively).[20] On the other hand, fully edentulous patients exhibited more coccoid forms (71.3%), fewer motile rods (0.4%), and no spirochetes. They concluded that microflora in partially edentulous implant patients were potentially more pathogenic than in fully edentulous patients. Implant longevity for greater than 3 and 4 years appears to have greater numbers of bacteria colonized than implants in place for 1 or 2 years.[21]

Probing Depths

Probing depths around teeth are an excellent approach to assess the past and present health of natural teeth. The increasing sulcus depth around natural teeth is related to disease and bone loss.[22] However, probing depth indices used to evaluate dental implants are more controversial because relating implant sulcus depth to health is not always directly related.

For natural teeth, the surrounding soft tissue has an average biological width of 2.04 mm between the depth of the sulcus and the crest of the alveolar bone.[23] It should be noted the biological "width" is actually a height dimension with a greater range in the posterior region compared with the anterior and may be greater than 4 mm in height.[24] In teeth, it is composed of a connective tissue (CT) attachment (average, 1.07 mm) above the bone and a junctional epithelial attachment (JEA) (average, 0.97 mm) at the sulcus base, with the most consistent value between individuals being the CT attachment (Figure 34-1).

The sulcular regions around an implant and around a tooth are similar in many respects. The rete peg formation within the attached gingiva and the histologic lining of the gingiva within the sulcus are similar in implants and teeth.[25] A free gingival margin forms around a tooth or implant with nonkeratinized sulcular epithelium, and the epithelial cells at its base are also similar in teeth and implants, with junctional epithelial cells for both. However, a fundamental difference characterizes the base of the gingival complex around teeth. A tooth has two primary regions that make up of the biological width compared with one region in an implant (Figure 34-1).

When probing a tooth, the probe measures the sulcus depth, and may penetrate and measure the JEA.[26] The junctional epithelial "attachment" of a tooth is not a true attachment. A periodontal probe easily separates the hemidesmosomal close approximation of the epithelial cells. High-volume air from a syringe may dislodge the attachment. Plaque destroys this attachment. The placement of impression string in the sulcus displaces it. The mucopolysaccharide approximation of the hemidesmosome found in the junctional epithelium is not an attachment (Figure 34-2).

The CT attachment zone of the "biological width" around a tooth prevents the probe from penetrating deeper into the sulcus and allows gingival fibers of the CT attachment zone to establish direct connection with the cementum of the natural tooth. This attachment acts as a physical barrier to the bacteria in the sulcus to the underlining periodontal tissues. Eleven different gingival fiber groups comprise the CT attachment zone observed around natural teeth and gingival tissues: dentogingival (coronal, horizontal, and apical), alveologingival, intercapillary, transgingival, circular, semicircular, dentoperiosteal, transseptal, periosteogingival, intercircular, and intergingival.[22] At least six of these gingival fiber groups insert into the cementum of the natural tooth: the dentogingival (coronal, horizontal, and apical), dentoperiosteal, transseptal, circular, semicircular, and transgingival fibers. In addition, some crestal fibers from the periodontal fiber bundles insert into the cementum above the alveolar bone. These Sharpey fibers form a true attachment to the tooth, preventing a periodontal probe from invading the periodontal ligament (PDL) space and preventing or delaying the apical movement of plaque biofilm.

A systematic study has investigated the biological seal phenomenon of the soft tissue around dental implants.[25] Hemidesmosomes from the JEA region help contribute to a basal lamina–like structure on the implant, which can act as a

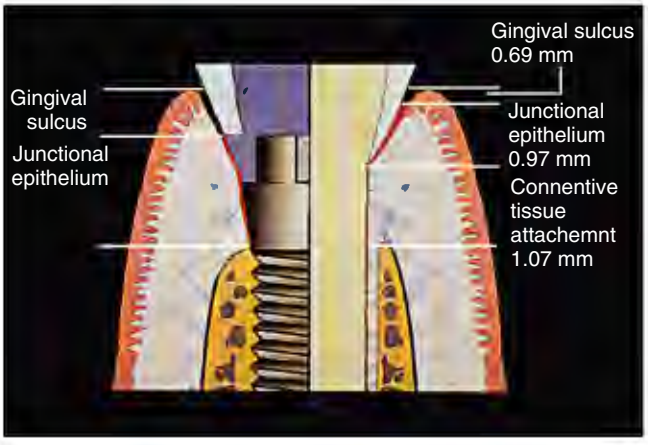


FIGURE 34-1. The natural tooth–tissue interface is usually composed of a sulcus, a junctional epithelial attachment, and a connective tissue attachment and is approximately 3 mm of tissue above the bone (*right* side of drawing). An implant has a sulcus and a junctional epithelial zone, and the tissue may be 2 mm to more than 8 mm above the bone (left side of drawing).

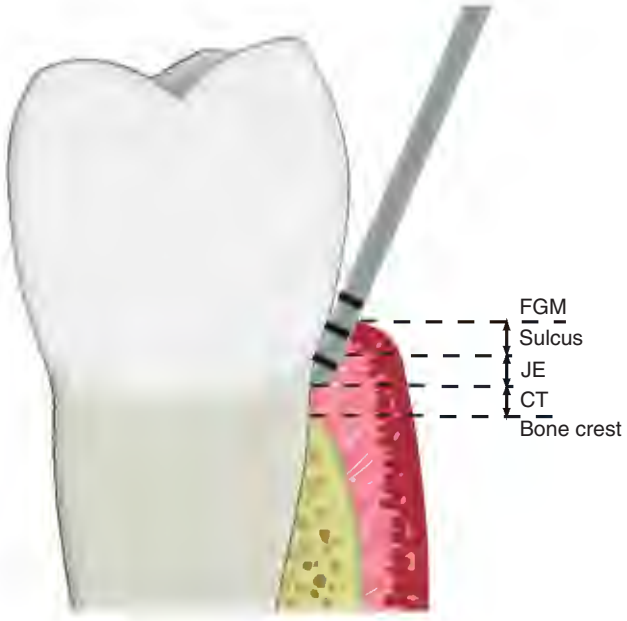


FIGURE 34-2. A dental probe will penetrate the sulcus and junctional epithelial attachment zone next to a tooth but not the connective tissue attachment zone. *CT,* Attached connective tissue; *FGM,* free gingival margin; *JE,* junctional epithelium.

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biological seal.[27] However, collagenous components of the linear body cannot physiologically adhere to or become embedded into the implant body.[28] The hemidesmosomal seal has a circumferential band of gingival tissue to provide mechanical support against tearing.[29] However, the mucopolysaccharide layer is less adherent to an implant surface than natural teeth. The hemidesmosome of natural teeth has a lamina lucida and a lamina densa. The hemidesmosome next to an implant has a lumina lucia, lamina densa, and sublamina lucida (which is less adherent).[30]

According to Cochran et al., the biological width for implants is 3.3 mm,[31] but unlike the biological width dimension for teeth, sulcus depth was included. In an implant gingival region, two of the gingival fiber groups are located around a tooth (circular and periosteogingival fibers), and no periodontal fibers are present.[32] These fibers do not insert into the implant body below the abutment margin as they do into the cementum of natural teeth. Instead, the collagen fibers around an implant run parallel to the implant surface, not perpendicular as with natural teeth. Hence, the implant only has a junctional epithelial "attachment" system.

The gingival and periosteal fiber groups are responsible for the CT attachment component of the biological width around teeth. These fiber groups are not present around the transosteal region of an implant. The "biological width" around the abutment–implant connection is not analogous to the CT attachment of teeth. The biological seal around dental implants can prevent or minimize the colonization of bacteria and endotoxins into the underlying bone. However, the seal does not constitute an attachment component of the biological width similar to the one found with natural teeth.

A dental probe introduced into an implant sulcus may proceed past the junctional epithelial close approximation of the tissue, and the probe may proceed to the crestal bone (Figure 34-3). The CT zone for an implant has two fiber groups, and neither inserts into the implant. As a result, with an implant, the probe goes beyond the sulcus, through the JEA, and through the type III collagen CTs and extends closer to bone.[26] Because the probe penetrates deeper next to an implant compared with a tooth, dental clinicians have the potential to cross-contaminate the implant sulcus with bacteria from a diseased periodontal site during probing or scaling.

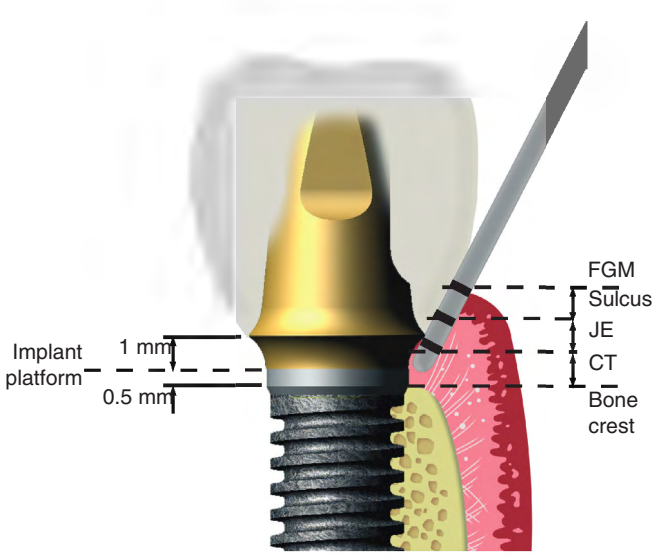


FIGURE 34-3. A probe next to an implant will penetrate the interface down to the bone. *CT*, Attached connective tissue; *FGM*, free gingival margin; *JE*, junctional epithelium.

The benefit of probing the implant sulcus has been challenged in the literature because sound scientific criteria for the rationale are lacking. The location of the probe tip subgingivally for a tooth depends on the pressure used, the presence of inflammation, and the angle at which the probe is introduced in the sulcus depth between the junctional epithelium and the root surface. The correct pressure recommended for probing is 20 g, yet conventional probing often exerts a force more than five times this level, and this varies greatly. Pressure-sensitive probes have been made available to address these issues but are rarely used in a clinical practice.[33] However, these pressures on probing issues are less important for probing next to an implant because the probe depth is limited by the bone, not a CT attachment.

The potential for damage to the fragile hemidesmosome attachment to the implant or marring of the implant surface exists during probing. In addition, reports in the literature suggest that the reproducibility of attachment level measurements may be questionable and independent from the instrument used to perform the measurements.[34,35] Many of these variables are similar for dental implants. In addition, unlike natural teeth, fixed implant prostheses with subgingival margins of crowns often have wide emergence profiles, which make probe positioning difficult around selected implant bodies.

Unlike natural teeth, the implant sulcus depth may be a reflection of the original soft tissue thickness (i.e., biotype) of the area before implant placement. The posterior maxillary tissue can be thicker than 4 mm after tooth extraction and subsequent bone volume loss before implant placement. As a result, the tissue above the bone before implant insertion may be 4 mm thick or more. As a result of greater tissue thickness before surgery and greater probing depth compared with teeth, the probing depth next to a healthy implant may be greater than that of healthy natural teeth.

When the tissues have a thick biotype, gingivoplasty to reduce the flap thickness and pocket depth may be performed at the initial surgery. The advantage of the reduction in tissue thickness at this time is that the tissue heals and matures as the bone–implant interface develops. However, thinning the flap during the initial surgery may cause greater loading of the implant body during healing from an overlying soft tissue–borne temporary prosthesis. After initial bone healing, the stage II uncovery surgery also may correct tissue thickness.

The presence of deep pockets is not always accompanied by accelerated marginal bone loss.[36] Stable, rigid, fixed implants were reported with pocket depths ranging from 2 to 6 mm. Healthy, partially edentulous implant patients consistently exhibit greater probing depths around implants than around teeth. An increasing probing depth next to an implant is a more significant sign than a probing depth unrelated to a time interval because it generally reflects bone loss except in cases of gingival hyperplasia or hypertrophy. Probing using fixed reference points on the abutment or crown margin allows evaluation of crestal bone loss versus tissue hypertrophy.

Despite the limitations, charting the attachment level in implant permucosal areas does aid the dentist in monitoring these regions. As the sulcus depth increases, the oxygen tension decreases. The bacteria in an implant sulcus are similar to those of natural teeth.[37] A toothbrush and daily hygiene procedures cannot clean a sulcus greater than 2 mm.[38] Sulcus depths greater

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than 5 to 6 mm have a greater incidence of anaerobic bacteria.[37,39] As a consequence, this sulcus depth often requires gingivectomy or bone revision surgery. As a general rule, to enable the patient to perform effective daily hygiene, the ideal implant sulcus should be maintained at less than 5 mm.

The monitoring of early crestal bone loss is most important during the first year of stress accommodation of the bone. Minor bone changes are clinically easier to observe with a periodontal probe than with radiographs. Early bone loss may occur on the facial aspect of the implant; radiographs only demonstrate the mesial and distal regions. Changes in crestal bone levels warrant close monitoring and early intervention. Patient education to reduce parafunctional stress on the implant system, the use of parafunctional appliances, and other stress-reducing methods are required when early crestal bone loss beyond the first thread is detected.

Despite the uncertain clinical implications of pocket depth increases, probing is an appropriate method to assess potential deleterious changes in the periimplant environment and should be performed every 3 to 4 months for 1 year after prosthesis delivery. After this time, if crestal bone levels are stable, probing is still relevant. Probing also reveals tissue consistency, bleeding, and exudate. Therefore, probing is important not only to measure increasing sulcus depths but also to allow the dentist to evaluate several periimplant parameters at the same time and at the same sites.

Clinical concern has been raised regarding selection of probes for implant evaluation. It has been argued that different metal types (e.g., stainless steel, titanium) should not come into contact because of a risk of metallic contamination of the two metals and the resulting galvanic corrosion that may develop and cause crestal bone loss. As a result of this concern, the suggestion has been made that only titanium surgical instruments be used to contact the implant and that only titanium or plastic instruments be used to probe or scale the implant (Figure 34-4).

Touching the surface of the abutment subgingivally with a stainless steel instrument is not a clinical concern (Figure 34-5). However, scratching the surface may contribute to plaque biofilm colonization following the direction of the scratch (Figure 34-6). Plaque biofilm follows the direction of scratches on a titanium plate even though right angles and a maze pattern may be scratched onto the surface. Therefore, when probing almost to the bone level around the implant, clinicians should avoid scratching the surface because plaque that forms at the surface may follow the scratch subgingivally to the bone level. This is particularly important during scaling procedures or during the removal of cement below a crown margin. When possible, one should use semicircular strokes, parallel to the sulcus or crown margin, to scale the implant above the bone. If a scratch on the implant body occurs, plaque will not have a direct "highway" below the tissue.

Bleeding Index

Gingival bleeding when probing around teeth correlates with sulcular inflammation and the plaque index. Easily ulcerated sulcular epithelium represents inflammation from plaque biofilm and is the primary cause of bleeding upon probing. A bleeding index is an indicator of sulcus health. Bleeding also can be provoked by undue pressure on the probe.

Controversy surrounds the issue of using bleeding and gingival health as an implant health indicator.[27] Unlike a natural tooth, implant success in the first few years is related more often to biomechanical equilibrium than to gingival health. Compared with a natural tooth, soft tissue inflammation from bacteria may be more restricted to supracrestal bone because of the lack of a periodontal membrane or fibrous tissue between the implant and the bone interface. As a result, the bleeding index may not be an important factor when evaluating the early implant quality of health.

The correlation between gingival health and implant success appears in part to be related to the cervical surface condition of the implant. It has been stated with dental implants, there is no evidence that gingivitis is a precursor of progressive bone loss.[40] Gingivitis and deep sulcular pockets were not accompanied by accelerated bone loss.[36] Both of these reports evaluated a machined-surface titanium screw design (e.g., Nobel Biocare).

In contrast to the previous reports with machined-surface implants, correlations were reported between gingival sulcus depth and implant failure.[41] The implant design evaluated in this report had an intramobile element with a larger implant body abutment crevice and a roughened, titanium plasma spray body (IMZ, Germany). A similar correlation between implant failure and gingival health status was observed when a porous titanium alloy microball surface was exposed above the bone (Endopore, Canada).[42,43]

In addition to the surface condition of the implant, other studies show a correlation to gingival health and implant health.[44] One study identified elevated levels of proteolytic enzymes in an implant sulcus with inflammation and bleeding on probing as predictors of implant disease.[44] Other studies reported that plaque and gingivitis around implants were correlated.[36,45] Another study concluded that the gingival bleeding index is correlated highly with plaque index and the crevicular fluid index.[46]

The dentist already is encouraged to probe the sulcular region to evaluate crestal bone loss around the implant. Periodontal probing is less demanding and more commonly used than the determination of gingival sulcular fluid volume index. One may observe the bleeding index while probing for sulcus depth and therefore readily record it to evaluate gingival health (Figure 34-7).

Regardless of whether gingival health is relative to implant success, all dentists agree that the ideal soft tissue condition around an implant includes an absence of inflammation. Radiographic bone loss and increased pocket depth have been correlated with sulcular bleeding.[46] Therefore, the gingival status around an implant should be recorded and used to monitor the patient's daily oral hygiene. However, surrounding soft tissues around implants have fewer blood vessels than around teeth. Therefore, inflammation is typically less often observed around implants than around teeth.[28,31]

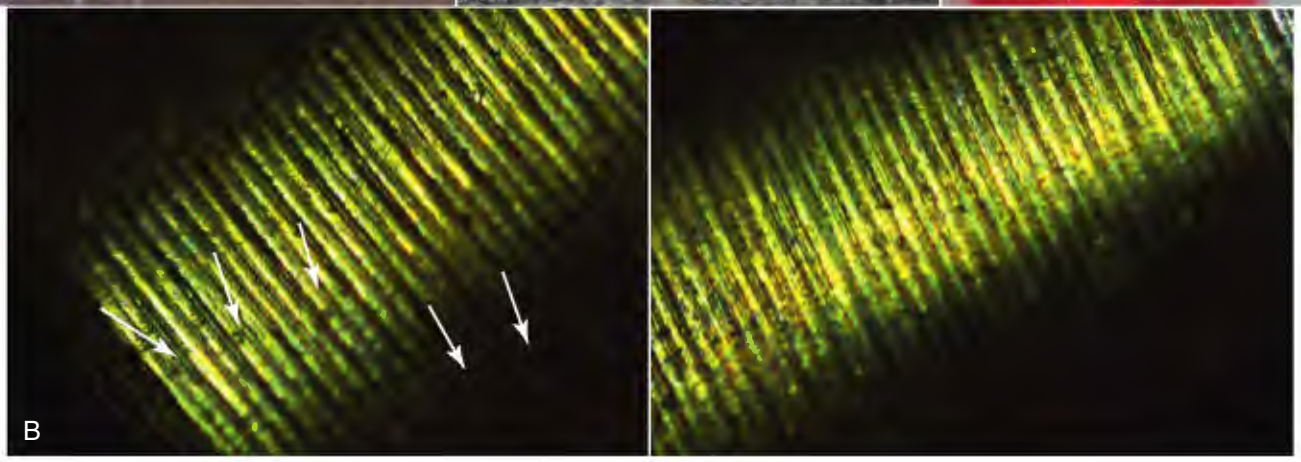
The most common bleeding gingival index adapted from teeth and applied to implants is the Loe and Silness Gingival Index.[22] When used on teeth, this index scores gingival inflammation from 0 to 3 on the facial, lingual, and mesial surfaces of all teeth. The symptom of bleeding comprises a score of at least 2.

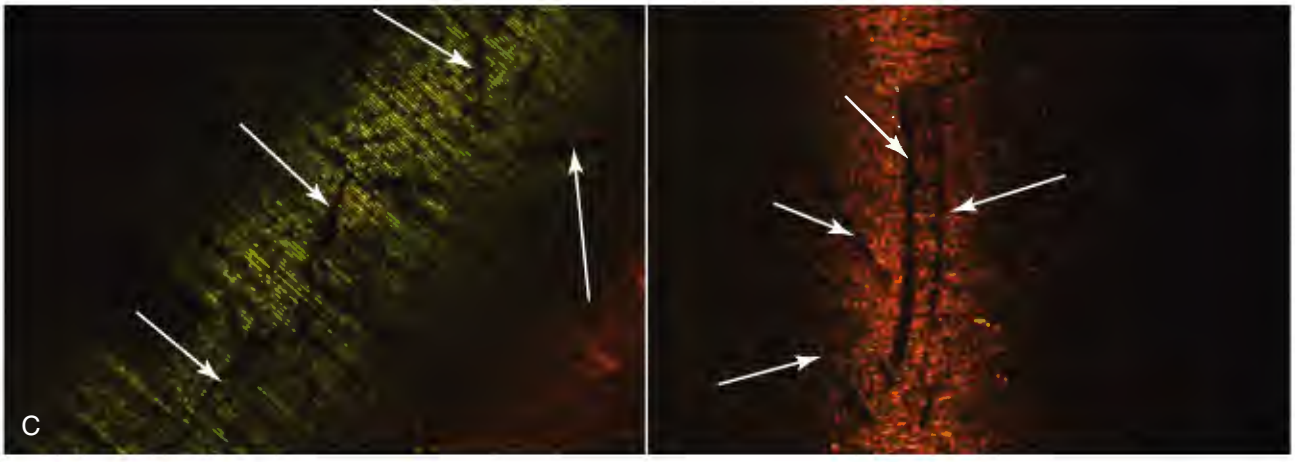
The gingival index scores may be adapted on implants to record gingival inflammation on the facial, lingual, and mesial surfaces. The facial and lingual are already probed to evaluate bone loss that cannot be seen on a radiograph. Because the bleeding index evaluates inflammation, the Loe and Silness Gingival Index is adequate for implants, and because fewer implants typically are used to restore a region compared with the presence of natural teeth, the clinician also may evaluate the

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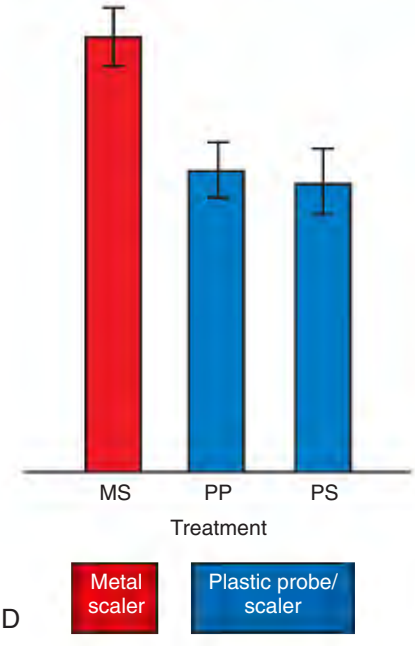


FIGURE 34-4. **A,** A study evaluated the effects of probing and scaling an implant abutment made of titanium alloy. (From Falkhravar B, Khocht A, Jefferies SR, Sazuki JB: Probing and scaling instrumentation on implant abutment surfaces: an in vitro study, *Implant Dent* 21: 311–316, 2012.) **B,** No significant difference in surface condition was found between plastic and metal probes. **C,** A clinical difference was observed with plastic versus metal scalers. **D,** Metal scalers (MS) altered the surface of the implant abutment; plastic probes (PP) and plastic scalers (PS) did not significantly alter the interface.

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FIGURE 34-5. A plastic or metal probe may be used to assess probing depth next to an implant. Proper probing technique is shown using a resin-covered periodontal probe (Colorvue; Hu-Friedy, Chicago).



FIGURE 34-6. Scratching the implant surface may contribute to plaque biofilm colonization that follows the direction of the scratch.

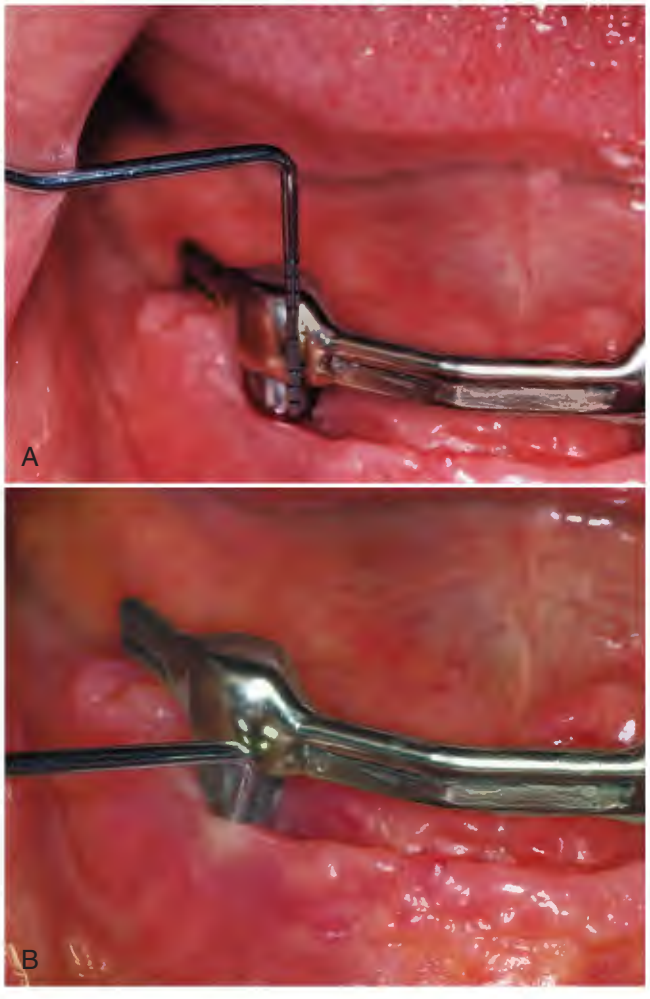


FIGURE 34-7. **A,** A dental probe may assess bleeding upon probing, which is a sign of mucoimplantitis or periimplantitis. **B,** A probing depth of several millimeters is present and indicates periimplantitis.

distal surface when bleeding is present because the implants are more than 2 mm apart and access often is unobstructed.

When the sulcus depth is less than 5 mm and the bleeding index increases, use of chlorhexidine rinses and irrigation often is indicated along with other professional and home care methods. Sulcus depths in excess of 5 to 6 mm have a greater incidence of bleeding and may require gingivectomy or gingivoplasty surgery to modify an anaerobic environment.

During the first year of clinical examinations for periimplant tissues, the dentist should ideally record the color, form, and consistency of the gingival tissues. Also, bleeding on probing and probe depths should be determined for all sites. After 1 year of stable recording probing depths, the recordings may not necessarily be individually recorded at maintenance appointments. Instead, they may be correlated with radiographic observation for the mesial and distal surfaces. Removal of the prosthesis for more accurate probing and evaluation is not indicated unless warranted by signs of disease activity (e.g., bleeding upon probing, erythema). Repeated removal of a screw-retained fixed prosthesis causes wear of the screw attachment system and causes more frequent partially unretained restorations over the long term.

Crestal Bone Loss

The marginal bone around the implant crestal region is usually a significant indicator of implant health. Unlike natural teeth, the causes of crestal bone loss around the implant are multifactorial and may occur at different time periods: surgical bone loss, initial "biologic width" bone loss, early loading bone loss, intermediate-term bone loss, and long-term bone loss. Each time period may have a different cause for the bone loss. The

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early loading bone loss, intermediate-term, and long-term bone loss are most important to evaluate at implant maintenance appointments.

The level of the crestal bone is modified from the crestal position of the implant at the stage II uncovery surgery. After the implant is connected to a permucosal element, the marginal bone may be lost during the first month from (1) the position of the abutment–implant connection or (2) the crest module design of the implant. The abutment–implant connection will cause 0.5 to 1.0 mm of bone loss when it is at or below the bone. When the abutment is attached to the implant body, approximately 0.5 to 1 mm of CT forms apical to this connection. This bone loss may be caused by an "implant biologic width." An implant originally placed 2 mm above the bone and another countersunk 2 mm below the bone have different initial bone loss histories after the abutment is attached to the implant.[47] Therefore, whenever possible, the implant should be inserted at or above the bone crest to avoid an increase in the sulcus depth around the implant related to the crestal bone loss after abutment placement.

In addition to the abutment–implant connection cause of bone loss, when smooth metal is below the abutment–implant connection and extends onto the neck of the implant, additional bone loss will occur in direct relation to the smooth metal region. The bone levels will most often reside at the first thread or at a roughened surface after the first month a permucosal element or abutment extends through the soft tissue[31] (Figure 34-8).

When the implant receives an occlusal load, crestal bone loss may occur beyond the first thread or rough surface of an implant[48] (Figure 34-9). The periodic hygiene appointments should evaluate and monitor crestal bone loss. If bone loss beyond the first thread or rough surface condition occurs, occlusal stress reduction is considered. This includes an occlusal adjustment and retainer (night guard) in a parafunctional clinical situation.

The intermediate- and long-term bone loss around implants is most often periimplantitis. Daily hygiene procedures coupled with professional maintenance appointments are necessary to reduce this condition. Surgical correction is indicated when the oral environment is conducive to the bacteria-related loss of bone.

Patient Oral Hygiene

Reduction of supragingival plaque by removal with toothbrushes significantly reduces the amount and composition of subgingival microbiota around teeth. This reduction should translate to a decreased risk of periodontal disease initiation or recurrence. Furthermore, the decreased prevalence of periodontal pathogens in supragingival plaque lowers potential reservoirs of these species.[49]

The absence of adequate keratinized mucosa in endosseous dental implants, especially in posterior implants, was associated with higher plaque accumulation and gingival inflammation but not with more annual bone loss regardless of the implant's surface configurations.[50] The implant type, with the presence or absence of keratinized tissue, may be a challenge for oral hygiene procedures for many patients. The clinician should stress the importance of adequately performing plaque control and select products and procedures that are well suited to the needs and ability of the patient.

Patients rely on clinicians to suggest or recommend products for oral hygiene procedures. As with most patients, the "tell, show, do" method of home care instruction is important. Documentation in the patient record regarding recommendations and instructions as well as the patient's compliance and effectiveness are important to evaluate their relationship to long-term success for each patient.[51,52] When choosing and recommending implements for oral hygiene, the clinician should take into consideration the location, length and angulation of abutments, superstructure design, anatomical limitations, patient habits, motivation, and manual dexterity of each patient.[53]

Contributing factors that may influence product selection are plaque and calculus accumulation and the general health of the patient (and diseases and medications). To avoid patients becoming discouraged and poorly motivated, it is wise to keep oral hygiene instructions simple.[54] Remember that partially edentulous patients exhibit higher pathogenic bacterial counts than edentulous patients, which may cause seeding of pathogenic bacteria from one site to another.[55]

The final prosthesis should allow for access by the patient and clinician to keep the areas plaque free.[56] The clinician

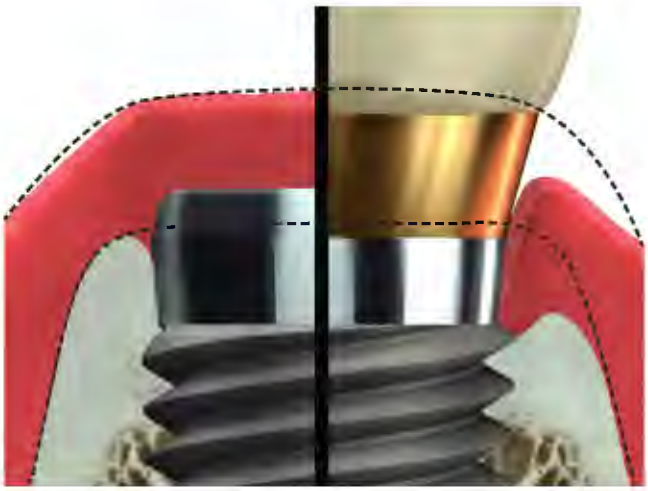


FIGURE 34-8. When the implant is covered with soft tissue, bone often resides at the crest of the implant *(left)*. When the implant is uncovered and an abutment is added, the bone often recedes to the first thread of the implant body *(right)*.



FIGURE 34-9. When the implant is occlusal loaded, the bone loss may extend beyond the first thread or rough surface of an implant.

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should instruct the patient in the use of toothbrushes (power is preferred), floss (with threading devices if necessary), tufted brushes, interdental brushes (with coated wires), toothpicks, and oral irrigators (Figure 34-10). Patient instructions may include the use of antimicrobials such as cetylpyridinium chloride (Crest Pro-Health, Procter and Gamble, Cincinnati, OH) or chlorhexidine gluconate, 0.12% or 0.2% (Peridex, Omni-3M, West Palm Beach, FL) because of substantivity and ability to inactivate oral bacteria.[57] Chlorhexidine gluconate or cetylpyridinium chloride may be used as a rinse or applied site specific with brushes or cotton swabs.

If oral irrigation is used, the patient should be instructed to use the lowest setting and direct the irrigation flow through the contacts to avoid excessive pressure to the implant tissue cuff. Incorrect excessive pressure may alter tissue adaptation and induce bacteremia around the implant.[58] Additionally, clinicians should recommend that the patient be gentle yet thorough after surgery to avoid complications of healing from aggressive hygiene procedures.

Instrument Selection

Maintaining a smooth surface of titanium without pits and scratches can prevent plaque accumulation.[59] Instrument selection should depend on tip designs that are not bulky (to avoid unnecessary tissue manipulation), and the design should facilitate manipulation by the clinician (Figure 34-11). A clinician may also evaluate the prosthesis design, location of deposits, and tenacity of calculus to help select appropriate instruments.

Metallic ultrasonic and sonic scalers have been reported to gouge titanium.[60] A plastic or rubber sleeve (Dentsply International, York, PA) over an ultrasonic scaler is safe and does not damage titanium[61] (Figure 34-12). After the removal of calculus, polishing with a rubber cup and toothpaste, fine prophy paste, commercial implant polishing pastes, and tin oxide have been shown be safe for titanium surfaces.[62,63] A rubber point or soft unitufted rotary brush may also be used.

Although the use of ultrasonic tips with plastic sheaths or implant safe designs has been proven effective, plastic sleeves on ultrasonic scalers may leave particles embedded in the implant coating.[64] Conventional ultrasonic scalers with nonmetal tips are also suitable for implant maintenance.[65] Air polishers are effective and safe for maintenance procedures around implants.

The primary purpose of instruments used is to thoroughly remove plaque and calculus. Plastic curettes and air-powder-water spray do not alter implant surfaces, but these instruments may leave deposits.[66] These deposits should be removed by irrigation to avoid any adverse tissue healing.

Stainless steel–tipped instruments have been found to be detrimental to a smooth titanium surface.[67] A variety of nonmetallic plastic-, graphite-, nylon- or Teflon-coated instruments are available and have been proven to be safe to use on titanium implant surfaces.[58–64,66–68] Improved gingival and soft tissue architecture result from scaling with these instruments. Although research demonstrates titanium curettes and rubber cups with flour of pumice to be suitable for cleaning implant surfaces,[69,70] a review of the literature found titanium curettes caused a roughening of the implant surface in all studies.[65]

Nonmetal instruments such as resin curettes (Implacare II; Hu-Friedy, Chicago; see Figure 34-11) and rubber cups seem to be the instruments of choice for the treatment of a smooth implant surface, especially if the preservation of surface integrity is the primary goal. Similarly, for rough implant surfaces, nonmetal instruments and air abrasives are the instruments of choice, especially if surface integrity needs to be maintained.



FIGURE 34-11. Plastic (resin-filled), Teflon, and carbon carbide materials may be used on implant scalers. Pictured is a resin (unfilled) curette (Implacare; Hu-Friedy, Chicago, IL).



FIGURE 34-10. Antimicrobial irrigation with Pik Pocket (Water Pik, Inc., Fort Collins, CO).



FIGURE 34-12. An implant insert may be used on a cavitation device to decrease the risk of damaging the implant surface (Softip; Dentsply, York, PA).

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Metal instruments and burs are recommended only when the removal of the coating is required.

Implant Maintenance Procedures

As dental implants become more widely used as a replacement for missing teeth, clinicians will certainly see increases in clinical problems in complex cases.[71] Frequent recall visits after implant placement and restorations are necessary for evaluation and establishment of good oral hygiene after treatment. Healthy tissue should be free of inflammation whose primary etiology is plaque and calculus formation. Implant probings may be taken with metal or plastic probes as long as the surface of the implant is not scratched (see Figure 34-5) (Colorvue; Hu-Friedy, Chicago). The recall visit is also a time to detect potential problems to encourage early intervention if problems arise.

Unlike the attachment to the porosities of cementum with teeth, adherence and tenacity of calculus around implants is usually less binding. This can minimize the chance of traumatizing the tissue and permucosal seal during procedures to remove deposits. With adequate oral hygiene, subgingival calculus should be minimal if present at all. Because titanium usually does not have calculus embedded in it, adequate oral hygiene should prevent the accumulation of heavy accretions. If crestal bone loss has occurred, the type of implant surface or coating exposed may encourage plaque or calculus adherence.

Healthy implant tissues may have a tight seal and can create challenges while scaling. Because the permucosal seal is more fragile than a normal tooth sulcus, using short, exploratory working strokes with light pressure is important. Depending on the location of the calculus, a horizontal stroke is preferred while avoiding tissue trauma.[72] When an instrument must be used subgingivally to remove calculus or excess cement, insertion and instrumentation should be gentle, and light strokes should be in a semicircular pattern. Attention to carefully placing the blade under the deposit and drying calculus or cement may make detection and removal easier and more comfortable for the patient.

Poor tissue tone (i.e., flaccid, friable tissue) around an implant abutment can harbor food, plaque, and calculus and increase the occurrence of inflammation and infection. If maintenance and hygiene procedures cannot adequately improve tissue tone, surgical correction may be necessary to reduce chronic inflammation and infection.

Hygiene procedures performed by the clinician and patient may be limited by prosthetic designs that have bulky restorations and inadequate embrasures, preventing ready access to the implant–gingival margin interface area.[73] Because loss of osseous support is a factor in implant failure, problems that may arise from a prosthesis that is difficult to maintain should be considered in the treatment planning phase.[74] Periodic occlusion monitoring is also important to detect discrepancies indicating that occlusal changes are needed.[75]

Chemotherapeutic Agents

Chlorhexidine gluconate has been shown to reduce plaque in the oral cavity and around dental implants.[76] Long-term use of antimicrobials, including chlorhexidine gluconate 0.1% (United States) or 0.2% (Europe) or cetylpyridinium chloride, may be used with brushes and floss to minimize staining. With newer generations of chlorhexidine, it is significant to note that alcohol in chlorhexidine serves to preserve and stabilize the solution.[77] Studies have shown a decrease of antimicrobial benefits in preparations that are alcohol free.[78]

If the clinician uses subgingival irrigation, the cannula should be carefully inserted in the periimplant tissue to avoid gouging the surface. Care should be taken to avoid inserting the cannula to the base of the implant sulcus to prevent fluid distention into surrounding tissues.[79] Chlorhexidine gluconate has been proven to be a useful irrigant.[80]

A study on nonsurgical mechanical treatment on sites with periimplantitis lesions with microencapsulated minocycline (Arestin; Orapharma, Horsham, PA) and 20% chlorhexidine gel (available only in Europe) found reductions of pocket depths and bleeding on probing for up to 12 months.[81] Local antibiotic therapies have also proved successful in the treatment of periimplantitis[82] and successful management (off-label use) of periimplantitis using microencapsulated minocycline.[82] Systemic antibiotics may be useful to treat infection. Assessing the problem, complication, or condition to be treated is as important as knowing the cause.[83] It is wise to use a neutral sodium fluoride in a patient with dental implants because certain acidic fluorides may alter titanium.[84,85]

Implant Quality of Health Scale: A Clinical Assessment of the Health–Disease Continuum

The criteria for success in implant dentistry remain complex. The vast majority of clinical studies reporting success and failure do not qualify the type of success achieved. Instead, the term *success* primarily has been used interchangeably with *survival* of the implant. The term *failure* has been used to indicate the implant is no longer present in the mouth. Nearly all reports in the prosthetic literature also report survival as success.

What is success for a natural tooth? In the periodontal literature, a quality of health is presented, and well-established guidelines based on clinical criteria describe the ideal health of natural teeth. The general term *success in implant dentistry* should be replaced with the concept of *quality of health,* with a health–disease continuum describing the status of implants.

Success criteria for endosteal implants have been proposed previously by other authors, including Schnitman and Shulman,[86] Cranin et al.,[87] McKinney et al.,[88] Albrektsson et al.,[89] and Albrektsson and Zarb.[90] As Box 34-3 shows, the report by Albrektsson et al. was specific for implants with rigid fixation and is used widely today.[91] An implant quality of health scale with five levels has been established by James and

BOX 34-3 Criteria for Implant Success[89]

- An individual, unattached implant is immobile when tested clinically.
- A radiograph does not demonstrate any evidence of periimplant radiolucency.
- Vertical bone loss is less that 0.2 mm annually after the first year of service of the implant.
- Individual implant performance is characterized by an absence of persistent or irreversible signs and symptoms such as pain, infections, neuropathies, paresthesia, or violation of the mandibular canal.
- In the context of the foregoing, success rates of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are the minimum criteria for success.

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modified by Misch.[91] The James-Misch scale also proposes management modalities corresponding to these five levels. In 2007, a consensus conference in Pisa, Italy (sponsored by the International Congress of Oral Implantologists; www.icoi.org) modified the James-Misch scale to four conditions that describe success, survival, and failure.[92]

Ideal clinical conditions for natural teeth include absence of pain, less than 0.1 mm of initial horizontal mobility under lateral forces of less than 100 g, less than 0.15 mm secondary mobility with lateral forces of 500 g, absence of observed vertical mobility, periodontal probing depths of less than 2.5 mm, radiographic crestal bone height 1.5 to 2.0 mm below the cementoenamel junction, intact lamina dura, no bleeding on probing, no exudate, and absence of recession or furcation involvement on multirooted teeth (Box 34-4).[92] Many of these same criteria are listed as ideal conditions for dental implants.[86–90]

The American Academy of Periodontology has defined five periodontal types for diagnosis and treatment of natural teeth.[93] The American Academy of Periodontology's categories of disease do not indicate strict success or failure but rather a range from health to disease. This classification allows a clinical approach to treatment in each category. A similar scale for implants has been established as an aid to diagnosis and treatment that also proposes management approaches according to the signs and symptoms.[94]

The James-Misch scale presented for implant quality of health based on clinical evaluation was supported by the International Congress of Oral Implantologists in 2007[92] (Table 34-1). This quality of health scale allows the implant dentist to evaluate an implant using the listed criteria, place it in the appropriate category, and then treat the implant accordingly. The prognosis also is related to the quality scale.

Group I: Optimum Health

Group I represents implant success with optimum health conditions. No pain is observed with palpation, percussion, or function. No mobility is noted in any direction with loads less than 500 g of implant movement (IM). Less than 2.0 mm of crestal bone has been lost since the placement of the implant. This bone loss is typically a result of the "implant biologic width" below the abutment connection and surface of the implant. The implant has no history of exudate, and no radiolucency is present around the implant body (Figure 34-13, *A*-*C*). The probing depth is equal to or less than 5 mm and is stable after the first year. Ideally, the bleeding index is 0 to 1. Group I

BOX 34-4 Ideal Clinical Conditions of Teeth

- Absence of pain
- Less than 0.1 mm initial horizontal mobility under lateral forces less than 100 g
- Less than 0.15 mm secondary mobility with lateral forces of 500 g
- Absence of observed vertical mobility
- Periodontal probing depths less than 2.5 mm
- Radiographic crestal bone height 1.5 to 2.0 mm below the cementoenamel junction
- Intact lamina dura
- No bleeding on probing
- No exudate
- Absence of gingival recession
- Absence of furcation involvement on multirooted teeth

TABLE 34-1
Health Scale for Dental Implants

Implant Quality Scale	Clinical Conditions	Treatment
I. Success	No pain or tenderness upon function 0 Mobility <2 mm radiographic bone loss from initial surgery Probing depth, <5 mm BOP = 0 to 1 No exudate history	Normal maintenance
II. Survival (satisfactory health)	No pain 0 mobility 2–4 mm radiographic bone loss Probing depth, 5 to 7 mm BOP = 0 to 2 No exudate history	Reduction of stresses Shorter interval between hygiene appointments Gingivoplasty Annual radiographs
III. Survival (compromised health)	0 mobility Radiographic bone loss >4 mm (less than ½ of implant body) Probing depth, >7 mm May have exudate history No pain upon function	Reduction of stresses Drug therapy (antibiotics, antimicrobials) Surgical reentry and revision Change in prosthesis or implants
IV. Failure (clinical or absolute)	Any of the following: Pain upon function Mobility Radiographic bone loss > ½ length of implant Uncontrolled exudate No longer in mouth	Removal of implant

BOP, Bleeding index.

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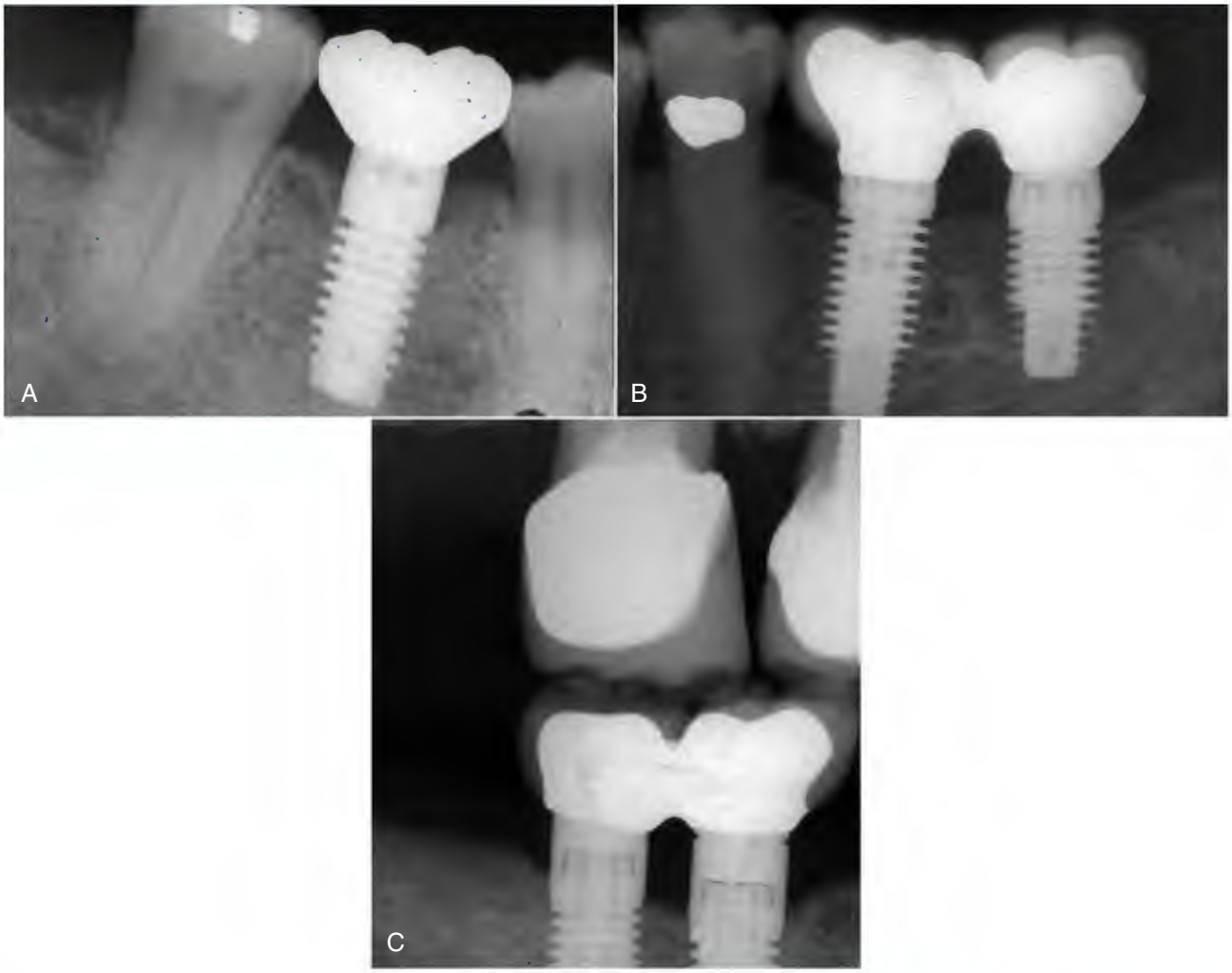


FIGURE 34-13. **A** and **B,** Group I represents optimum health conditions around an implant. Less than 1.5 mm of crestal bone loss occurs during the first year of occlusal loading from the time of prosthesis delivery. **C,** A vertical bitewing radiograph can be obtained to assess mesiodistal bone levels.

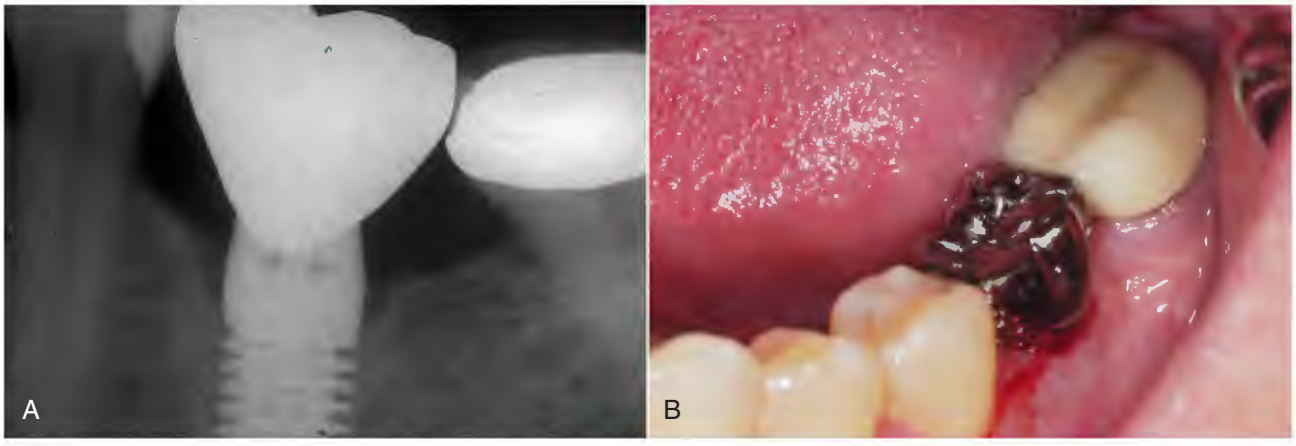


FIGURE 34-14. **A,** Group II represents satisfactory health around an implant. This implant has lost 2 mm of crestal bone. **B,** The implant crown has bleeding upon probing index of 2.

implants follow a normal maintenance program every 6 months. The prognosis is very good to excellent.

Group II: Satisfactory Health

Group II implants exhibit satisfactory health and are stable but show a history of or potential for clinical problems. No pain or tenderness is observed on palpation, percussion, or function. No observable mobility exists in the horizontal or vertical direction with loads less than 500 g. Crestal radiographic bone loss is between 2 and 4 mm from implant placement (Figure 34-14, *A, B*). The most common cause is the early loading bone loss related to the amount of occlusal force and the density of the

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bone. The probing depths may be as much as 5 to 6 mm because of the original tissue thickness and marginal bone loss but are stable. Bleeding upon probing index is often 1 or even 2. These implants may be considered to have periimplant mucositis. The treatment indicated for group II implants consists of a stress reduction protocol for the implant system, shorter intervals between hygiene appointments (e.g., 9 months), reinforcement of oral hygiene instructions, annual radiographs until the crestal bone has stabilized, and gingivoplasty or sulcus reduction procedures where indicated. The prognosis is good to very good depending on the depth of the implant sulcus.

For pockets less than 6 mm in depth, the following can be concluded[95]:

1. Mechanical therapy alone or combined with chlorhexidine results in the clinical resolution of periimplant mucositis lesions.
2. Histologically, both treatments result in minimal inflammation compatible with health.
3. The mechanical effect alone is sufficient to attain clinical and histologic resolution of mucositis lesions.

Group III: Compromised Survival

Group III implants are classified as *compromised survival* and exhibit a slight to moderate periimplantitis and compromised health status. Periimplantitis is defined as an inflammatory process affecting the tissue around an implant that results in loss of supporting bone.[83]

Group III implants are characterized by radiographically evident vertical bone loss, periimplant pocket, bleeding on probing (plus occasional suppuration), and mucosal swelling and redness but no pain upon function (Figure 34-15, *A*). These implants warrant more aggressive clinical therapy. No pain is apparent in function, but tenderness may be slight on percussion or function. No vertical or initial horizontal mobility (IM-0) is evident. Greater than 4 mm of crestal bone loss has occurred since implant insertion but less than half the length of the implant. Greater than 7 mm and increasing probing depths are also present, usually accompanied by bleeding when probing. Exudate episodes may have lasted more than 1 to 2 weeks and may be accompanied by a slight radiolucency evident around a crestal region of the implant.

Group III implants warrant aggressive surgical and prosthetic intervention. Stress factors are also addressed. The prosthesis may be removed in nonesthetic regions or the bar may be removed under overdentures during the surgical therapy. Modification of the occlusal scheme and methods to decrease the forces in the afflicted regions after hard and soft tissue surgical treatment include decreasing cantilever length, occlusal adjustment, and occlusal splint therapy.

In cases of rapid bone changes, the prosthesis design may be modified completely from a fixed to a removable restoration to stress relief and soft tissue support. Additional implants to support the restoration may be indicated, especially if the patient is unwilling to wear a removable prosthesis.

Systemic and topical antibiotics and local chemical agents such as chlorhexidine are indicated in the presence of exudate. However, this method is usually of short-term benefit if the causative agents of implant failure are not eliminated. Bacterial culture and sensitivity tests (Oral Microbiology Testing Service, Temple University, Philadelphia; www.temple.edu/dentistry/omts) may be indicated, especially if existing signs and symptoms do not subside within a few weeks.



FIGURE 34-15. **A,** Group III implants have a compromised health status and warrant a surgical procedure to decrease the risk of further deterioration. Probing on the facial of this implant indicates a 6-mm pocket, and exudate is present. **B,** This implant required surgical reentry to decontaminate the surface of the implant and remove the noxious elements. A reduction of thread depth and a bone graft or apical-positioned flap was indicated.

Surgical management most often consists of soft tissue removal or exposure of a portion of the implant (Figure 34-15, *B*). Bone grafts may be used along with these approaches around the implant. A three-step approach is implemented for this category in the following order: (1) antimicrobial therapy (local or systemic), (2) stress reduction, and (3) surgical intervention. The prognosis is good to guarded, depending on the ability to reduce and control stress after the surgical corrections have improved the soft and hard tissue health.

Group IV: Clinical Failure

Group IV of implant health is clinical or absolute failure (Figure 34-16). The implant should be removed under any of these conditions: (1) pain on palpation, percussion, or function; (2) greater than 0.5 mm of horizontal mobility; (3) any vertical

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FIGURE 34-16. **A,** Implants in group IV represent clinical failure and implants no longer in the mouth. The center implant in this radiograph is an implant with more than 50% loss; it is category IV. **B,** The implant should be removed when group IV exudates are present. **C,** The implant is removed from the site. The implant now is converted to group V (absolute failure). **D,** The prosthesis is modified to become a three-unit fixed partial denture.

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mobility; (4) uncontrolled progressive bone loss; (5) uncontrolled exudate; (6) more than 50% bone loss around the implant; (7) generalized radiolucency; or (8) implants surgically placed but unable to be restored (sleepers). Implants that are surgically removed or exfoliated are also in the category of failure.

This category also includes implants surgically removed or exfoliated and no longer in the mouth. The remaining edentulous area often is treated with autogenous or synthetic bone graft procedures, which are performed to replace the missing bone. After the favorable bony conditions are restored, implants may be inserted again with a good prognosis (see Fig. 34-16).

The terminology for implant failure often is confusing, with different terms describing similar situations. Terminology for implant failure using the time period of failure has been suggested as a primary criterion.[96] Many implant failures are not described ideally by the time of the complication and are not addressed in this nomenclature.

Occasionally, the patient will not permit removal of the implant. Regardless of whether the patient returns for implant removal, the implant is recorded as a failure in all statistical data. The patient should be warned against the irreversible damage to the surrounding bone with implants retained in this condition. Consideration should be given to their removal because future treatment may be compromised.

Repair of Ailing, Failing Dental Implants

I. If an active infection (purulence, bleeding, swelling) is present with radiographically visible bone loss and the disease process is continuing, the following steps should be implemented:
   A. Reflect the tissue and degranulate the defect (metallic curettes are acceptable).
   B. If the implant is hydroxyapatite (HA) coated and the HA is undergoing resorption and has changed color and texture, remove all the HA until the metallic surface is visible. Use of ultrasonics such as Cavitron (Dentsply, York, PA) is recommended. Use of hand curettes is slow, and use of air abrasives is dangerous because of the potential of air emboli in marrow spaces.
   C. Detoxify the dental implant with citric acid or etching gel applied with a cotton pledget or camel's hair brush. Thirty seconds per surface is sufficient. The supersaturated citric acid solution (40%, pH 1, crystals mixed with sterile water) will last in the refrigerator for about 1 year.
   D. Graft with freeze-dried bone or alloplast if completely detoxified. Graft with an alloplast such as HA or bioglass if not completely detoxified.
   E. Protect the graft with a membrane for guided bone regeneration if needed. Resorbable membranes (e.g., Alloderm

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or Memloc [BioHorizons, Birmingham, AL]) are acceptable.

F. Leave the repaired implant out of function and "covered" for 10 to 12 weeks.

Note: If the surface of the implant is metallic (titanium, Ti-6Al-4V, titanium plasma spray), go from step A to step C.

II. If no active infection is present and if an HA-coated implant in place looks intact without continuing resorption (e.g., bone loss from traumatic occlusion, overloading, off-axis loading), the following steps should be implemented:

A. Reflect the tissue and degranulate the defect with metallic curettes.

B. Detoxify the HA surface with citric acid (40%, pH 1) or etching gel for 30 seconds per surface. Flush and irrigate with sterile water or sterile saline to stop the demineralization process of the acid. Thirty seconds of acid application will detoxify and "freshen" the surface.

C. Continue with grafting, guided bone regeneration materials, and procedures as noted previously for treatment of the "infected" implant.

Note: The only difference is that removal of the HA is not necessary because the coating is relatively noncontaminated and still capable of biological healing.

Important: Do not use tetracycline on intact HA because it changes the calcium–phosphate ratio of HA. Do not leave citric acid on HA surface for more than 1 minute; it continues to "resorb the surface."

Implant Crown Esthetic Index

An implant crown esthetic index was developed as an objective tool in rating esthetics of implant-supported single crowns and adjacent soft tissues.[97] The important item of esthetics is rarely included in evaluation studies. Esthetics can be rated in both a subjective and an objective manner. A subjective method is the use of questionnaires, which must be completed by the patient.

An objective method with a rating score, which has to be carried out by a professional observer, has never been described in the field of dental implants. An index was introduced to assess the height of interproximal mucosa adjacent to single-implant restorations but did not account for entire periimplant contour and surface structure.[98] An objective rating score, with a division in different items, provides insight into the esthetic result of a specific treatment and facilitates analysis to improve surgical or prosthetic treatment. It is also possible to compare the esthetic result as a function of time to analyze the stability of a treatment procedure.

The nine selected items are[97]:

1. *Mesiodistal dimension of the crown*. The mesiodistal dimension must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 5-point rating scale (grossly undercontoured, slightly undercontoured, no deviation, slightly overcontoured, grossly overcontoured).
2. *Position of the incisal edge of the crown*. The position must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 5-point rating scale (grossly undercontoured, slightly undercontoured, no deviation, slightly overcontoured, grossly overcontoured).
3. *Labial convexity of the crown*. The convexity of the labial surface of the crown must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 5-point rating scale (grossly undercontoured, slightly undercontoured, no deviation, slightly overcontoured, grossly overcontoured).
4. *Color and translucency of the crown*. The color and translucency of the crown must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 3-point rating scale (gross mismatch, slight mismatch, no mismatch).
5. *Surface of the crown*. The labial surface characteristics of the crown, such as roughness and ridges, must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 3-point rating scale (gross mismatch, slight mismatch, no mismatch).
6. *Position of the labial margin of the periimplant mucosa*. The labial margin of the periimplant mucosa must be at the same level as the contralateral tooth and in harmony with the adjacent teeth; a judgment can be given on a 3-point rating scale (deviation of 1.5 mm or more, deviation less than 1.5 mm, no deviation).
7. *Position of mucosa in the approximal embrasures*. The interdental papillae must be in their natural position; a judgment can be given on a 3-point rating scale (deviation of 1.5 mm or more, deviation less than 1.5 mm, no deviation).
8. *Contour of the labial surface of the mucosa*. The contour of the mucosa at the alveolar bone must be in harmony with the adjacent and contralateral tooth; a judgment can be given on a 5-point rating scale (grossly undercontoured, slightly undercontoured, no deviation, slightly overcontoured, grossly overcontoured).
9. *Color and surface of the labial mucosa color (redness) and surface characteristics (presence of attached mucosa)* must be in harmony with the adjacent and contralateral tooth and must have a natural appearance; a judgment can be given on a 3-point rating scale (gross mismatch, slight mismatch, no mismatch).

BOX 34-5 Esthetic Scale

0 points = Excellent esthetics
1 or 2 points = Satisfactory esthetics
3 or 4 points = Moderate esthetics
5 or more points = Poor esthetics

Use of the adjacent and contralateral teeth as a reference, rather than the generally accepted rules for shape and position of teeth, has been standardized. Penalty points were given to each of these items if not matching to the desired situation: 1 penalty point for minor (slight) deviations and 5 penalty points for major (gross) deviations. The total score leads to a judgment about esthetics (Box 34-5). It should be noted that one major deviation automatically leads to a poor esthetic result and can never be accepted as moderate or satisfactory in this aspect of care.

Summary

Implant success has broad definitions in clinical practice. A range from health to disease exists for both teeth and implants. The primary criteria for assessing implant quality are inflammation, pain, and mobility. The presence of either pain or mobility greatly compromises the implant; removal usually is indicated. Probing depths may be related to the presence of local disease or preexisting tissue thickness before the implant was

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inserted. An increasing probing depth is more diagnostic and signifies bone loss, gingival hyperplasia, or hypertrophy. The most common causes of bone loss during the first few years of function are related to factors of stress and retained cement. The bleeding index is observed easily and indicates inflammation of the gingiva. However, implant health status is not as related to sulcular inflammation as would be the case with a natural tooth.

Implant failure is easier to describe and may consist of a variety of factors. Any pain, vertical mobility, uncontrolled progressive bone loss, or generalized periimplant radiolucency warrants implant removal. Implant quality factors were established by the International Congress of Oral Implantologists (2007) into an implant quality scale that not only assesses the implant health–disease continuum but also relates treatment and prognosis to the existing conditions.

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