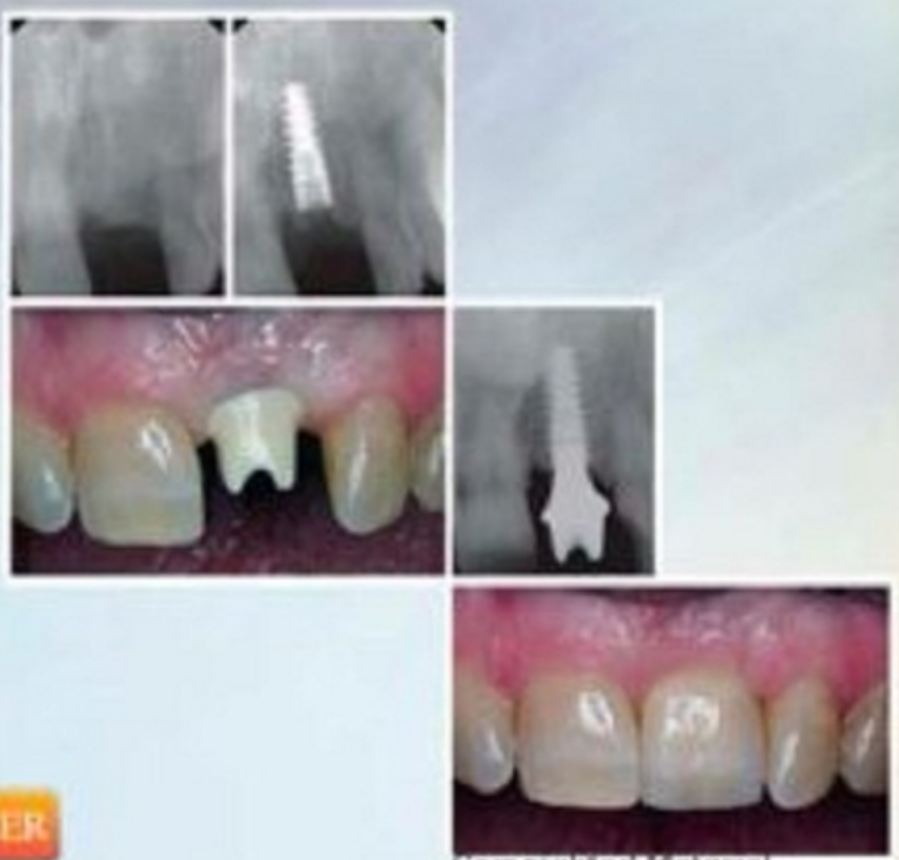
Mahmoud Torabinejad • Charles Goodacre • Mohammed Sabeti

Principles and Practice of

SINGLE IMPLANT and RESTORATIONS



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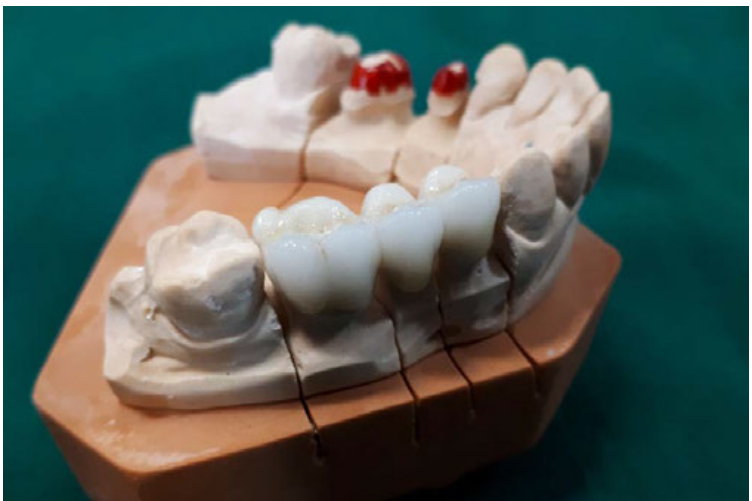

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Preface

For decades, dentists have been preventing tooth loss by providing information to the general public regarding oral hygiene and methods of preventing tooth decay and periodontal disease as well as avoiding dental trauma. Despite these efforts, some people still develop decay and periodontal disease and are involved in dental trauma that requires various dental treatment modalities. Endodontics and periodontics are the fields in dentistry that deal with the morphology, physiology, and pathology of the human dental pulp and periodontium, and the diagnosis and treatment of diseases and injuries related to these tissues. The main objective of these two fields in dentistry is to preserve the natural dentition. Teams of general dentists and specialists have saved millions of teeth and have provided patients with sustained comfort, function, longevity, and esthetics. Although high success rates have been documented for endodontic and periodontal treatments, some teeth cannot be maintained and require removal. When a tooth is lost, a dental implant is often considered to be the treatment of choice because of its long-term predictability and preservation of tooth structure compared to conventional fixed partial dentures.

Like other dental procedures, implant dentistry has two inseparable components—art and science. The art of single tooth replacement, like other procedures in implant dentistry, consists of carefully executing technical procedures during both implant placement and restoration. The science component involves application of the basic sciences related to biological and pathological conditions in the area where the single implant is placed and use of the principles and methods of evidence-based treatment. Evidence-based dentistry is healthcare that integrates the best clinical evidence to support a practitioner's clinical expertise for each patient's treatment needs and preferences. Because of the available evidence supporting the use of single implants, patients have become increasingly aware of the benefits of implants and expect dentists to be conversant regarding this treatment option.

The main purpose of this book is to familiarize both general dentists and specialists, such as endodontists, with the science of implant dentistry. In addition, when a patient with a potential single implant presents to a dental office, the general dentist or a specialist must be able to determine the needs of the patient and complexity of treatment to determine whether he or she is properly positioned to perform the necessary treatment, or if referral will provide the patient with the most favorable outcome. In other words, this book is not only about *how* to place a single implant, but it also teaches new practitioners in implant dentistry *why* and *when* to perform the procedures associated with a single implant.

Many advances have been made in the field of implant dentistry within the last 10 years that enhance the functional and esthetic results achieved with dental implants. This book discusses the history of single tooth implants and contains contemporary information regarding the following:

- Diagnosis and treatment planning for single implants
- Bone physiology
- Metabolism
- Biomechanics in implant therapy
- Bone grafts and bone substitute materials
- Tooth extraction and site preservation
- Implant placement with simultaneous guided bone regeneration
- Immediate implant placement and provisionalization of maxillary anterior single implants
- Restoration of the single implant
- Dental implant maintenance and the relevance of scientific evidence in the decision-making process
- Treatment outcomes for single implant therapy

This textbook offers several distinctive features, including:

- Easy-to-follow content generally outlines the diagnosis and treatment planning for a single implant and restoration, describing how a clinician might *actually* perform the required procedures
- Condensed, convenient format
- Updated pertinent references
- Presentation of new scientific and technological advances in the field of endodontics
- Vivid color images

By listing the objectives in the beginning of each chapter, we have tried to provide the reader with a concise idea of what is expected and should be learned from that chapter. This format gives the reader an opportunity to learn the scope of principles and practices associated with single implants. This textbook is not intended to include all background information on the art and science, nor is it not designed to be a "cookbook" as a preclinical laboratory technique manual. We have tried to provide the reader with the key information required for clinical use of single tooth implants and gain a thorough understanding of what can be done when a tooth cannot be saved. Like other treatment modalities for patients, providing the best quality of care should be the guiding light for diagnosis and treatment planning.

We would like to thank the contributing authors for sharing their materials and experiences with our readers and the principal authors. Their contribution improves the quality of life for people who benefit from single implants. We also express our appreciation to the editorial staff at Elsevier, whose collaboration and dedication made this project possible, and Mohammad Torabinejad for conceiving the need for such a text and providing the driving force behind its realization. In addition, we would like to thank our colleagues who provided their treatment examples that enhance the quality of this textbook.

Mahmoud Torabinejad **Mohammad A. Sabeti** **Charles J. Goodacre**

CHAPTER 1

History of Single Implants

Shane N. White, Mohammad A. Sabeti

Chapter Outline

From Ancient Times to the Pioneering Era
Osseointegration and the Scientific Era
From the Fully Edentulous State to Single Tooth Replacement
Diagnostic Technologic Innovations
Implant Design Innovations
Surgical Innovations
- Immediate and Early Implant Placement
- Augmentation and Grafting Advances
- Soft Tissue Management, Minimally Invasive Flapless and Computer-Guided Surgery

Prosthetic Innovations
- Implant Abutments
- Immediate, Early, and Delayed Loading Protocols

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the current state of single implant treatment.
- Understand ancient and pioneering implant developments.
- Understand the historic significance of true osseointegration.
- Understand the series of diagnostic, design, surgical, and prosthetic innovations that have made contemporary single tooth implants predictable and widely used.

Single implants have expanded the ability of dentists to provide predictable replacements for missing or hopeless teeth. The ultimate outcome—a satisfied patient—is the result of careful assessment and meticulous surgical and prosthetic procedures by the dental team.[1]

Treatment outcomes for single implants are now excellent. Long-term success and survival rates are equivalent to those for endodontically treated teeth and are superior to those for tooth-supported fixed partial dentures.[2-6] Short-term bone-level, soft tissue, and esthetic results are also excellent.[7] However, complication rates and the need for additional interventions may be higher than desired.[5,8,9] The scientific study of prognostic factors for single implants is still in its infancy.[6,9,10] However, dentists need to make prudent treatment decisions now. Dentists also need to minimize the possibility of complications and the need for additional corrective procedures. Patients expect predictability, long-lasting functional results, minimally invasive procedures, comfort, minimal risks, minimal complications, and cost-effectiveness.[11]

How was the success of the single implant achieved? How can we continue to meet patients' demands with even greater predictability in the future? A review of the history of single implants can guide us. This chapter frames the many innovations that have made single implant treatment predictable, accessible, and widely applicable. It is an introduction to the detailed descriptions of current procedures and future directions found in the rest of the text. This book serves as a guide to single implant planning and technique through a review of the best available evidence, the opinions of leading experts, and descriptions of current procedures.

FROM ANCIENT TIMES TO THE PIONEERING ERA

From the very beginning, humans have strived to retain their teeth (Figure 1-1) and also to replace teeth; a pleasing smile has had enormous psychosocial importance since earliest times. Stone, metal, ivory, and sea shell implants are all cited in the archaeological records of China, Egypt, and the Americas. Success was extremely rare. In 1685, in the first modern textbook on dentistry *(Operator for the Teeth),* Charles Allen suggested that the teeth of dogs, baboons, and sheep be used for implantation. However, the possibility of disease transmission was recognized.[12] Transplantation was also described by Pare, Fauchard, and by Hunter, who used boiling for disinfection.[13-15] Autotransplantation still has a place in clinical dentistry today. In 1807 Maggiolo developed a

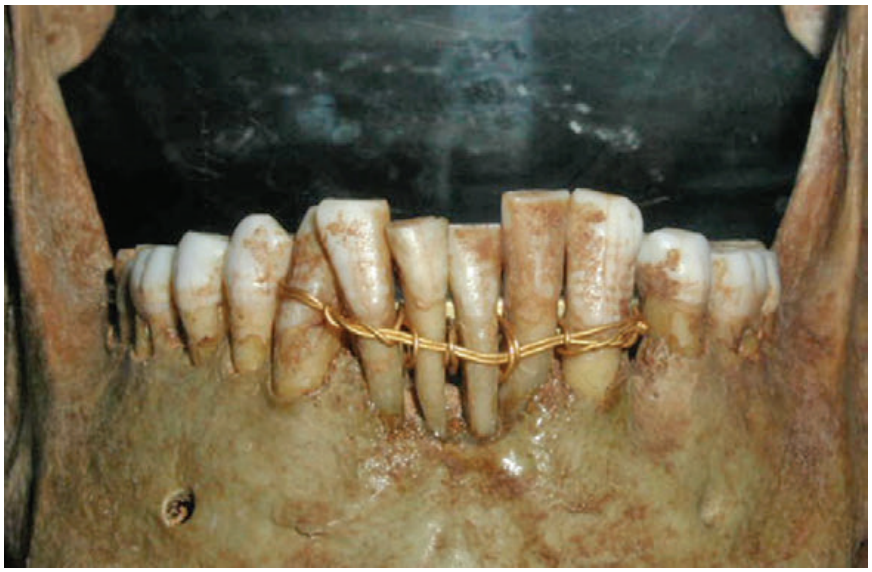

Figure 1-1 Frontal view of a mandible discovered in Lebanon at the ancient site of Sidon. The mandible is from about 500 BC and the periodontally involved anterior teeth have been splinted together with gold wire. (Courtesy the Archaeological Museum, American University, Beirut, Lebanon.)

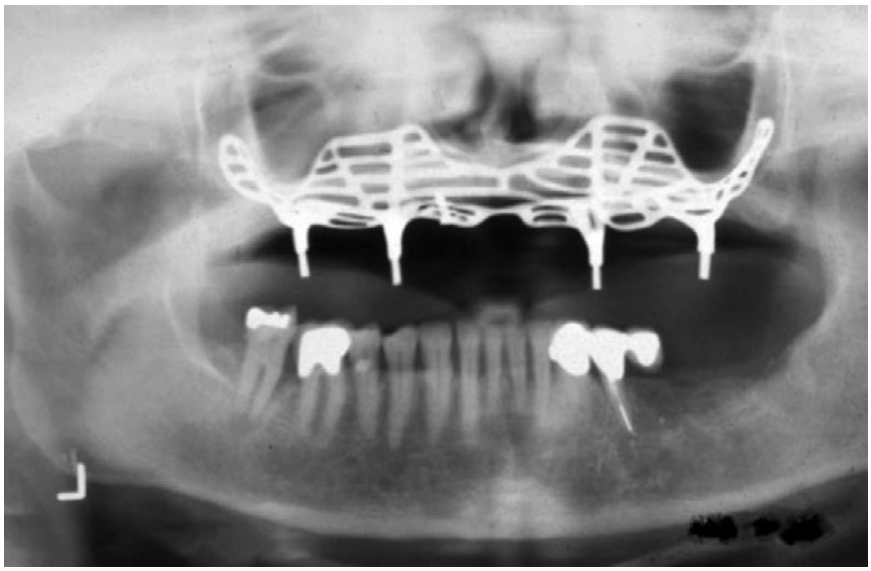

Figure 1-2 Maxillary subperiosteal implant with four posts that will be used to support and retain a prosthesis. (Courtesy R. James.)

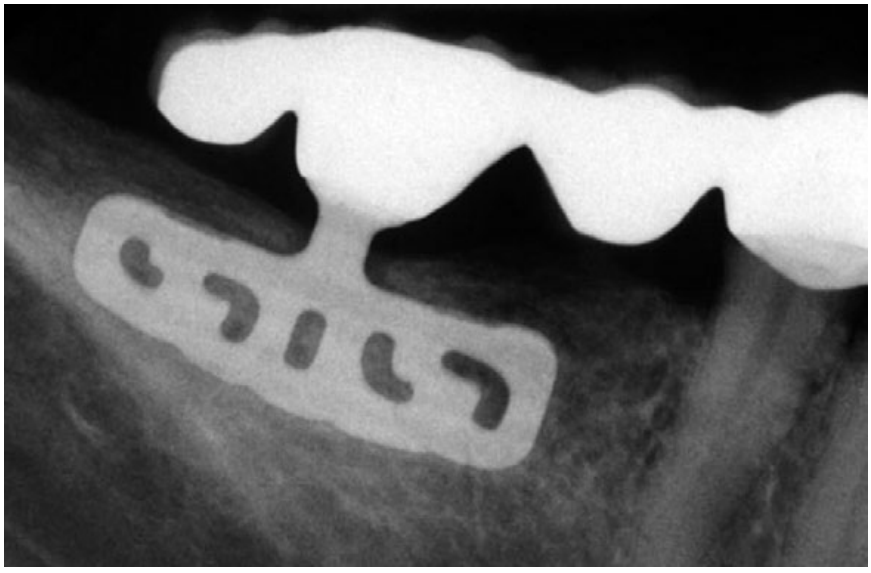

Figure 1-3 Periapical radiograph of a blade implant that supports the distal aspect of a mandibular fixed partial denture.

single-stage gold implant that was to be placed in fresh extraction sockets and allowed to heal passively without loading; however, pain and inflammation resulted.[16] At the beginning of the twentieth century, Greenfield[17] introduced latticelike precious metal basket implants that were used to support complete dentures and single teeth. This hollow basket design continued to inspire implant designs used through the 1990s.

From the 1930s through the 1960s, new metallic alloys were used to form a variety of subperiosteal implants (Figure 1-2), which are classified as eposteal (placed on or upon bone) implants. Other types of implants include endosteal blade implants (Figure 1-3) and transmandibular or staple implants (Figure 1-4). These approaches were generally directed toward supporting multiple prosthetic teeth. Most of these implants were one piece and were not fully submerged; various one-stage endosteal root form pins, screws, and cylinder designs were also developed. Linkow[18] developed a variety of implant designs during this period but was best known for blade-type implants, which were designed to maximize the contact area between bone and implant.

In the 1930s Strock[19] used immediate placement and a porcelain crown for single tooth replacement using a Vitallium implant. He reported a 15-year case study, noting the role of occlusion, and described the histology. Adams[20] considered a

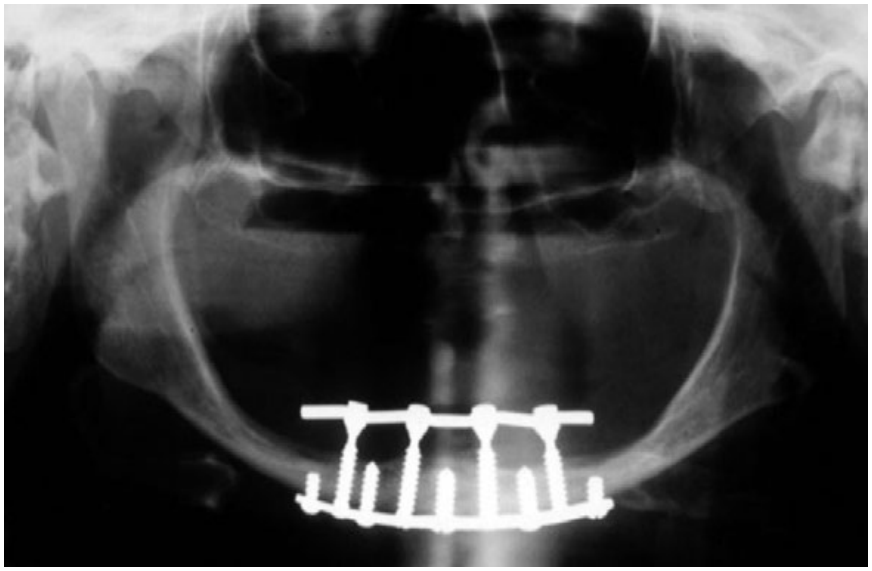

Figure 1-4 Panoramic radiograph of a one-piece transosseous implant consisting of a metal plate located on the inferior border of the mandible, five posts that are placed into the mandible, and four posts that pass through the mandible. A bar has been attached to the four posts to provide retention and stability for a mandibular implant overdenture.

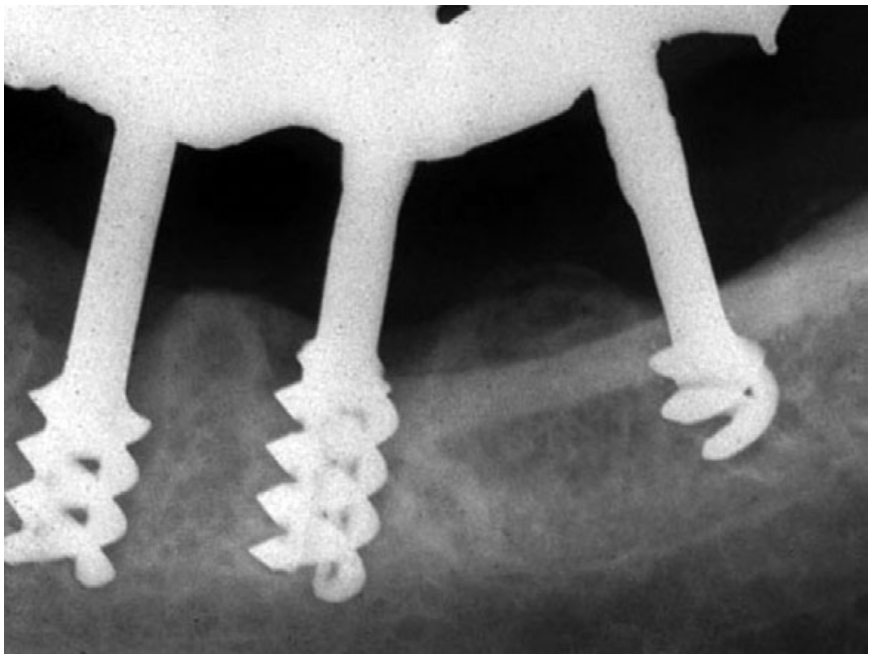

Figure 1-5 Radiograph of implants placed by Dr. Rafael Chercheve. (Courtesy R. James.)

two-stage surgical procedure for placing a cylindrical screw implant with a healing cap. In the late 1940s, Formiggini[21] introduced a helicoidal screw tantalum implant. This design was modified by Chercheve in the 1960s to increase the distance between the screw threads and implant head (Figure 1-5).[22] Some of these endosteal designs began to resemble contemporary solid, cylindrical or moderately tapered, threaded osseointegrated implants (Figure 1-6). Although the Dental Implants—Benefit and Risk Consensus Development and Technology Conference held in 1978 at the Harvard School of Dental Medicine set new standards for reporting implant data, an overly

Figure 1-6 Several endosseous root form implants have been aligned so that the different designs, thread patterns, and surfaces can be compared. The original Brånemark external hex implant can be seen at the end of the row.

broad and liberal definition of implant "success" was permitted.[23]

Meanwhile, the results of decades of research by Dr. Per-Ingvar Brånemark in Sweden were coming to fruition. By then other implant teams, notably in Germany and Switzerland, were developing dental implants concurrently with Brånemark's team in Sweden. At this point, they were still unable to produce long-term clinically successful outcomes.[24] However, those teams later produced successful systems (e.g., Schroeder [now Straumann] and Frialit [now Dentsply]).[25]

OSSEOINTEGRATION AND THE SCIENTIFIC ERA

Brånemark began to publish a series of experimental studies on the use of intraosseous anchorage of dental prostheses in the late 1960s, leading to a landmark, 10-year study in 1977.[24,26] His two-stage threaded titanium screw-type root form implant (Nobelpharma, now Nobel Biocare) was first presented in North America in 1982 (see Figure 1-6) at the Toronto Implant Conference organized by Dr. George Zarb.[27] Brånemark described the work he had started two decades earlier in Gothenburg, Sweden, which had been recently replicated in Toronto. Brånemark discovered the ability of titanium to osseointegrate with bone to provide robust, long-lasting anchorage for dental implants. Zarb defined osseointegration as, "A process whereby clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in bone during functional loading."[24,28]

Brånemark described the placement of implants in the healed edentulous ridges. His original protocol for dental implant placement included a two-stage implant system, pure titanium screw-type implants, 6 to 8 months of healing after extraction; sterile conditions; use of a mucobuccal flap; placement of machined titanium implants in a two-stage approach; and a 3 to 6 months stress-free healing period. Well-documented, long-term, prospective landmark studies by Adell, Albrektsson, and others offered clear evidence of prolonged survival, function, and bone maintenance.[29,30] Albrektsson, Brånemark, and Zarb described new criteria for implant success that included absence of mobility and radiolucency, low rates of vertical bone loss, absence of signs and symptoms, and a minimum l0-year success rate of 80%.[31-33] The 1988 Consensus Development Conference on Dental Implants held at the National Institutes of Health added several more suggestions to those

made in 1978.[34] These included necessary descriptions of the study population, independence of the examiners, adjustments in sample size because of attrition, reasons for attrition, and documentation and follow-up of failures. As osseointegration became a clinical reality, many additional implant designs, surgical techniques, and prosthodontic protocols were introduced.

FROM THE FULLY EDENTULOUS STATE TO SINGLE REPLACEMENT

Osseointegrated endosseous implants were first used in the treatment of fully edentulous jaws more than four decades ago. Brånemark's original protocol for dental implant placement in the anterior parts of edentulous jaws included a mucobuccal flap; a two-stage surgical approach, followed by 3 to 6 months of stress-free healing for osseointegration to occur; prior to restoration with complete implant-supported prostheses. By 1985 Zarb, Jansson, and Jemt were already investigating the longitudinal application of osseointegrated implants in the areas of overdenture application, treatment of partially edentulous patients, and single implants.[35] Many innovations facilitated achievement of the current, predictable, widespread use of single implants; however, future challenges may arise from too rapid launching of untested novelties or procedures.[36] Because many of these advances occurred concurrently, took varying times to become well documented, and were accepted at different times in different places, these innovations are reviewed thematically.

DIAGNOSTIC TECHNOLOGIC INNOVATIONS

As recently as the late 1980s, one implant manufacturer produced a clear plastic surgical treatment planning guide with life-sized images of implants, designed to be overlaid on inherently distorted orthopantographic (OPG) radiographs for surgical treatment planning. By the early 1990s, the first three-dimensional (3D) treatment planning software systems were marketed (e.g., Simplant). Much progress has since been made, and many types of products are now available. Three-dimensional imaging techniques are now generally used. Because of its lower radiation exposure and reduced cost, cone beam computed tomography (CBCT) has replaced conventional medical computed tomography (CT). Many manufacturers provide CBCT machines; they are used in many dental offices and at local imaging centers. Specialized software facilitates precise treatment planning. Surgical guides can now be fabricated directly from 3D radiographic images, often using stereolithography, and clinical validation of these techniques is ongoing. Although bone form and density can be quantified radiographically, measurement of bone quality remains elusive, and little concrete progress has been made in this area since 1985.[35] Indirect estimates of anchorage can be made using insertion torque and sonic vibrational frequency. Currently, ultrasound is taking a pioneering role in implant site diagnosis, treatment planning, and intraoperative soft tissue management.[37]

IMPLANT DESIGN INNOVATIONS

Approximately 300 manufacturers make a dizzying array of implants. Although a great many systems are available, remarkably few have received thorough scientific documentation.[38] Nevertheless, we have come a long way from the first Brånemark pure titanium screw-type implants.

Currently, several titanium alloys are used; these offer improved mechanical properties without compromising osseointegration. Ceramics, such as zirconia, are also used but lack long-term documentation and are inherently brittle.

Most current implants have threads of some kind; unthreaded press-fit implants have largely disappeared from the market. The balance between the competing factors of initial stabilization and minimizing trauma to the surrounding bone is now better understood. Specific implants are now designed for specific clinical scenarios. A variety of implant widths have been used, but the success rates of very wide and very narrow implants have been relatively poorly documented. Hollow or vented implants have been used; however, currently vents or openings are generally limited to the apical areas, and hollow implants, too, have

largely disappeared from the market. One implant (IMZ) included a polymeric "intramobile element," with the aim of dampening functional loads; however, it was not shown to be effective in load dampening and had limited durability.

Osseointegrated implant surfaces originally had relatively smooth machined titanium surfaces. Very rough metallic and hydroxyapatite surfaces followed. Plasma spraying, etching, and airborne particle abrasion have been used to modulate surface texture. Currently, most implant surfaces are moderately rough.[39] Surface textures are now optimized to promote bone deposition. A variety of growth factors, other proteins, and even gene therapy have been investigated, but definitive clinical results have not yet been produced.

The original Brånemark implants had a short, hexagon-shaped, antirotational external connection. Some other designs had no antirotational device, which precludes their effective use for single implant crowns. Currently, a variety of internal and external devices is available in a range of geometric shapes. Some have internal connections with parallel or tapered walls and internal hexagons or octagons; others have interlocking channels; some are passive, whereas others are friction-fit. Longer internal connections may provide increased stability, which is important in a single tooth situation, but they may also weaken the implant head.

SURGICAL INNOVATIONS

IMMEDIATE AND EARLY IMPLANT PLACEMENT

Implants can be immediately placed in extraction sockets at the time of or within a week of tooth extraction. Early or immediate-delayed implants are placed from weeks to months to allow for soft tissue healing. Delayed implants are placed in partially or completely healed bone, as was done in the original Brånemark protocol.

Two decades ago Dr. Richard Lazzara became an early advocate of immediate implant placement. Potential advantages of immediate placement are that the treatment time can be shortened and bone volume might be better maintained to provide esthetic results. Potential disadvantages are increased risks of infection and failure. After implant placement, gaps can be present between the implant and the bony socket walls. Bone augmentation may be used to fill these gaps. To date, systematic reviews have reported a paucity of reliable evidence[40]; however, some reports suggest that immediate and immediate-delayed implants may be at slightly higher risk of implant failure and complications than delayed implants, but that the esthetic outcomes might be better when implants are placed just after tooth extraction.[41,42] Short-term results seem encouraging.[43] Recently some have suggested that, with careful débridement, implants can be successfully placed into sites with periapical and periodontal infections.[44] Bone augmentation procedures are generally effective in promoting bone fill and defect resolution at implants in extraction sites and are more successful with immediate and early placement than with late placement.[45] Many studies have reported high survival rates for augmented implants. Recession of the facial mucosal margin is common with immediate placement; risk indicators include a thin tissue biotype, facial malposition of the implant, and a thin or damaged facial bone wall. Early implant placement is associated with a lower frequency of mucosal recession compared with immediate placement. Unfortunately, immediate placement does not necessarily prevent physiologic remodeling after tooth extraction.[46]

AUGMENTATION AND GRAFTING ADVANCES

A variety of graft materials, barrier membranes (both reabsorbable and nonreabsorbable), and techniques have been used for bone augmentation or grafting.[47] Several strategies are used for single implant sites. These primarily include guided bone regeneration, onlay bone grafts, inlay grafts, particulate grafts, and socket preservation techniques. Graft materials have included autografts, xenografts, hydroxyapatite or other engineered materials, and combinations. Grafting is primarily used for alveolar ridges, including dehiscence or fenestration repair, and for maxillary sinus augmentation. To date, supportive evidence for benefits of grafting and augmentation techniques is relatively weak,[48-51] but favorable results in supporting dental implants are often reported.[45] Alveolar ridge augmentation procedures may be quite technique and

operator sensitive. One common complication is the exposure of membranes to the oral cavity. Implant survival may be a function of residual bone supporting the dental implant rather than grafted bone.[48]

SOFT TISSUE MANAGEMENT, MINIMALLY INVASIVE FLAPLESS AND COMPUTER-GUIDED SURGERY

Esthetic soft tissue complications are not uncommon. Appreciation for careful soft tissue management has grown as more single tooth anterior implants have been placed. From the early 1990s, Dr. Dennis Tarnow and others established that the preoperative distance from bone crest to the maximum convexity on the crown of the adjacent tooth is a key predictor of postoperative papilla height; they also emphasized the importance of a thick soft tissue biotype. Flapless implant surgery may decrease postoperative morbidity, may reduce bone loss, and is well suited to computer-guided surgery.[43,52,53] However, mucosal recession has been observed with both flapless and immediate placement and restoration, so careful planning and realistic expectations remain crucial. Positional deviations have been found between virtual planning and actually obtained implant position after computer-guided surgery.[53]

PROSTHETIC INNOVATIONS

IMPLANT ABUTMENTS

Connections between implants and crowns may be direct non-segmented or segmented through an intermediate abutment. Segmented crowns may be attached to abutments by screws or luting cements. The original Brånemark implant protocol used implants seated to the level of the bony crest and transmucosal cylindrical titanium abutment cylinders. Some subsequent single-stage systems dispensed with the transmucosal abutment, with the implant body extending through the mucosa (e.g., Straumann). It has subsequently become clear that single-stage surgery can produce equivalent results to those of two-stage surgery in many clinical situations, and with the potential for less morbidity and decreased cost.[54]

Researchers quickly realized that esthetic needs were compromised by nonsubmerged systems. The UCLA abutment was the first customizable abutment that could be directly attached to the implant head; this allowed freedom to create any desired emergence profile and the ability to bring porcelain subgingivally. However, the casting of customized abutments was more expensive and time-consuming and probably less accurate than using preformed machined components. A wide variety of cylindrical, conical, curved, and angled prefabricated abutments is available; they come in a number of coronal shapes, are made of metals and ceramics, and are designed for screw or cement retention. Custom abutments in an infinite variety of forms can now be fabricated using computer-aided design/computer-aided manufacturing (CAD-CAM) technology (e.g., Procera). Prefabricated or custom abutments can accommodate various implant angulations, amounts of interocclusal space, materials, and system choices. Screw attachment of crowns facilitates retrievability but may diminish esthetics; clinical guidelines for the choice of screw versus cement retention have yet to be established.[55] Some systems now rely on frictional fit through a locking taper rather than on cement or screws (e.g., Biocon).

IMMEDIATE, EARLY, AND DELAYED LOADING PROTOCOLS

The original Brånemark protocol included empirically based 3-month mandibular and 6-month maxillary submerged healing phases before delayed prosthetic loading. However, nonsubmerged implant systems (e.g., TPS, Straumann) began to receive clinical documentation in the 1980s and 1990s. More recently, it has become evident that a small amount of micromovement may be tolerated.[56] However, systematic reviews have yet to demonstrate predictability in all areas of the mouth for immediate or early loading of single implants.[57,58]

SUMMARY

The single implant has become an important treatment option for partially edentulous patients. Society and individual patients place great

importance on a pleasing smile, the replacement of visible teeth, and maintenance of masticatory function. Single implants have high success and survival rates, higher than for tooth-supported fixed dental prostheses, which may necessitate the removal of sound tooth structure from abutment teeth. Over the past two decades, myriad diagnostic, implant design, surgical, and prosthodontic innovations have advanced the single implant restoration; it has become part of mainstream general dentistry. However, evidence often lags behind the latest innovations. To date, consensus statements have generally been too broad to guide clinicians' decisions in specific clinical situations. Complication rates for the single implant are still higher than desirable. Future challenges may arise from rapid launching of untested novelties or recommendations to apply overly bold clinical procedures. The dentist must be cautious, follow the best available evidence, and be guided by qualified expert opinion.

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CHAPTER 2

Diagnosis and Treatment Planning for Single Implants

Mahmoud Torabinejad, Hessam Nowzari

Chapter Outline

Etiology and Treatment of Tooth Loss
Indications for Root Canal Treatment and Restoration
- Systemic and Local Health Factors
- Patient Comfort and Perceptions
- Biologic Environmental Considerations
- Teeth with Unique Color Characteristics
- Quantity and Quality of Bone
- Soft Tissue Anatomy
- Procedural Complications
- Adjunctive Procedures

Extraction Without Tooth Replacement
Tooth Extraction and Replacement with a Fixed Partial Denture
Tooth Extraction and Replacement with a Single Implant
- Indications for Implants
- Systemic and Local Health Factors
- Patient Comfort and Perceptions
- Teeth with Unique Color Characteristics
- Quantity and Quality of Bone
- Soft Tissue Anatomy
- Procedural Complications
- Adjunctive Procedures

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Discuss the etiologies of tooth loss and their treatments.
- List the indications for and contraindications to root canal treatment.
- Identify factors affecting planning for root canal treatment.
- Discuss the consequences of tooth loss without replacement.
- Discuss the effect of implants on prosthodontics.
- Discuss the indications for a single implant.
- Identify factors affecting treatment planning for a single implant.

Despite significant advances in the field of dentistry over the past century, numerous teeth still develop decay or periodontal disease or are lost because of traumatic injuries. Traditional measures called for the treatment and restoration of afflicted teeth with root canal therapy or periodontal procedures. If determined to be incapable of adequate restoration, the teeth were subsequently extracted and replaced with either fixed or removable prostheses.

Attempts were made to use dental implants in ancient civilizations, and as early as the 1800s endosseous root form implants were placed. In the twentieth century, implants were used in completely and partially edentulous patients to provide much-needed stability and function for fixed and removable prostheses (Figure 2-1). However, implant survival rates were not as high as desired, and sometimes substantial bone loss occurred in conjunction with loss of the implant. The survival rates of implants improved substantially with the introduction of modern cylindrical endosseous implants,[1,2] adding another valuable treatment option for teeth that could not be retained endodontically or periodontally (Figure 2-2).

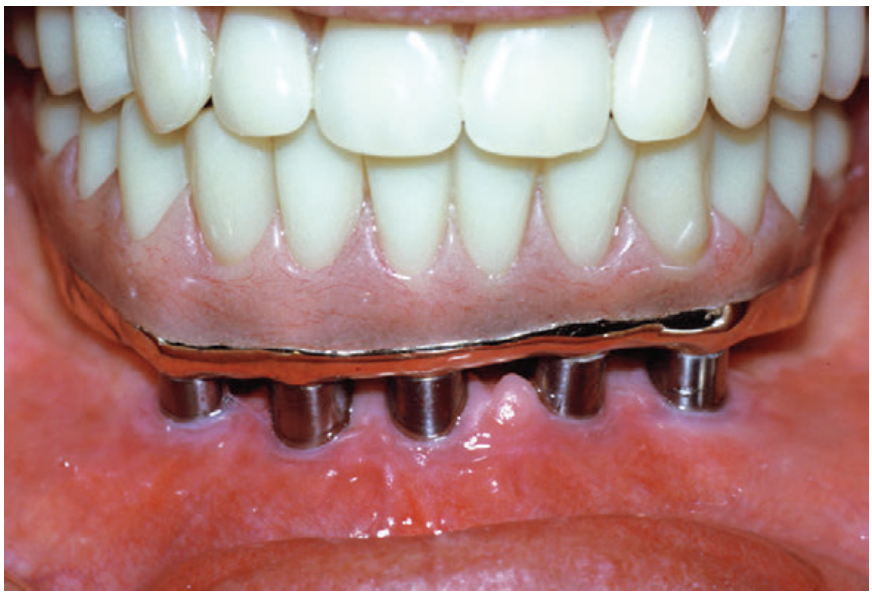

Figure 2-1 Early implants were used as a base to provide stability and function for fixed and removable prostheses.

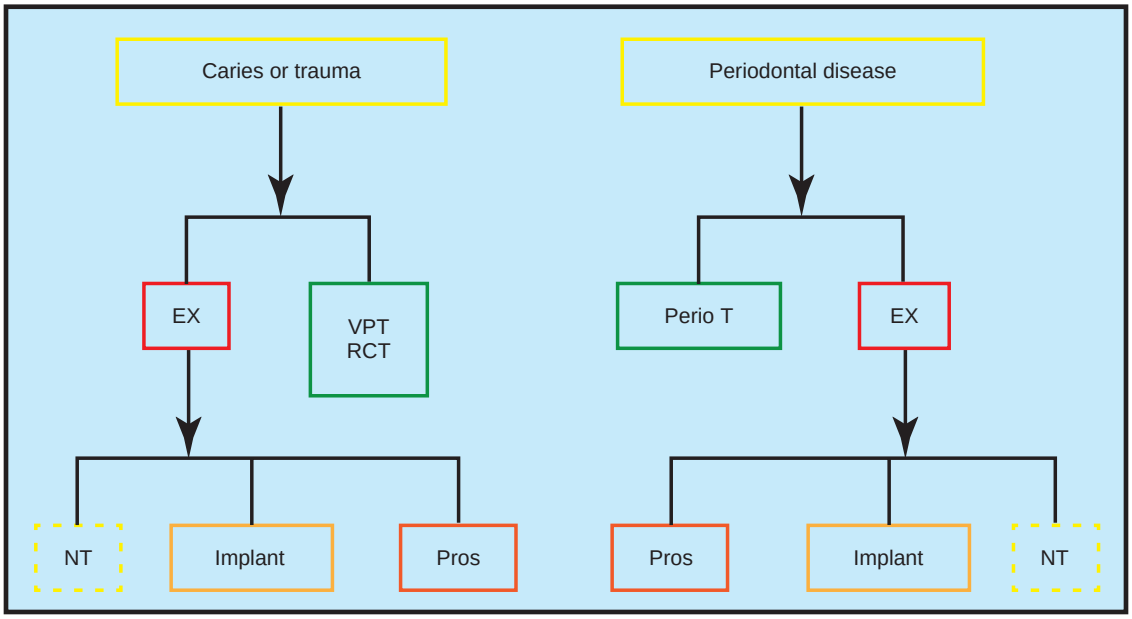

Figure 2-2 Etiologies of tooth loss and their treatments.

Dentists and patients are regularly confronted by a difficult treatment question: *Should a tooth be saved by traditional treatment modalities (root canal treatment or periodontal treatment), extracted without any tooth replacement, or replaced with a fixed partial denture (FPD) or a single tooth implant (STI) and a crown?* The purpose of this chapter is to answer these questions by discussing the diagnosis of and treatment planning for teeth with pulpal and periodontal diseases.

Diagnosis is a detective process and therefore must be performed systematically. It consists of (1) ascertaining the chief complaint, (2) collecting pertinent information regarding the patient's medical and dental history, and (3) performing complete subjective, objective, and radiographic tests. As the starting point for treatment planning, diagnosis can make or break the process. Given its importance, it is a skill that even well-trained clinicians must regularly re-evaluate.

The first step involves the chief complaint, which is usually the first piece of information the patient volunteers with her or his understanding of the condition. The second step requires that clinicians record the patient's comprehensive medical and dental history. The dental history usually provides information about previous treatments, and it can give clues to the patient's attitude toward dental health. Finally, examinations (extraoral and intraoral, in addition to radiographs) help the clinician identify the cause of a patient's complaint and the presence and extent of a pathologic condition. To provide the patient with the best treatment and to arrive at the proper diagnosis, multiple tests and procedures should be performed.

By conducting a systematic examination and careful analysis of the data obtained, the clinician is better equipped to make the right diagnosis. Once the diagnosis has been made, appropriate treatment planning can be carried out for most patients (Figure 2-3). However, treatment planning can become quite complicated when the expectations of the involved parties (patients, insurance companies, and dentists) are not completely met. An ideal treatment plan addresses the chief complaint of the patient, provides the longest lasting, most cost-effective treatment, and meets the patient's expectations. In this way, treatment planning is truly a patient-centered process. Adequate treatment planning also includes relevant scientific evidence and preserves the biologic

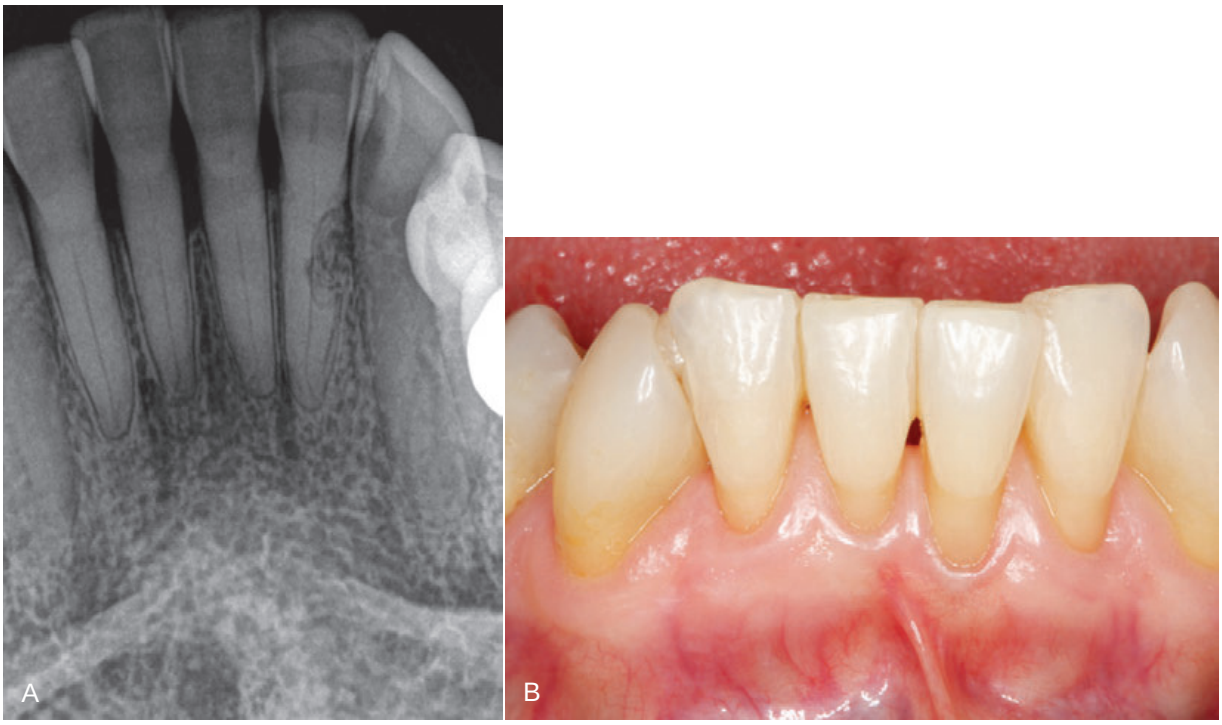

Figure 2-3 **A,** Radiograph of mandibular incisor (#26), which was diagnosed with external root resorption and referred for extraction. **B,** Clinical image 25 years later; the tooth is functional and asymptomatic.

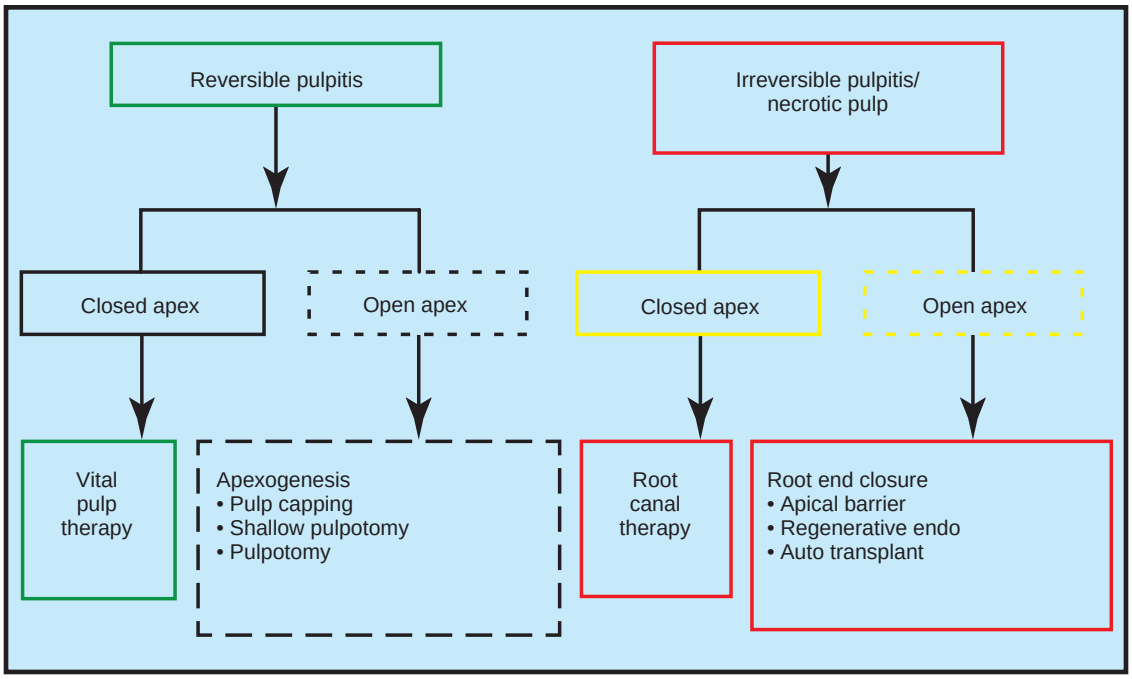

Figure 2-4 Treatment options for teeth with various pulp conditions with closed and open apices.

environment while maintaining or restoring esthetics, comfort, and function.

ETIOLOGY AND TREATMENT OF TOOTH LOSS

Although the main causes of tooth loss are decay and periodontal disease, traumatic injuries can also result in significant tooth loss. The extent of damage to a tooth as a result of these injuries depends on the force of impact. Enamel fractures, crown fractures without pulp exposure, crown fractures with pulp exposure, crown-root fractures, root fractures, tooth luxations (concussion, subluxation, lateral luxation, extrusive luxation, intrusive luxation), avulsions, resorptions, and alveolar fractures are all potential outcomes of such trauma.[3] Because of the range of injuries, clinicians should be prepared to treat affected teeth with a variety of procedures, ranging from enamel recontouring and smoothing of rough edges to replantation of an avulsed tooth.[3]

Regardless of the specific nature of the trauma, it is important to note more generally that trauma to teeth affects the dental pulp either directly or indirectly. Endodontic considerations, therefore, are vital in the evaluation and treatment of dental injuries. In crown fractures with pulp exposure or crown-root fractures, the pulpal status and the degree of root development (Figure 2-4) are the major factors in treatment planning.[4] If the diagnosis is reversible pulpitis, the treatment of choice is vital pulp therapy, regardless of the degree of root development. If the diagnosis is irreversible pulpitis or pulpal necrosis, the amount of root development determines the treatment.[4] If the apex is closed, root canal therapy can be performed, with high survival rates.[5,6] Teeth with irreversible pulpitis, pulpal necrosis, or immature apices present additional challenges to clinicians during obturation should endodontic treatments be required.

Conventionally, the apexification procedure carried out during such treatments consists of multiple long-term applications of calcium hydroxide to create an apical barrier before obturation of root canals.[7] Because this procedure might alter the mechanical properties of dentin and make the teeth more susceptible to root fractures,[8] a one- or two-step artificial apical barrier using mineral trioxide aggregate (MTA) has been suggested.[7] High success rates have been reported for this procedure (Figure 2-5).[9] However, the procedure may not result in complete root formation and may not reduce the chance of root fracture.[7]

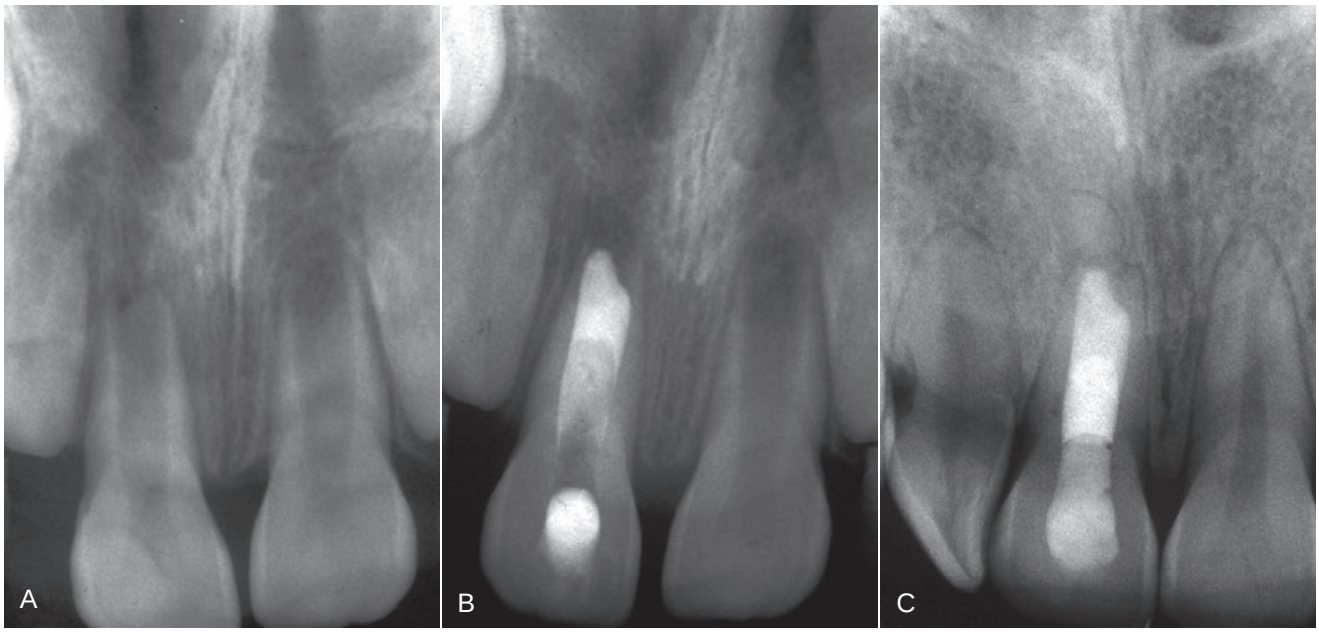

Figure 2-5 **A,** Preoperative radiograph of the right central incisor with an open apex, pulpal necrosis, and chronic apical periodontitis. **B,** Postoperative radiograph after cleaning and shaping of the root canal and placement of a mineral trioxide aggregate (MTA) plug. **C,** Postoperative radiograph 11years later shows complete resolution of the periradicular pathosis and closure of the root end with hard tissues. (Courtesy Dr. G. Bogen.)

The ideal outcome for a tooth with an immature root or a necrotic pulp is regeneration of pulp tissue into a canal capable of promoting continuation of normal root development.[10] A growing body of evidence suggests that regeneration of the pulp, along with continued growth of the root, may in fact be possible after pulpal necrosis and the development of apical pathosis in teeth with immature apices (Figure 2-6). Several single patient treatment reports and treatment series have been published demonstrating radiographic signs of continued thickening of the dentinal walls and subsequent apical closure of roots in teeth with necrotic pulps, open apices, and periapical lesions.[10]

Luxation injuries involve trauma to the supporting structures of the teeth and often affect the neural and vascular supply to the pulp.[3] Every effort should be made to preserve the natural dentition in these cases. If that is unsuccessful, alternative treatments include removable partial dentures, fixed partial dentures, autotransplantation, and single implants.

Another major cause of tooth loss is severe inflammation of the periodontium. With the establishment of extensive periodontal inflammation, teeth start to shift position, and in severe cases they may be lost (Figure 2-7). Extrusion or protrusion of maxillary incisors after periodontal bone loss, destruction of papillae, or loss of maxillary or mandibular anterior teeth may seriously damage facial expression.

Traditionally, all efforts were made to save teeth with periodontal disease (Figure 2-8). Currently, the high survival rates of implants have affected the popularity of this approach, causing a paradigm shift in periodontics.[11] The benefits of successful treatment of a tooth with periodontal disease include (1) conservation of the crown and root structure, (2) preservation of alveolar bone and accompanying papillae, (3) preservation of pressure perception, and (4) lack of movement of the surrounding teeth. Extraction, on the other hand, can include some harmful effects, such as (1) bone resorption,[12] (2) shifting of adjacent teeth,[13-15] and (3) reduced esthetics and chewing ability.[16]

Studies on the long-term prognosis for teeth with periodontal disease show less than 10% tooth loss for periodontal reasons.[17-19] Single rooted teeth have a better prognosis than do molar teeth.[17-19] Cases with furcation involvement, with or without surgical intervention, are associated with a poorer prognosis than are cases without furcation involvement.

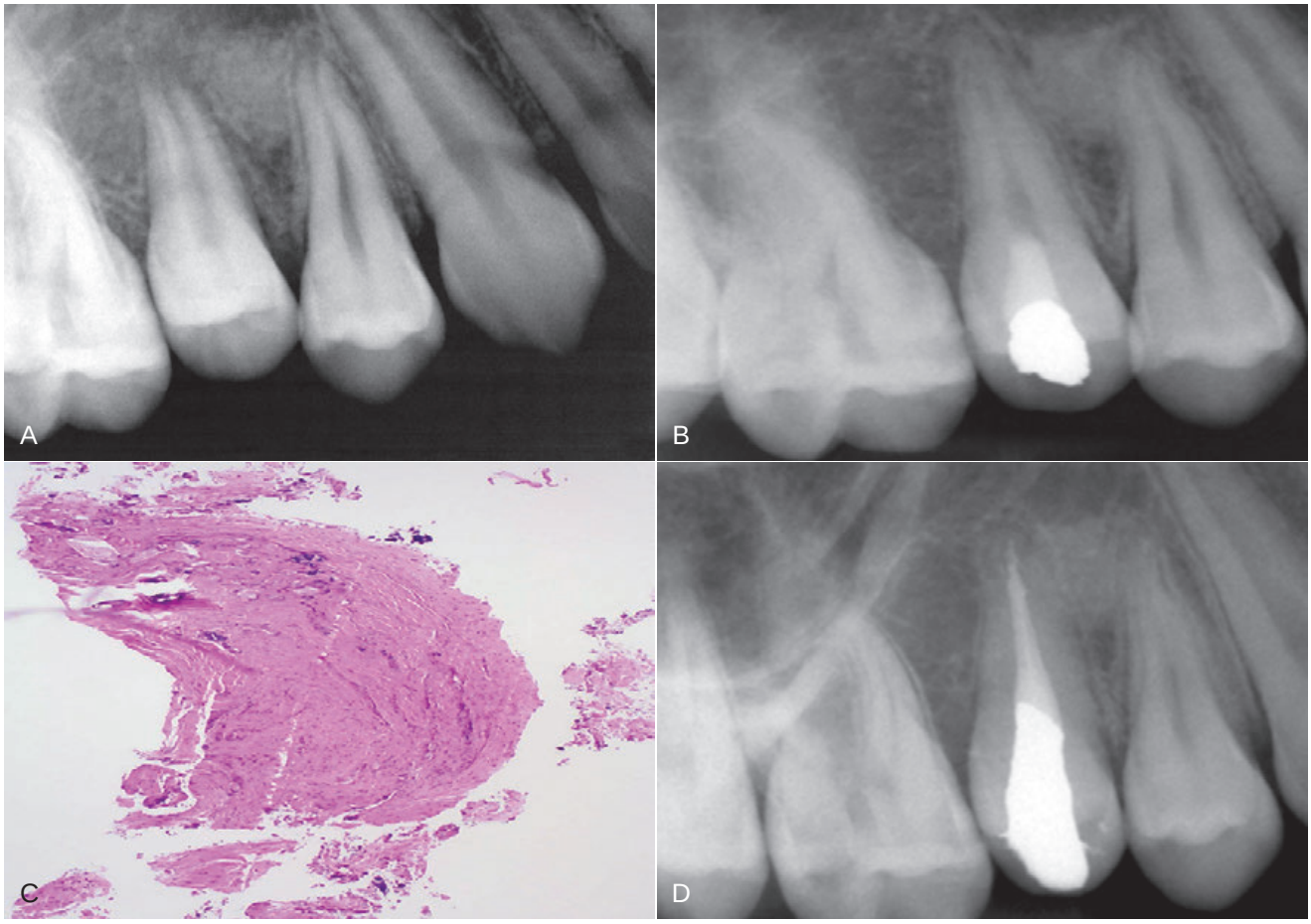

Figure 2-6 **A,** Preoperative radiograph of the right second premolar tooth with an open apex, pulpal necrosis, and chronic apical periodontitis. **B** and **C,** Follow-up radiograph 14 months after regenerative endodontics. Soft tissue removed from the canal at this time showed histologic characteristics of pulp tissue. **D,** Postoperative radiograph 14 months after root canal treatment on the tooth showed thickening of root canal walls and closure of the apex in the tooth.

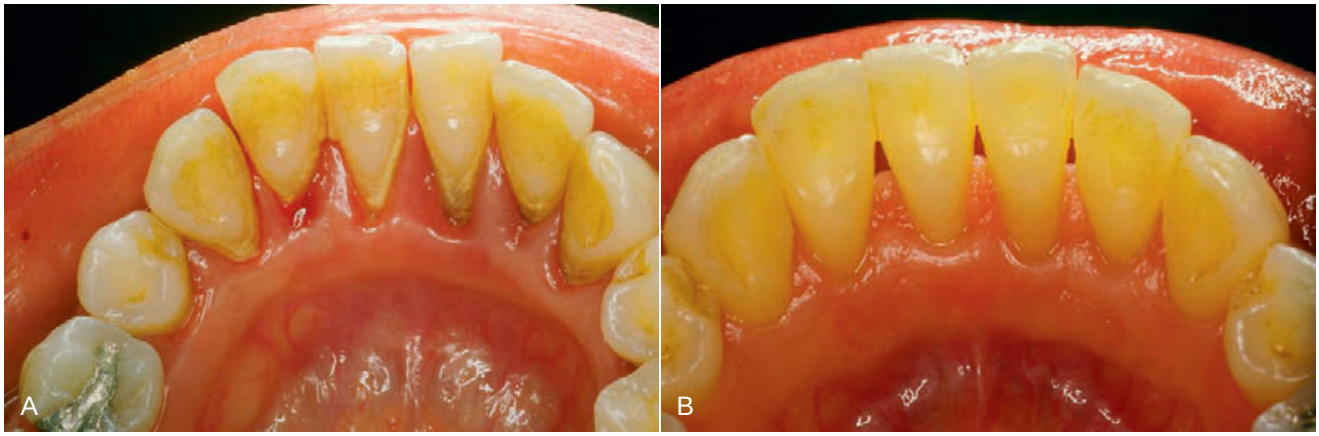

Figure 2-7 **A,** Preoperative photograph of mandibular teeth of a patient with severe periodontitis. **B,** Postoperative photograph 2 years after periodontal treatment shows excellent results. (Courtesy Dr. T. Kepic.)

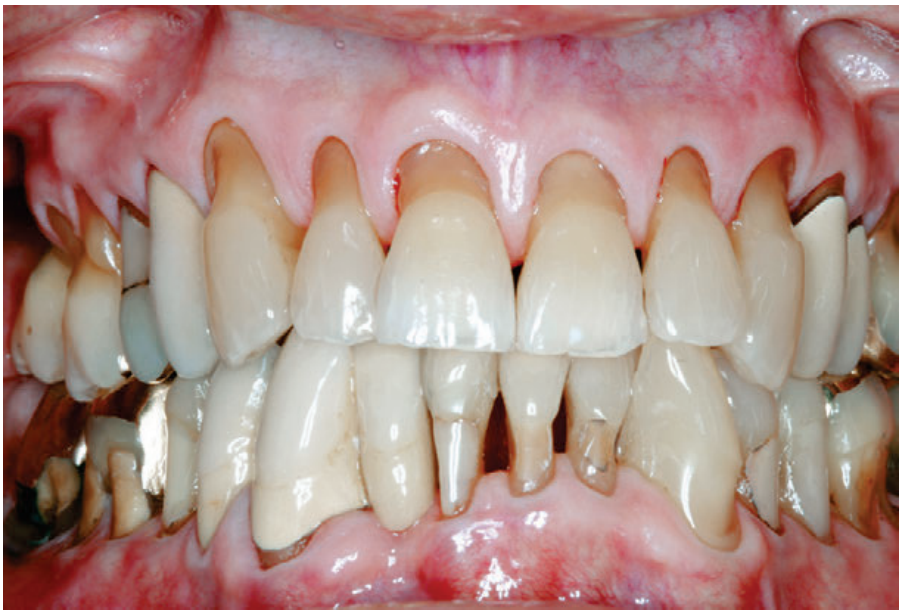

Figure 2-8 At age 40 this patient had severe periodontal disease and was referred for multiple extractions. At age 87, after 47 years of periodontal treatment and regular recall and maintenance, the patient has kept all his dentition.

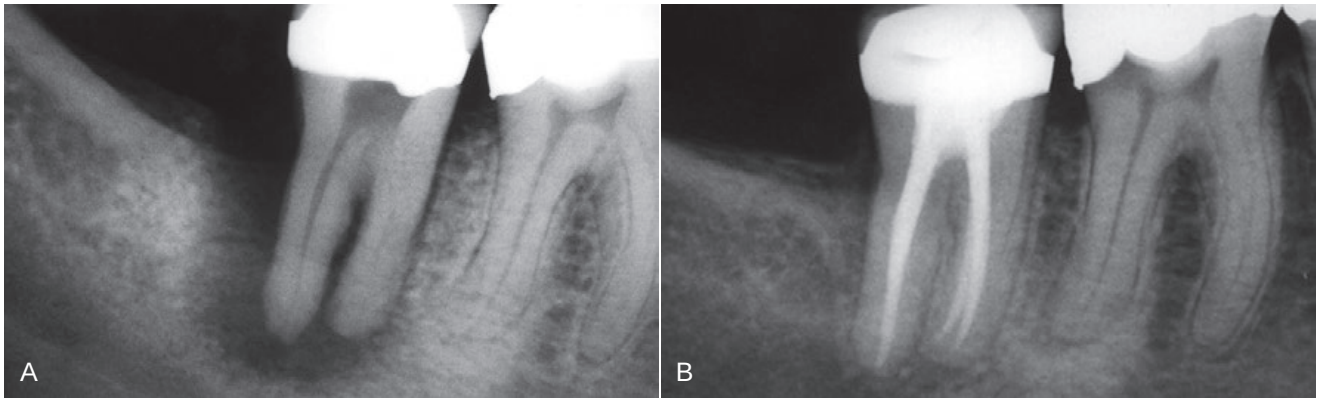

Figure 2-9 **A,** Preoperative radiograph of a second mandibular right molar shows pulpal necrosis and severe chronic apical periodontitis. **B,** Postoperative radiograph 2 years after root canal therapy shows complete resolution of the periradicular pathosis. (Courtesy Dr. G. Harrington.)

Recent innovations in implant dentistry have also reduced the reliance on higher risk periodontal procedures for tissue preservation and regeneration in teeth with moderate to severe periodontal disease.[22] Surveys conducted by the American Academy of Periodontology in 2004 showed that 63% of periodontists put primary emphasis on periodontics, and 27% put primary emphasis on implants.[23]

Although periodontal disease affects many teeth, the major cause of tooth loss is dental decay. Microorganisms in dental caries are the main source of irritation to the dental pulp and periradicular tissues.[24] As the decay progresses toward the pulp, the intensity and character of the infiltrate change. As a consequence of exposure to the oral cavity and caries, the pulp harbors bacteria and their byproducts. The dental pulp usually cannot eliminate these damaging irritants. At best, defenses temporarily impede the spread of infection and tissue destruction.

If irritation persists, the ensuing damage becomes extensive and spreads throughout the pulp. As a consequence of pulpal necrosis, pathologic changes can occur in the periradicular tissues, resulting in the development of periapical lesions (Figure 2-9). Periapical lesions have been classified into five main groups: (1) symptomatic (acute)

apical periodontitis, (2) asymptomatic (chronic) apical periodontitis, (3) condensing osteitis, (4) acute apical abscess, and (5) chronic apical abscess.[24]

Treatment of decayed teeth varies from caries removal and sealing of the exposed dentin (in the case of reversible pulpitis) to pulp capping pulpotomy, root canal treatment, nonsurgical and surgical endodontics, and tooth extraction.

INDICATIONS FOR ROOT CANAL TREATMENT AND RESTORATION

Indications for root canal treatment include teeth with irreversible pulpitis; necrotic pulps, with or without periapical lesions that have restorable crowns; treatable periodontal conditions; salvageable resorptive defects; and favorable crown-to-root ratios.[25] Teeth with pulpal and periapical pathosis that have a restorable crown, sound periodontal structures, an adequate crown-to-root ratio, and no major tooth resorption must be saved by root canal treatment. When such posterior teeth are saved and are extensively restored or are missing considerable coronal tooth structure, crowns are indicated. In a comparative study, Aquilino and Caplan[26] found a strong association between crown placement and the survival of endodontically treated teeth. In addition, a retained tooth may be at risk of future root fracture and development of caries or periodontal disease. These factors should be considered during treatment planning.

In contrast to posterior teeth, intact or minimally restored anterior teeth are usually treated with only restoration of the coronal access opening. Crowns are used on root canal–treated anterior teeth only when these teeth cannot be restored more conservatively or when such conservative treatments are unable to satisfy esthetic requirements.

Root canal treatment is contraindicated or results in less than optimal tooth fracture resistance when limited tooth structure remains and the overlying crown cannot engage at least 1.5 to 2 mm of tooth structure with a cervical ferrule (Figure 2-10).[27,28] When a post is required in a root canal–treated tooth to retain the core, the tooth is weakened but the negative effect of the post is countered by a 2-mm ferrule. When a fixed partial denture is attached to root canal–treated teeth, the teeth fail more often than do teeth with vital pulps[29-31]; *this emphasizes the need to exercise caution with longer span prostheses and heavier occlusal forces, as indicated by substantial wear facets.*

Given that root canal therapy retains a natural tooth, many clinicians recognize this as a benefit that extraction cannot provide. Of course, the natural tooth must not have residual pathology of clinical significance, must fulfill its function in the dentition, must not be a source of discomfort for the patient, and must have acceptable esthetics. If these requirements are met by the retention of a tooth, then the alternative treatment, to be justifiable, must provide greater functionality, less discomfort, or better esthetics than root canal therapy.

In a systematic review, Torabinejad et al.[6] compared the outcomes of endodontically treated

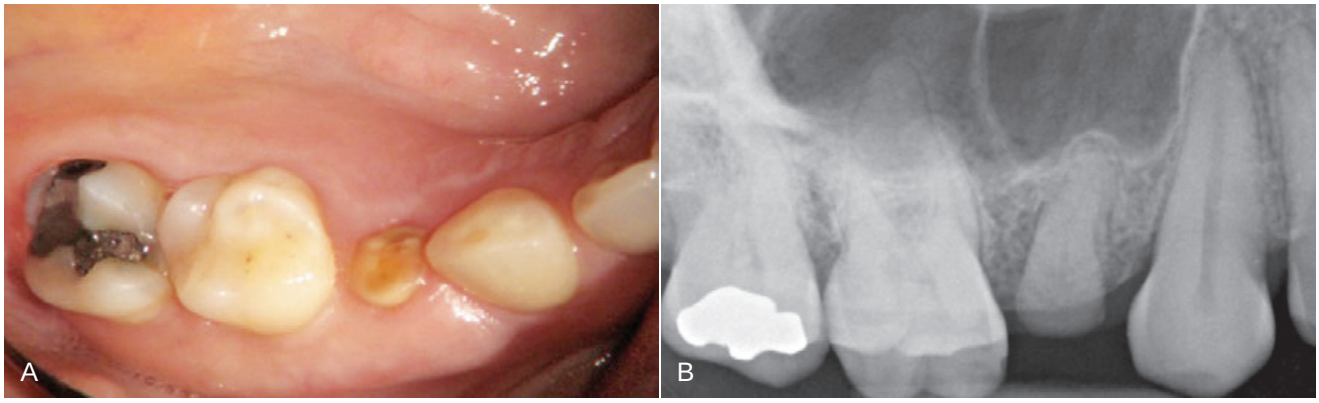

Figure 2-10 **A,** Photograph of a maxillary premolar with limited remaining tooth structure to allow adequate cervical ferrule. Note the two intact adjacent teeth. **B,** Radiograph of this region confirms the unrestorability of the maxillary premolar.

Table 2-1 Factors Affecting Planning for Root Canal Treatment or Single Tooth Implantation

PATIENT FACTORS	TOOTH FACTORS	TREATMENT FACTORS
Systemic health status and local factors	Restorability conditions	Ethical considerations
Patient comfort and perception	Biologic considerations	Procedural accidents
Cost of treatment	Color characteristics Bone considerations Soft tissue anatomy	Adjunctive procedures Treatment outcomes

teeth with the outcomes of teeth treated with single dental implant–supported crowns, fixed partial dentures, and extractions without further treatment. Success data in this review consistently ranked implant therapy as superior to endodontic treatment, which in turn was ranked as superior to fixed prosthodontic treatment. At 97%, long-term survival was essentially the same for implant and endodontic treatments and was superior to extraction and replacement of the missing tooth with a fixed partial denture. Iqbal and Kim[5] reported similar findings when they compared the survival of restored endodontically treated teeth with implant-supported restorations.

In addition to the outcomes of various treatments, a number of other factors should be considered during treatment planning for patients whose teeth have been affected by decay (Table 2-1). The factors involved in the decision on whether a tooth receives treatment or is extracted and other treatment is rendered are usually related to the patient's systemic and local health conditions, the state of the tooth and periodontium, and the type of treatment required.[32]

SYSTEMIC AND LOCAL HEALTH FACTORS

Systemic and local health factors can affect the outcomes of root canal treatment. Clinical data seem to indicate that a history of diabetes may have a negative impact on the healing of periradicular lesions.[33] The presence of a periradicular lesion is the main preoperative factor associated with less favorable outcomes for root canal treatment.[34-39]

PATIENT COMFORT AND PERCEPTIONS

Most root canal treatments are performed with minimal patient discomfort and complications.[40,41] However, past positive and negative experiences can affect the decision on the modality that should be pursued.[6]

BIOLOGIC ENVIRONMENTAL CONSIDERATIONS

Certain patients are frustrated because of recurring problems with caries or periodontal disease (Figure 2-11). Retaining such teeth through root canal treatment may not be the best option, because retreatment procedures, which are frequently required, can be challenging and frustrating for the practitioner, producing compromised results. A more prudent course than root canal therapy may be to extract such teeth and place an implant.[32] Certain patients with limited ability to perform routine oral hygiene procedures may be better treated with an implant.[32]

TEETH WITH UNIQUE COLOR CHARACTERISTICS

Color matching can be a significant challenge in certain highly visible teeth with unique dentin colorations or large areas of enamel translucency (Figure 2-12). When such a tooth requires root canal treatment but does not need a ceramic crown, the esthetically advantageous approach may be to retain the tooth through root canal treatment, rather than extracting it and placing an implant crown that does not match the surrounding environment. It may even be prudent to perform challenging root canal treatments rather than extract such a tooth.[32]

QUANTITY AND QUALITY OF BONE

The quantity of available bone is a factor in the feasibility of root canal treatment. Retaining a tooth with poor bone support, particularly a cracked tooth, can lead to substantial bone loss by the time the tooth is eventually removed (Figure 2-13). The resulting bone defect can significantly

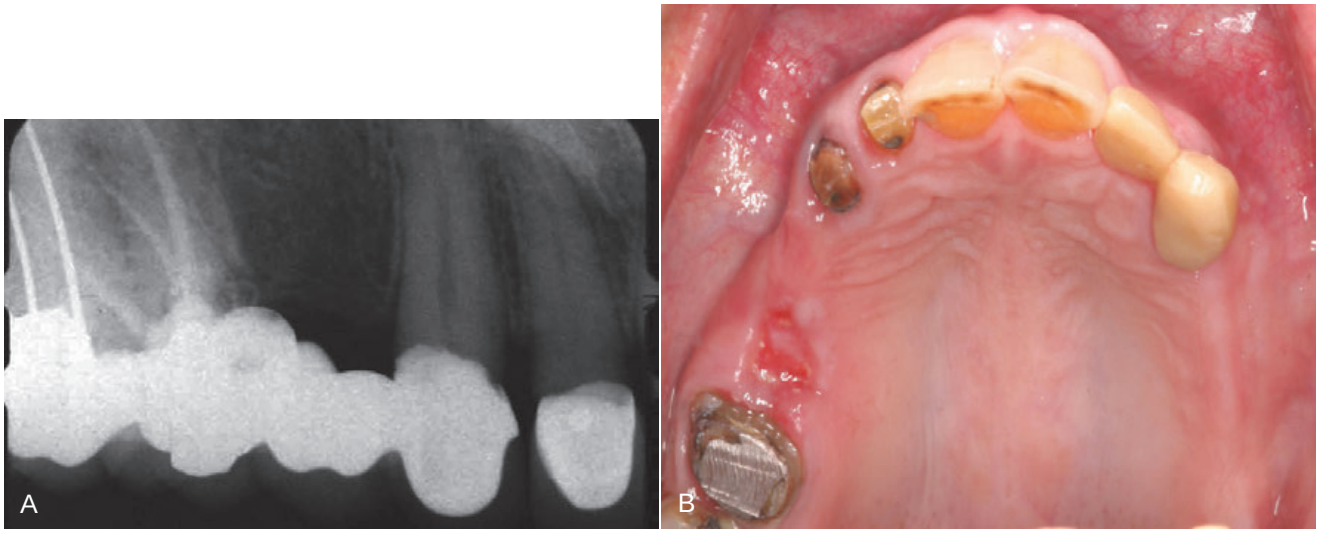

Figure 2-11 **A,** Preoperative radiograph of the maxillary right quadrant shows open margins under the crowns of teeth restored with crowns and a bridge. **B,** Photograph of this region after removal of the bridge and crowns confirms the radiographic findings.

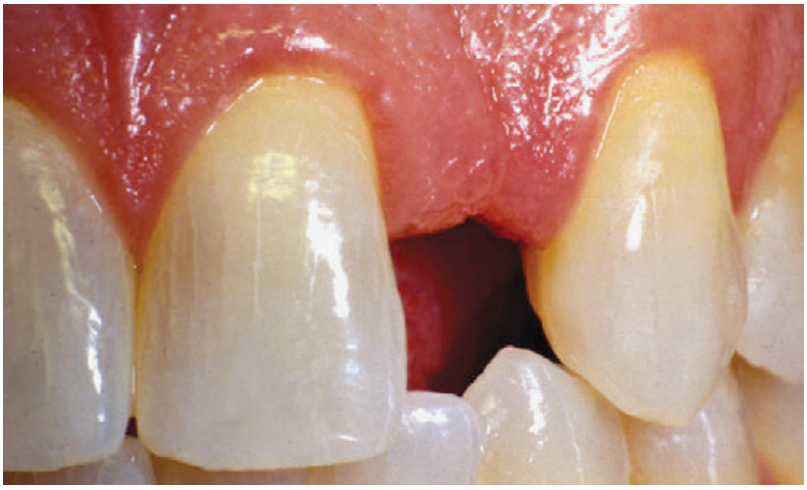

Figure 2-12 Unique dentin colorations or large areas of enamel translucency in the anterior region make color matching a significant challenge.

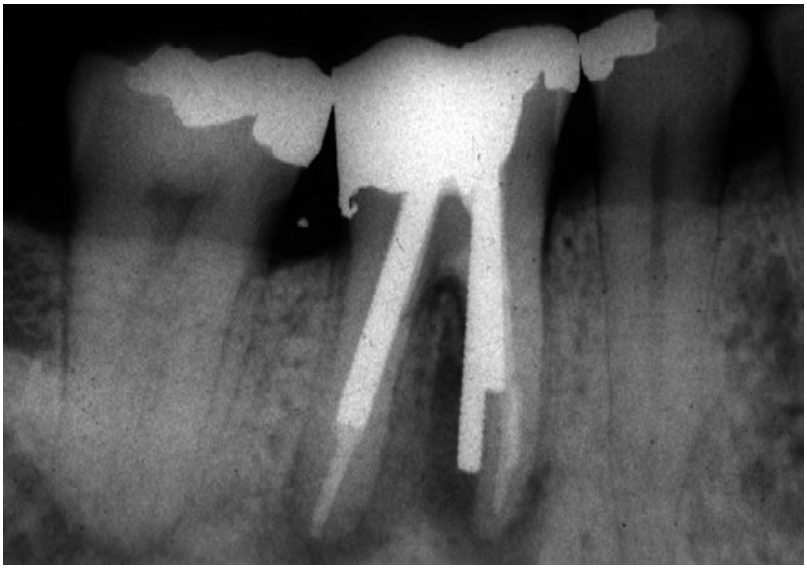

Figure 2-13 Retaining a tooth with poor bony support, such as a tooth with a cracked root, can jeopardize the outcome of a future implant.

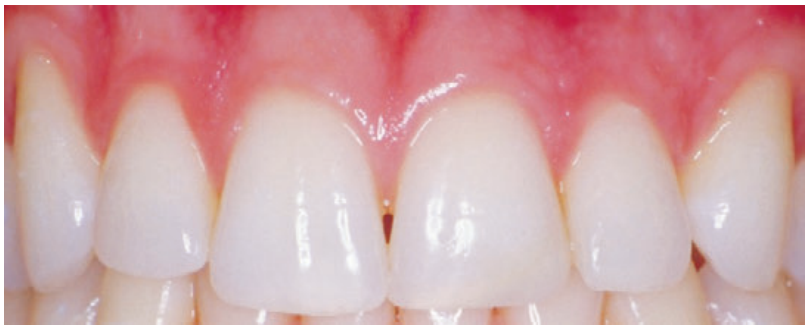

Figure 2-14 Extracting a tooth in a patient with a thin biotype and placing an implant in esthetic zones can be a major challenge and should be considered a primary factor during treatment planning.

affect the esthetic result. Early removal of the tooth and immediate placement of a dental implant may result in an environment more suitable for ideal implant positioning and optimal esthetics.[32]

SOFT TISSUE ANATOMY

The esthetic result around crowns can be negatively affected by an interdental papilla that does not fill the cervical embrasure space. This outcome can occur around crowns that attach to root canal–treated teeth. When the biotype is thin (Figure 2-14) but healthy around a natural tooth, preservation of the tooth through root canal therapy may provide more appropriate soft tissue esthetics than extracting the tooth and trying alternative treatments.[32]

PROCEDURAL COMPLICATIONS

As are other dental procedures, root canal treatment is sometimes associated with accidents (see Figure 2-13). These mishaps can occur during various phases of treatment.[42] Some accidents have a negative effect on the outcomes of root canal treatment.[43-45] For example, the extension of root canal filling materials and the quality of obturation affect the prognosis of root canal treatment.[46-48]

ADJUNCTIVE PROCEDURES

A number of adjunctive procedures, which can be both time-consuming and expensive, are available during or after root canal treatment. For instance, retaining some teeth through root canal therapy may require periodontal disease therapy, crown lengthening through surgery or orthodontic extrusion, a core buildup or post and core, or a crown (Figure 2-15). Each of these procedures adds complexity, presents additional complications and risks, increases cost, and makes comprehending and accepting a treatment plan more difficult for patients.[32] These factors should be carefully considered and compared with those of alternative treatments.

EXTRACTION WITHOUT TOOTH REPLACEMENT

The principal benefits of extraction are pain relief and removal of diseased tissues. The principal harmful effect of single tooth extraction without replacement is its tremendous impact on patients' perceptions of themselves. Physiologic effects appear to be relatively minor, but surgical complications and sequelae may be encountered. Torabinejad et al.[6] compared the outcomes of endodontically treated teeth with those treated with single dental implant–supported crowns, fixed partial dentures, and extractions without further treatment. Valid systematic search strategies for the effects of extraction without tooth replacement and for economic outcomes were not achieved because of the limitations of the available literature and indexing terms. Limited psychosocial data suggested that tooth retention through root canal therapy and restoration or tooth replacement with an implant or a fixed partial denture results in superior clinical outcomes compared with extraction without replacement. The reasons for the less favorable patient-perceived outcomes with extraction without replacement were diminution of esthetics and psychological trauma associated with tooth loss (i.e., self-image, not physiologic function).

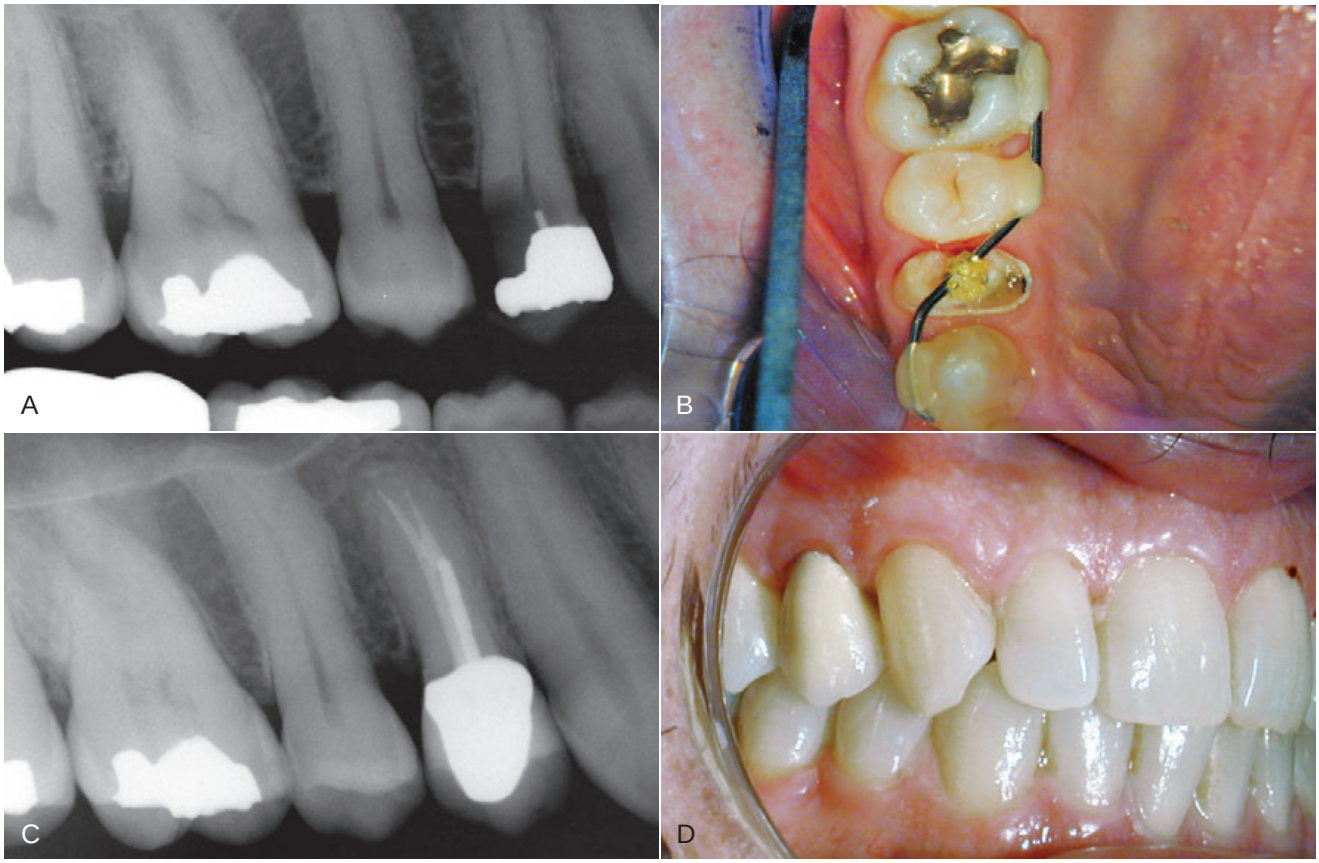

Figure 2-15 **A,** Preoperative radiograph of the right first premolar shows extensive decay requiring either root canal treatment or extraction. **B,** After root canal treatment, the tooth is extruded orthodontically. **C,** Follow-up radiograph 15 months after root canal treatment and extrusion of the tooth shows excellent results. **D,** Postoperative photograph of this region 24 months after treatment shows excellent restorative and esthetic results. (Courtesy Dr. M. Pouresmail.)

TOOTH EXTRACTION AND REPLACEMENT WITH A FIXED PARTIAL DENTURE

The benefits of extraction and replacement of a missing tooth with a fixed partial denture (FPD) include prevention of shifting of the adjacent teeth and improved chewing ability and esthetics.[11] Studies have shown no adverse effects on the surrounding alveolar bone,[49] the attachment level between teeth supporting FPDs and a homologous tooth,[50] and no difference in plaque index, gingival index, or probing depths between baselines.[51] Studies also have found that if hygiene is maintained to a high degree, no inflammation of the mucosa is observed under the pontic, regardless of the pontic material used.[52]

Tooth preparation, impression, provisionalization, and cementation while fabricating a crown or an FPD can result in pulpal injury.[53] Endodontic treatment (Figure 2-16) is often needed in the years after crown cementation.[54] Goodacre et al.[55] reported the incidence of decay (0 to 27%), pulpal problems (3% to 38%), and periodontal problems (4%), in addition to technical complications, such as porcelain fractures (2%), in patients who had fixed prosthodontics.

The findings in these studies should be considered during treatment planning in light of recent reports on the high success rate for single implants. Whereas previously all efforts would have been made to extract hopeless teeth and place fixed or removable prostheses (Figure 2-17), the palpable benefits of implants have changed the way clinicians approach treatment planning in prosthetic dentistry.

Placement of a dental implant rather than a fixed partial denture preserve the enamel and dentin of the adjacent abutment teeth. Furthermore, this approach is less invasive to the pulp of the adjacent

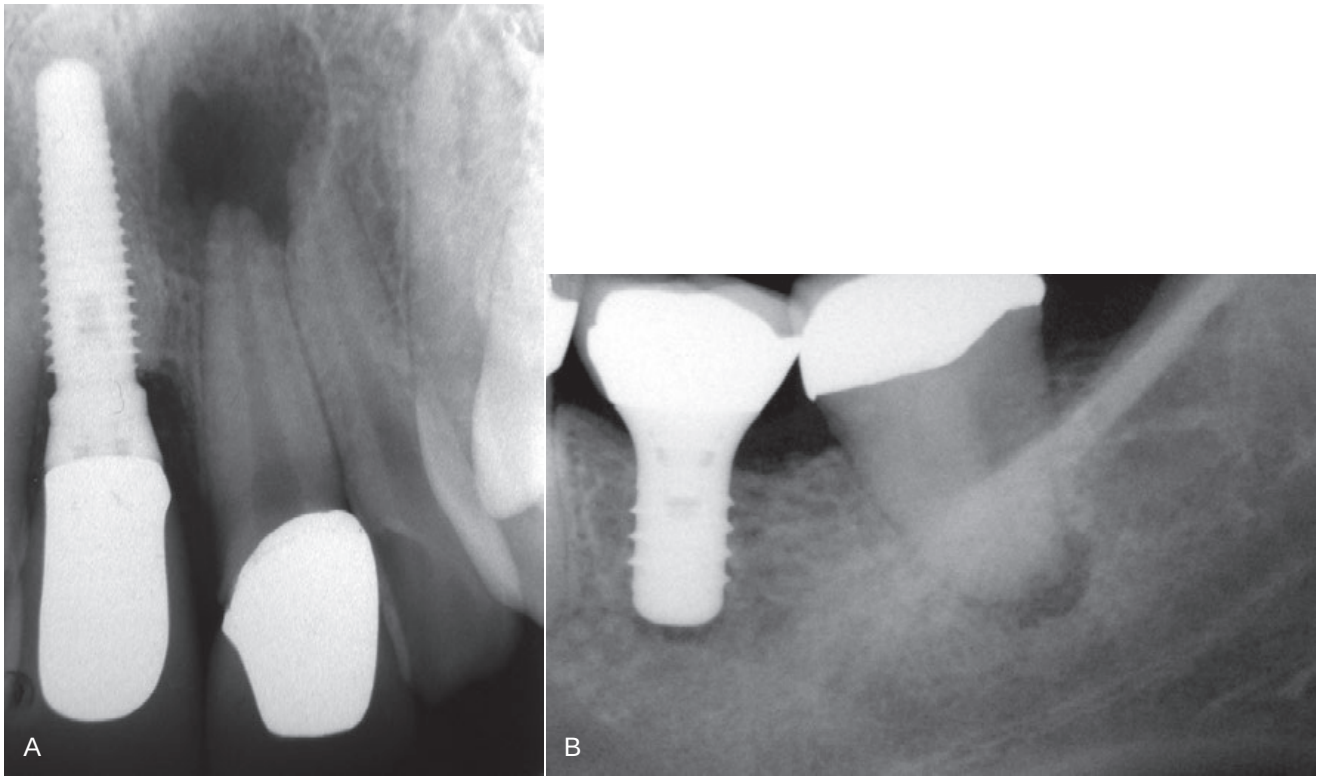

Figure 2-16 Tooth preparation, impression, provisionalization, and cementation during fabrication of a crown can result in pulpal and periapical pathosis and future treatments.

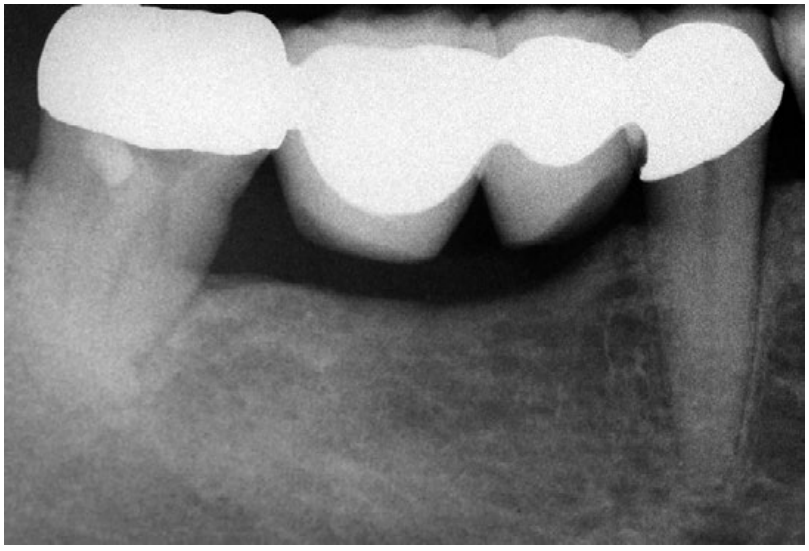

Figure 2-17 A fixed prosthesis is placed from the first mandibular premolar to the second molar. Clinicians today might seriously consider placing two implants rather than constructing a four-unit bridge for this patient.

teeth. The biologic advantages over traditional prosthodontic methods include preservation of the natural dentition and supporting periodontium[56,57] In a 3-year follow-up report of 78 single implants and 148 adjacent teeth, no adjacent teeth required extraction or endodontic treatment, and only four required restorations.[58] Comparison of the periodontal status at crown placement and at follow-up revealed no differences for plaque and bleeding indices or for pocket probing depths of the adjacent teeth. However, a significant influence of the horizontal distance on interproximal bone loss in closer distances was seen in the anterior region but not in the posterior region.

Furthermore, peri-implant tissue differs from the gingivae surrounding natural teeth by having greater probing depths and twice as much bleeding on probing.[59] The connective tissue around implants contains significantly more collagen than that around natural teeth (85% versus 60%) and fewer fibroblasts (1% to 3% versus 5% to 15%).[60] Most peri-implant tissue recession occurs during the first 3 months, with 80% showing buccal recession.[60] In patients with appropriate oral hygiene, however, the intracrevicular position of the restoration margin does not appear to affect adversely the health or stability of the peri-implant tissue.[61]

Curtis et al.[62] discussed the impact of recent scientific advances on treatment planning in dentistry. According to these authors, treatment planning in prosthodontics has changed significantly as a result of improvement of the success rate for single implants. Creugers et al.[63] performed a meta-analysis on the dental literature since 1970 presenting clinical data on the durability of conventional fixed bridges. These authors reported an overall survival rate of 74% (± 2.1%) after 15 years. In another meta-analysis of the literature, Scurria et al.[64] reported an 87% 10-year survival rate for fixed partial dentures and a 69% 15-year survival rate.

A systematic review by Salinas and Eckert[65] compared the outcomes of tooth-supported restorations with those of implant-supported restorations. The authors concluded that at 60 months, single tooth replacements supported by implants had a higher survival rate than those supported by FPDs; however, if resin-bonded FPDs were excluded, no difference was found. They reported that FPD success rates continued to drop steadily beyond 60 months. These results are consistent with the results of the review by Torabinejad et al.,[6] who reported that single implants and endodontic treatments resulted in superior long-term survival compared with fixed partial dentures.

TOOTH EXTRACTION AND REPLACEMENT WITH A SINGLE IMPLANT

INDICATIONS FOR IMPLANTS

Implants are indicated when teeth cannot be prepared with adequate retention and resistance form (see Figure 2-10). Other indications for the use of implants include edentulous sites adjacent to teeth without restoration or the need for restoration (Figure 2-18); abutment teeth with large pulp chambers; abutment teeth with a history of avulsion or luxation; and teeth with infractions, vertical root fractures, or an inadequate crown-to-root ratio.[32] As discussed previously with indications for root canal treatment, several other factors affect treatment planning for single implants, including the patient's systemic and local health conditions, the patient's comfort and perception, biologic factors, tooth color, soft and hard tissue biotypes, procedural complications, and adjunctive treatments.[32]

SYSTEMIC AND LOCAL HEALTH FACTORS

A patient's systemic health status can affect the outcomes of implants.[32] Patients who have an elevated risk of complications after placement of implants include those who have uncontrolled or poorly controlled diabetes; those who have a history of osteomyelitis in the area; those who are immunosuppressed; those who have chronic, severe alcoholism; and those who smoke. The use of intravenous bisphosphonates has been associated with bone osteonecrosis, and such patients must be carefully evaluated to determine whether mucosal healing over the bone will occur after surgery.

PATIENT COMFORT AND PERCEPTIONS

Clancy et al.[67] reported general satisfaction, comfort, esthetics, and function for patients who had had dental implants. The patients in their study experienced some discomfort with the surgery but little discomfort after healing. The patients stated that implant treatment was "worth the investment in time and expense" and that they would accept a similar treatment plan again. Weibrich et al.[68] reported similar findings for patients who had had dental implants.

TEETH WITH UNIQUE COLOR CHARACTERISTICS

When a tooth with challenging color characteristics requires both root canal treatment and a ceramic crown (see Figure 2-12), developing an

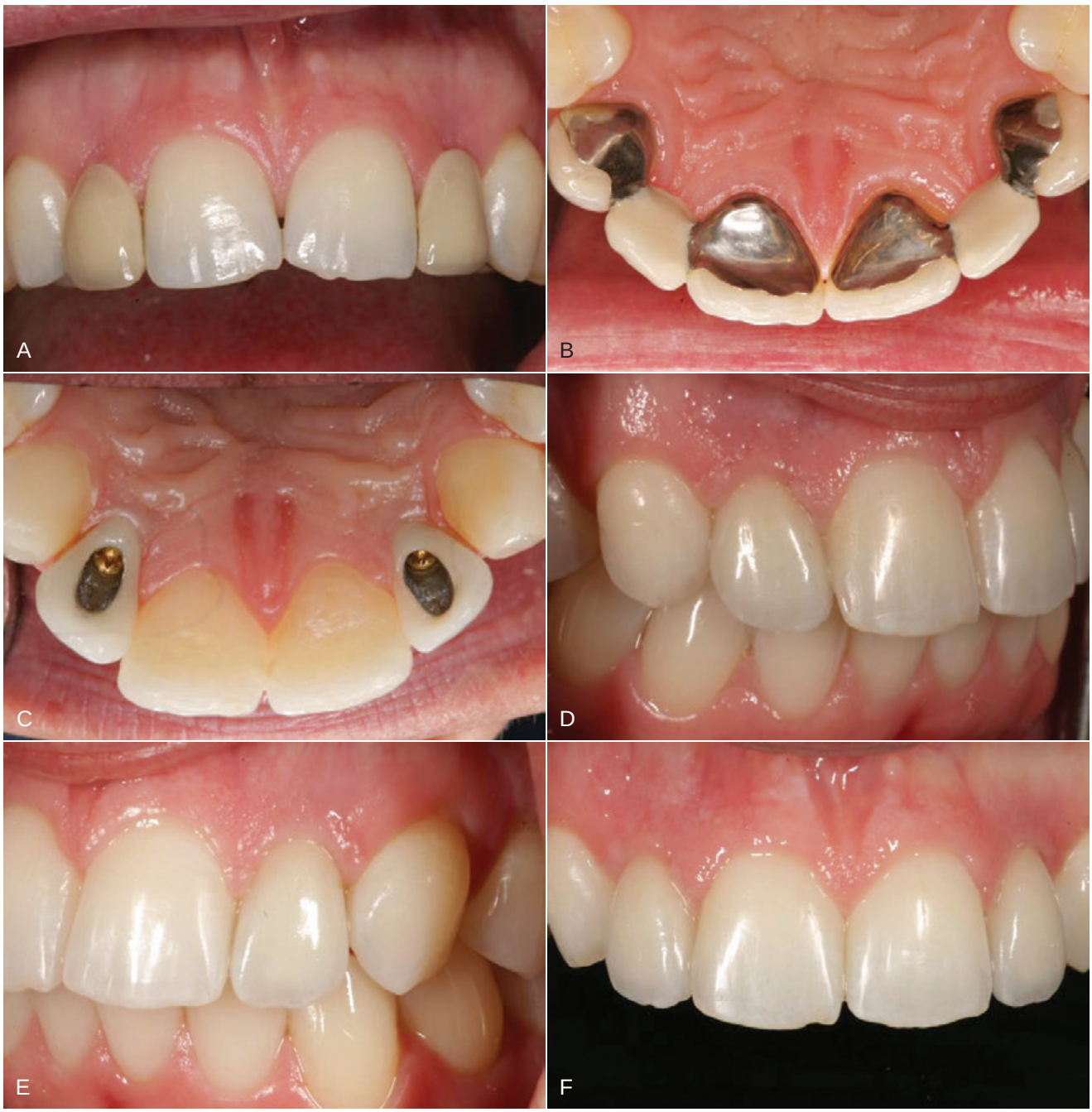

Figure 2-18 **A,** Lack of maxillary lateral incisors adjacent to intact periodontium. **B,** Palatal view. **C.** Note the optimal position of implants, which are restored using nonangled screw-retained abutments. **D,** Clinical view of the finished maxillary right lateral incisor. **E,** Clinical view of the finished maxillary left lateral incisor. **F,** Frontal view of the final result.

appropriate color match in the crown may not be possible because of thickness limitations imposed by the amount of achievable tooth reduction.[32] Although a ceramic crown made for an implant may not be ideal, it usually produces a better color result, because it can be fabricated with a greater thickness of porcelain, which enhances the color-matching potential, particularly in the challenging cervical areas.[32]

QUANTITY AND QUALITY OF BONE

The quantity of available bone affects the feasibility of placing implants without bone grafting.

Bone quality also affects implant success; for example, type IV bone produces lower success rates than types I, II, or III bone.[55] The success rate for short implants (10 mm or less) is lower than that for longer implants.[55] New implant surfaces and geometries have produced promising results[69-71] in overcoming the problems that cause the lower success rates of short implants; however, the available clinical data are limited.

After tooth extraction, an implant can be placed immediately in the root socket; however, the initial thickness of bone significantly affects the responding level of facial bone and soft tissue. Using cone beam computed tomography (CBCT), Nowzari et al.[72] and Ghassemian et al.[73] provided evidence of a predominantly thin facial bone overlying anterior teeth. As a result of naturally occurring biologic events, this thin, fragile facial bone wall is prone to resorptive processes that can lead to fenestration and dehiscence after tooth extraction. Therefore, the facial aspect of an extraction site in this area is susceptible to defects that may interfere with osseointegration of an immediately placed implant. In these authors' studies, a thin facial bone was noted in more than 92% of the teeth analyzed in the randomly selected patient scans, regardless of age, gender, or ethnicity.[72,73]

When substantial infection is associated with an extracted tooth, implant placement may have to be delayed to permit resolution of the infection.[74]

It is essential to consider that immediate implant placement in the anterior position may create the possibility of bone-related or esthetic complications for most patients. Informed treatment decisions based on thorough site evaluation before implant placement are crucial; also, effective dentist-patient communication helps encourage realistic patient expectations and ensures understanding of potential outcomes.

SOFT TISSUE ANATOMY

Around dental implants, soft tissue generally fills the cervical embrasure when the incisocervical distance from the proximal contact to the interproximal bone crest is 5 mm or less.[75] The periodontal biotype also affects the potential for soft tissue to fill the cervical embrasure space around implants. With a thin biotype (Figure 2-19), papillae

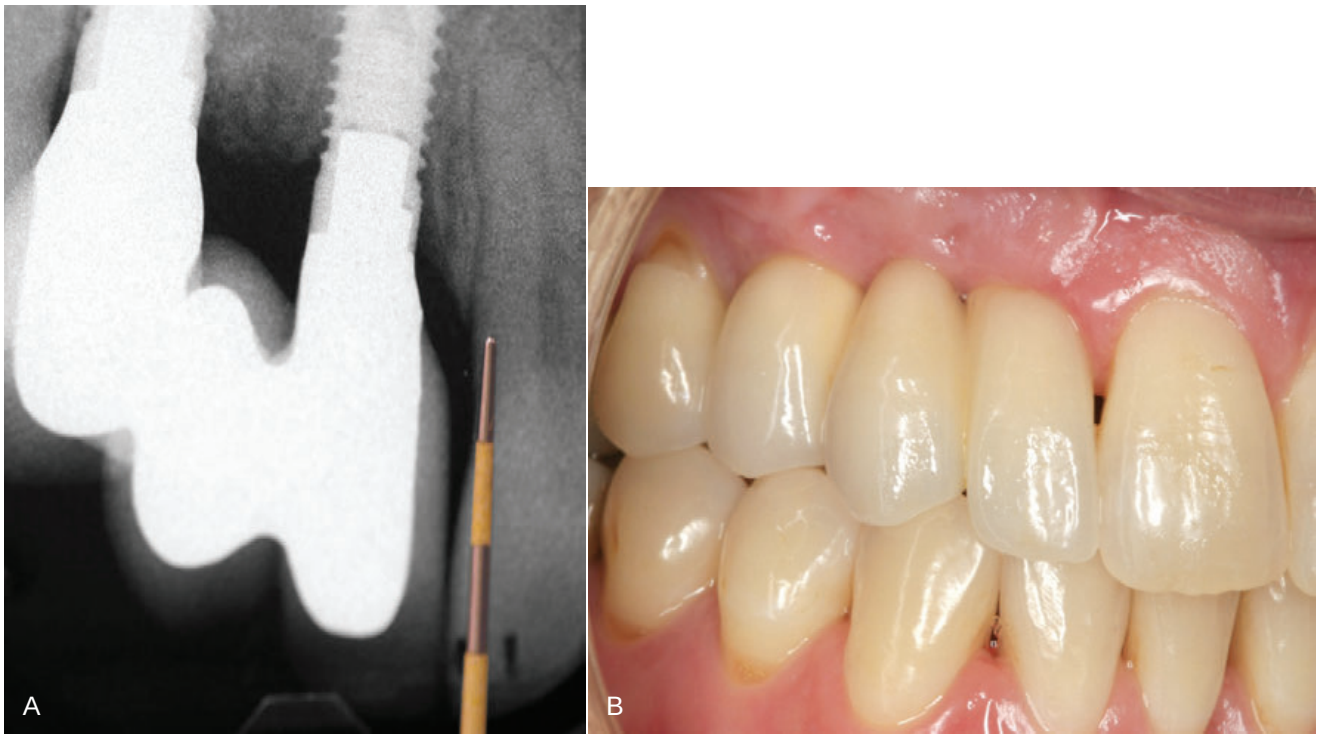

Figure 2-19 **A,** Periapical radiograph showing a periodontal probe in a deep pocket between an implant and the adjacent tooth. **B,** The papillae adjacent to the implant were not totally recreated, because the distance was more than 4 mm between the interproximal bone crest and the desired height of the interdental papillae.

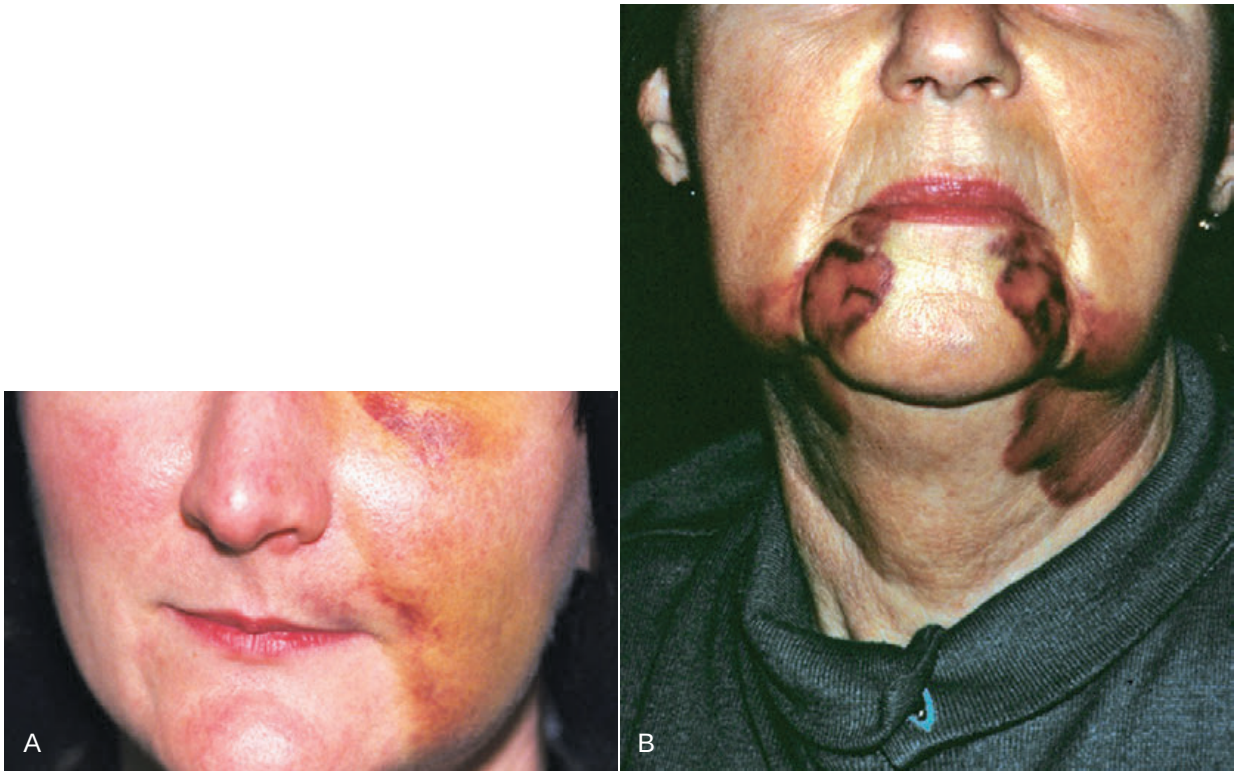

Figure 2-20 Surgical complications of the placement of dental implants include hematomas and ecchymosis.

adjacent to implants can seldom be recreated when the distance is more than 4 mm between the interproximal bone crest and the desired height of the interdental papillae.[76] When two implants are placed adjacent to one another, the amount of soft tissue present incisal or occlusal to the bone is even more limited and may average only about 3 mm.[77]

PROCEDURAL COMPLICATIONS

Complications can occur in conjunction with dental implants. They include surgical complications (Figure 2-20), such as hematomas, ecchymosis, and neurosensory disturbance.[55] Implant loss can occur as a result of failure to integrate with the bone or bone loss subsequent to integration. Soft tissue complications also have been reported, such as inflammation or proliferation; soft tissue fenestration or dehiscence before stage II surgery; and fistulas. Mechanical complications can occur as well, such as screw loosening, screw fracture, prosthesis fracture, and implant fracture.[55] Some of these complications, such as screw loosening, can be corrected, but others can result in clinical failure.

ADJUNCTIVE PROCEDURES

Before or in conjunction with implant placement, grafting or distraction osteogenesis may be required so that adequate bone is available for implant placement.[32] Sinus grafting may be needed in the posterior maxilla (Figure 2-21), and horizontal or vertical bone grafting may be required in other areas of the mouth to provide an edentulous ridge with sufficient bone in the correct location. Ridge grafting that requires bone harvesting from a remote site increases patient discomfort (Figure 2-22). Not only do these procedures increase cost and treatment time, they can also complicate the provisional replacement of missing teeth for esthetic and functional reasons.

SUMMARY

Despite significant advances in the field of dentistry, numerous teeth still develop decay or periodontal disease or are lost because of traumatic injuries. Dentists and patients are regularly confronted by a difficult treatment question: *Should a*

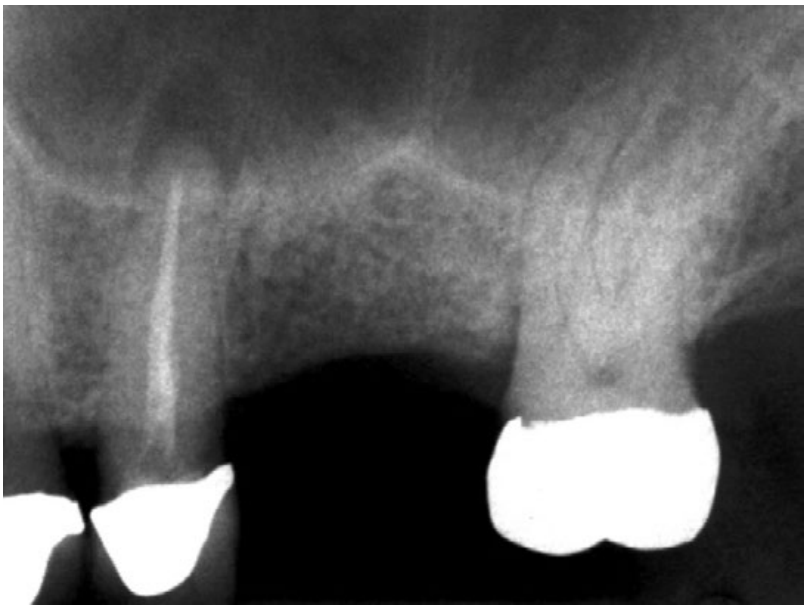

Figure 2-21 An alternative treatment for a failing, previously treated maxillary first premolar that can be retreated endodontically is extraction of the tooth and placement of an implant. Sinus lifting and grafting are needed to provide adequate bone for placement of the implant.

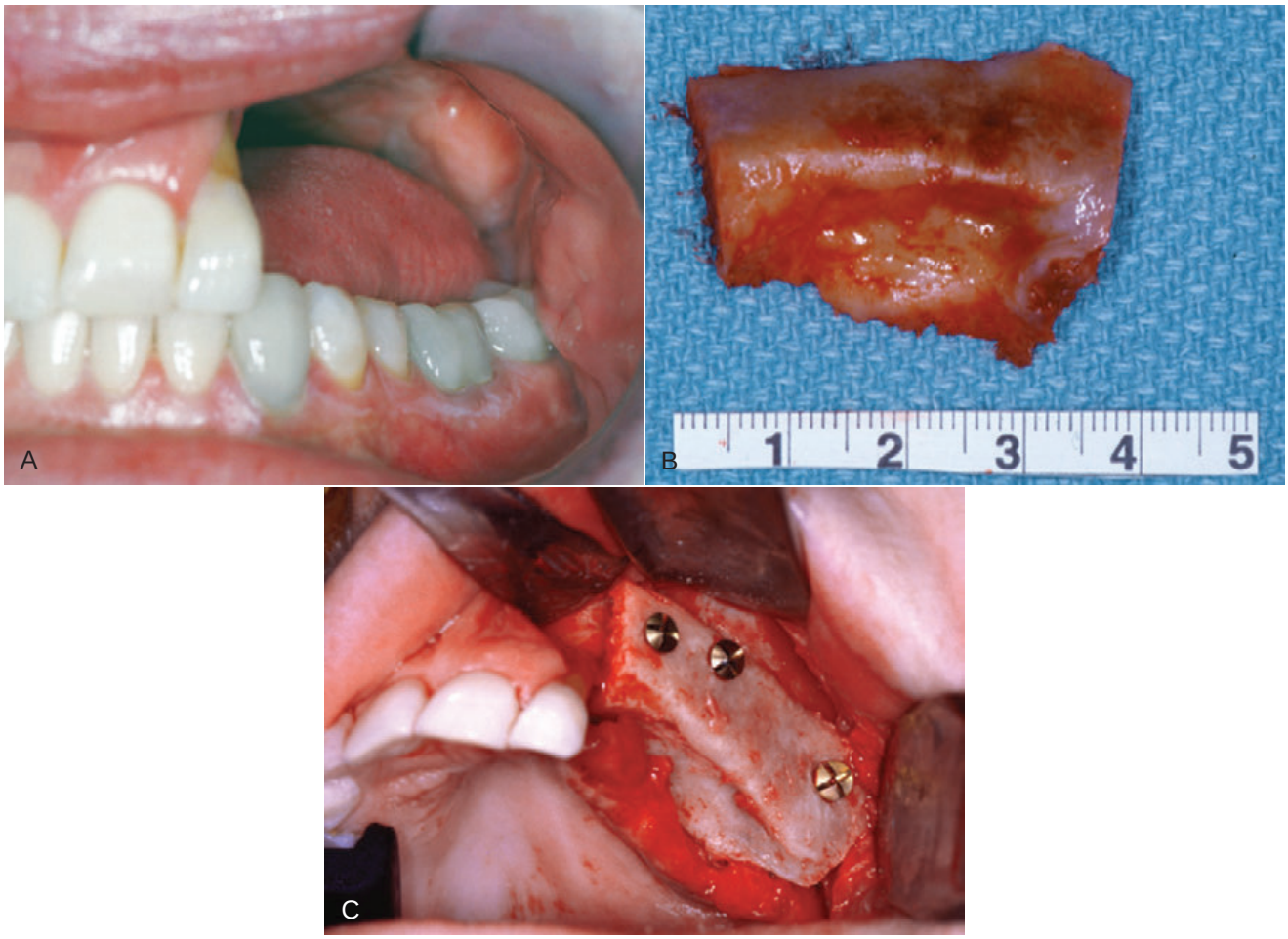

Figure 2-22 **A,** Preoperative photograph of the left quadrant in a patient who had extensive resorption requiring ridge grafting. **B,** A piece of the iliac bone is harvested for ridge grafting. **C,** The harvested bone is grafted and secured with titanium screws. (Courtesy Dr. A. Herford.)

tooth be saved by traditional treatment modalities such as root canal treatment or periodontal treatment or be extracted and replaced with a single tooth implant (STI) and a crown? The answer to this question is based on several factors. The factors involved in the decision on whether a tooth receives treatment or is extracted and replace with a single tooth implant or other treatments are usually related to the patient's systemic and local health conditions, the state of the tooth and periodontium, and the type of treatment required. An ideal treatment plan considers these factors, provides the longest lasting, most cost-effective treatment, and meets the patient's expectations. Adequate treatment planning must include relevant scientific evidence and preserves the biologic environment while maintaining or restoring esthetics, comfort, and function for the patient.

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CHAPTER 3

Factors Involved in Single Implants

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Chapter Outline

Classification
- Single Implants in the Esthetic Zone
- Single Implants in the Nonesthetic Zone

Osseous Considerations

Soft Tissue Considerations
- Apically Positioned Flap
- Free Gingival Graft
- Free Connective Tissue Graft

Implant Configuration
- Bone-Level Implants
- Tissue-Level Implants

Surgical Technique for Single Implants
- Single Implant Surgery in the Esthetic Zone
- Single Implant Surgery in the Nonesthetic Zone

Long-Term Prognosis

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Describe the classification of the various areas of the oral cavity for the placement of single implant placement.
- Explain osseous considerations.
- Understand soft tissue considerations.
- Explain the different types and shapes of implants.
- Understand surgical techniques of implant placement in esthetic and nonesthetic zones.

CLASSIFICATION

Single implants can replace any tooth in the dental arch. For purposes of single implant placement, the various areas of the oral cavity are broadly classified as comprising the esthetic zone (i.e., the central, lateral, canine, and first premolar areas in the maxilla) and the nonesthetic zone (i.e., the posterior maxilla, posterior mandible, and anterior mandible). This allows the characteristics of each area to be explained separately.

SINGLE IMPLANTS IN THE ESTHETIC ZONE

As mentioned, the esthetic zone in the oral cavity consists of the central, lateral, canine, and first premolar areas in the maxilla. These areas are very important because of their role in the esthetic appearance of the patient. A large number of articles have been published on the subject from surgical and prosthetic viewpoints. The principles of implant surgery and osseous and soft tissue considerations in these areas are different from those in other areas of the oral cavity.

SINGLE IMPLANTS IN THE NONESTHETIC ZONE

The nonesthetic zone of the oral cavity consists of the remaining areas of the two arches, which are classified as the posterior maxilla, posterior mandible, and anterior mandible. Each of these regions has specific characteristics and anatomic features that should be taken into account during the surgical procedure. For example, the maxillary sinuses in the posterior maxilla and the inferior alveolar nerve in the posterior mandible are two important anatomic structures in the nonesthetic zone; if they are ignored during surgery, irreparable injury to the patient may result.

In addition, the spaces between the incisors in the mandible are very small, and the possibility of damaging the adjacent teeth is an important consideration during surgery for single implants. In the following sections, these problems are discussed further, and the surgical techniques for each area are explained.

OSSEOUS CONSIDERATIONS

The fact that the process of bone resorption slows down after tooth extraction has been well-established. The amount of bone resorbed during the first year after tooth extraction is much greater than that during the following years.[1] A complex osseous situation exists when bone volume is diminished and the quality of bone is not uniform in different regions of the jaws. These two important factors, the quality and quantity of bone, play an important role in determining implant location and position. In 1985, Zarb and Lekholm created classification systems for the quality and quantity of jaw bones. They classified bone quality as type I to type IV and bone quantity as type A to type E (Figure 3-1).

From a qualitative viewpoint, type II and type III bones are the most appropriate for implant placement. Type I and type IV bones might pose problems in osseointegration and regenerative processes.

From a quantitative viewpoint, type A and type B bones are ideal; however, more problems are encountered with an increase in bone resorption. First, bone height is determined through radiographic evaluation of eligible jaw areas. Panoramic radiography is the method most commonly used to evaluate bone height.

Bone height is measured from the crest of the edentulous ridge to anatomic landmarks. The maxillary sinus and mandibular canal restrict bone height.

Generally, the prognosis for the implant improves as the implant's length increases. However, implant lengths exceeding 13 to 14 mm currently are not recommended. Implants less than 8 mm in length belong to the short implant category; the prognosis for these implants is less favorable than that for long implants. Therefore, if bone height is 8 to 14 mm and no impingement is made on anatomic structures, the condition is ideal for implant placement.

It should be noted that a distance of at least 2 mm should exist between the apex of the implant and the roof of the mandibular canal. However, contact of the apex of the implant with the floor of the maxillary sinus or its perforation does not cause problems if the mucous membrane of the sinus is not ruptured.

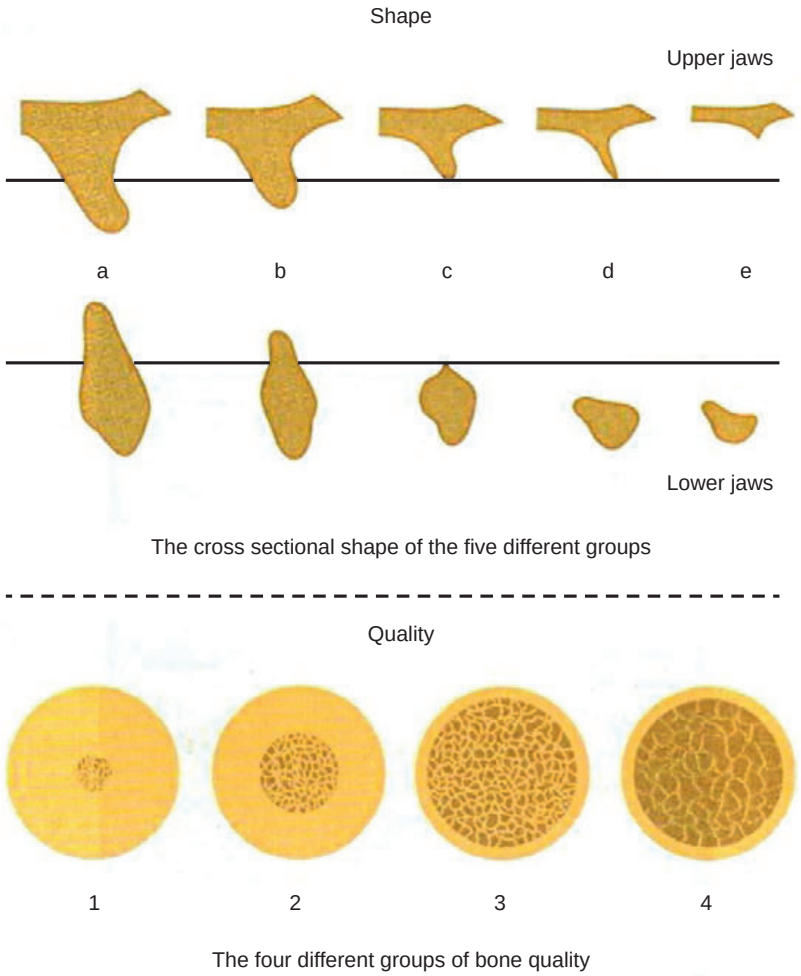

Figure 3-1 Classification of the quality and quantity of jaw bone. (From Lekholm U, Zarb GA: Patient selection and preparation. In Brånemark PI, Zarb GA, Albrektsson T, editors: *Tissue integrated prostheses: osseointegration in clinical dentistry,* Chicago, 1985, Quintessence.)

Another important factor, which is crucial to the longevity of the implant, is bone width. Implants with a diameter of 4 mm require a minimum of 6 mm of bone width; with a bone width of 7 mm, the long-term prognosis is much better. If thick implants with a diameter of 5 mm are to be used, a bone diameter of 7 to 8 mm is required.

If the remaining bone in the buccal aspect of the implant is less than 1 mm, the area should be reinforced with the guided bone regeneration (GBR) technique. This is more important in the anterior areas of the maxilla, because a thin buccal bone in this area leads to resorption of bone and subsequent gingival recession and exposure of the metallic margin of the implant, compromising the patient's esthetic appearance. To prevent such problems, all surgeries for single implants in the anterior area of the maxilla should be augmented with bone.[2]

SOFT TISSUE CONSIDERATIONS

Similar to bone, which is an important determining factor for the long-term maintenance and success of an implant, keratinized soft tissue around the implant can play an important role in the longevity of the implant and in prevention of peri-implantitis. Considerable research has been dedicated to this issue. Some studies have shown that implants are durable even without keratinized gingiva, and no problems are encountered. Other studies have emphasized that attached keratinized gingiva is favorable and in fact necessary for implants.[3] Therefore, to prevent subsequent problems, the logical course is to provide an environment for implant placement in which sufficient keratinized gingiva is present. This environment can be provided during implant placement or subsequent to it. Some advantages of

keratinized gingiva around implants are noted in Box 3-1.

During treatment planning for placement of implants, the presence of attached keratinized gingiva, which is very important, should be taken into account. This gingiva should be reconstructed during implant placement or after it if no keratinized gingiva is present. It has been empirically shown that at least 2 mm of attached keratinized gingiva around an implant is sufficient, and the prognosis improves with an increase to more than 2 mm. However, some authors believe that the need for keratinized gingiva is patient specific.[4] Therefore, during treatment planning, the amount of attached keratinized gingiva can be measured. If insufficient keratinized gingiva is present, measures can be taken to provide it. If sufficient keratinized gingiva is present, plans should be made so that this gingiva is located in its proper place around the implant.

The techniques commonly used to provide attached keratinized gingiva around implants are the apically positioned flap, the free gingival graft, and the free connective tissue graft.

Box 3-1 Advantages of Keratinized Gingiva Around Implants

- Keratinized gingiva stabilizes the crestal bone around the implant.
- The patient can control plaque more easily.
- The possibility of gingival recession and compromise of esthetic criteria decreases.
- The dental practitioner can easily take impressions.
- With an increase in gingival thickness, metallic surfaces are less likely to be visible.

APICALLY POSITIONED FLAP

The apically positioned flap is commonly used in the maxilla, because the palate is predominantly covered with keratinized gingiva. When attached gingiva on the buccal aspect of the implant is insufficient, a palatally inclined incision can be used to direct some keratinized gingiva from the palatal side to the buccal side. In the mandible, if the amount of keratinized gingiva is sufficient on the lingual aspect, the same procedure can be carried out (Figure 3-2).

FREE GINGIVAL GRAFT

The free gingival graft was introduced by Bjorn in 1963. For this graft, a split-thickness flap is made in the recipient site at the mucogingival junction (MGL). The periosteum is preserved on the bone, and a segment of the keratinized mucous membrane, approximately the size of the recipient site, is removed from the palatal mucosa or the edentulous ridge and placed in the recipient site (Figure 3-3). The success of this technique has been reported to be very high in the attached keratinized gingiva.

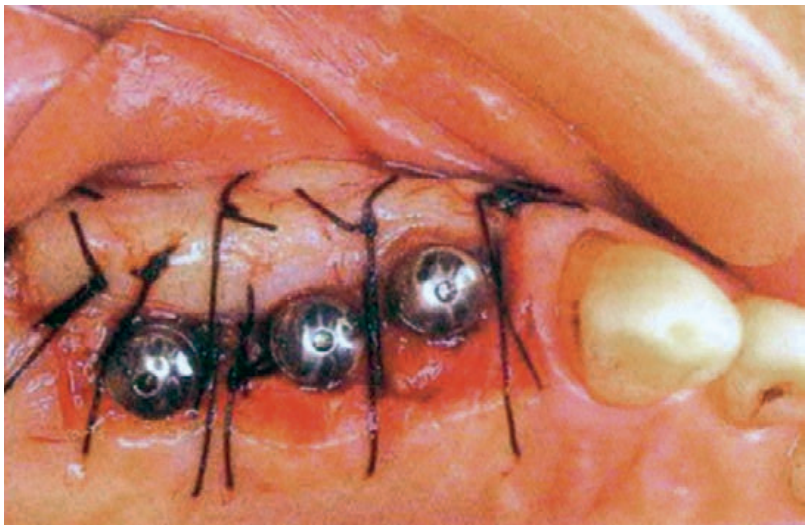

Figure 3-2 Clinical view of implant exposure with movement of palatal flap to buccal site.

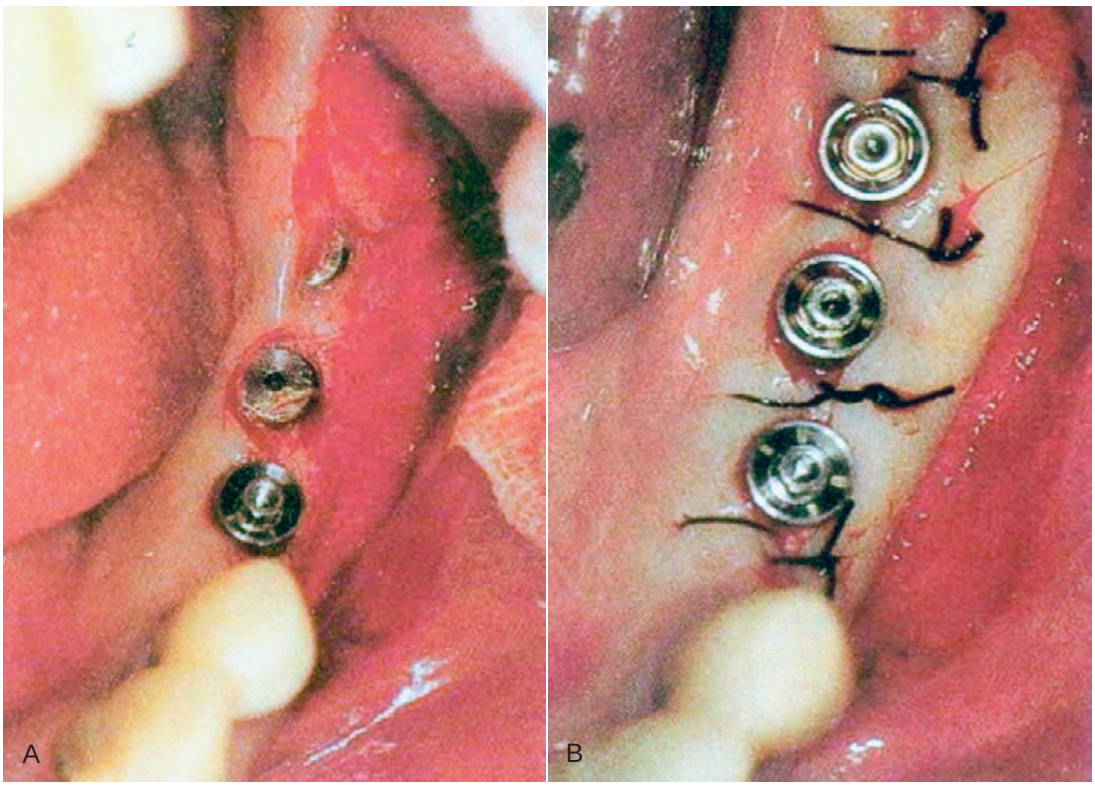

Figure 3-3 **A,** Clinical view of buccal site of implants that has been prepared as a recipient site for a free gingival graft. **B,** Suturing of free gingival graft in recipient site.

FREE CONNECTIVE TISSUE GRAFT

The free connective tissue graft, which is commonly removed from the palate, not only is used to provide attached keratinized gingiva, but also can be used to treat ridge defects. According to a classification system proposed by Seibert, ridge defects are divided into three classes. In class I defects, tissue is lost in the buccolingual dimension; in class II defects, it is lost in the apicocoronal dimension; and in class III defects, both dimensions are involved. Connective tissue can be used as either free or pedicled. Because this technique provides a better gingival color in the recipient area, its use has been recommended in the esthetic zone. To make the graft, a rectangular window is created in the palate; then, a sharp incision is made to elevate a maximum amount of supraperiosteal connective tissue from the palate. The connective tissue graft is placed and sutured in the recipient site of the subepithelial area. Different techniques are used for a connective tissue graft in the attached keratinized gingiva; these are comprehensively explained in reference books.

IMPLANT CONFIGURATION

In a general classification, implants are divided into two groups, bone-level implants and tissue-level implants.

BONE-LEVEL IMPLANTS

With bone-level implants, the platform is placed at the level of the jaw bones. These implants are used in the regions of the esthetic zone; they are placed deep into bone so that no metallic surfaces are visible (Figure 3-4). Current changes in implant surfaces and microthreads on the upper areas adjacent to the bone have resulted in assumptions that crestal bone may be more stable (Figure 3-5).

TISSUE-LEVEL IMPLANTS

Tissue-level implants usually have a collar with a smooth titanium surface (Figure 3-6). The platforms of the implants are usually located 1.5 to 3 mm above the bone level, and the titanium

Figure 3-4 Two types of bone-level implants.

Figure 3-6 Two types of tissue-level implants.

Figure 3-5 Implant with microthreads on top.

collar is a proper location for the attachment of the gingival soft tissue. An advantage of these implants is a decrease in resorption of bone at the crest, because formation of the biologic width does not require resorption of the crestal bone. A disadvantage of these implants is the visibility of the metallic collar of the implant, resulting in an unesthetic appearance when the gingival tissue is thin. However, because the posterior regions of both arches are not located in the esthetic zone and are not visible during speaking and smiling, these implants can be used in the nonesthetic zone.

Another advantage of tissue-level implants is that they can be placed with single-stage surgery, without any need for a second surgical procedure. This provides the peri-implant soft tissues with more time and opportunity for growth, development, and stability.

To summarize, bone-level implants can be used in both the esthetic and nonesthetic zones, but tissue-level implants can be used only in the nonesthetic zone.

In another classification system, implants are divided into parallel implants and conical implants. Parallel implants are cylindrical (Figure 3-7), and conical implants resemble tooth roots (Figure 3-8). Conical implants are thought to have firmer retention in bone and greater stability during surgery; this is more important and evident when type III or type IV weak bone is involved. Therefore, when immediate restoration is planned, these implants are both preferable and recommended. A review of the literature does not reveal significant differences in the success rates and longevity of these two implant types; they can be used interchangeably.

Figure 3-7 Parallel wall implant.

Figure 3-8 Conical implant.

SURGICAL TECHNIQUE FOR SINGLE IMPLANTS

Surgical techniques for single implants in different parts of the oral cavity are broadly divided into implant surgery in the esthetic zone and implant surgery in the nonesthetic zone.

SINGLE IMPLANT SURGERY IN THE ESTHETIC ZONE

After necessary analysis of the region to undergo implant surgery, taking into account osseous and soft tissue considerations, the patient is ready for implant surgery.

As described previously, the esthetic zone consists of the central, lateral, canine, and first premolar areas of the maxilla. The remaining mandibular and maxillary areas are not included in the esthetic zone.

Before performing implant surgery, the dental surgeon must consider three important questions:

1. Will the implant surgery be immediate?
2. If the tooth has already been extracted, how long has it been since the extraction?
3. Are any bony defects present in the area? If so, is the defect vertical, horizontal, or both?

Immediate Implant Surgery Without Flaps

If the tooth in question should be extracted because of endodontic problems or root fractures, immediate implant surgery can be carried out without any flaps if the following clinical characteristics are noted:

- Single-rooted tooth
- Healthy systemic condition
- Nonsmoking patient
- Low lip line
- Thick gingival biotype
- Intact and thick facial bones
- No acute infection
- Good vertical level at adjacent teeth

Surgical Technique

The tooth is removed with a periotome, and the buccal wall is inspected to make sure it is intact. Osteotomy then is carried out on the palatal wall of the socket to prepare the implant site. During the drilling procedure, care should be exercised to ensure that the implant is appropriately placed in its three-dimensional path.

A proper implant site in the esthetic zone has the following characteristics:

- The implant platform is 3 to 4 mm apical to the cementoenamel junction (CEJ) of the two adjacent teeth (Figure 3-9).

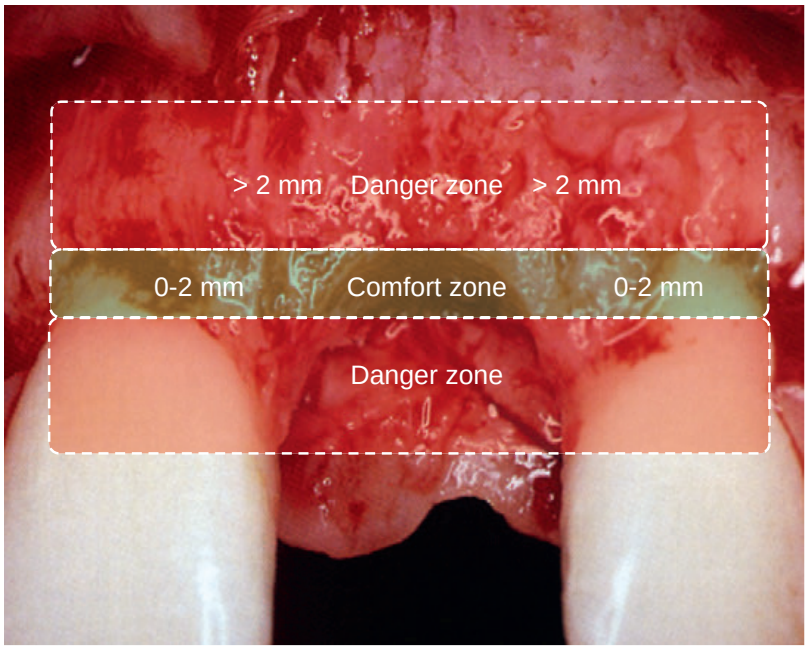

Figure 3-9 Outline of comfort and danger zones in the vertical dimension.

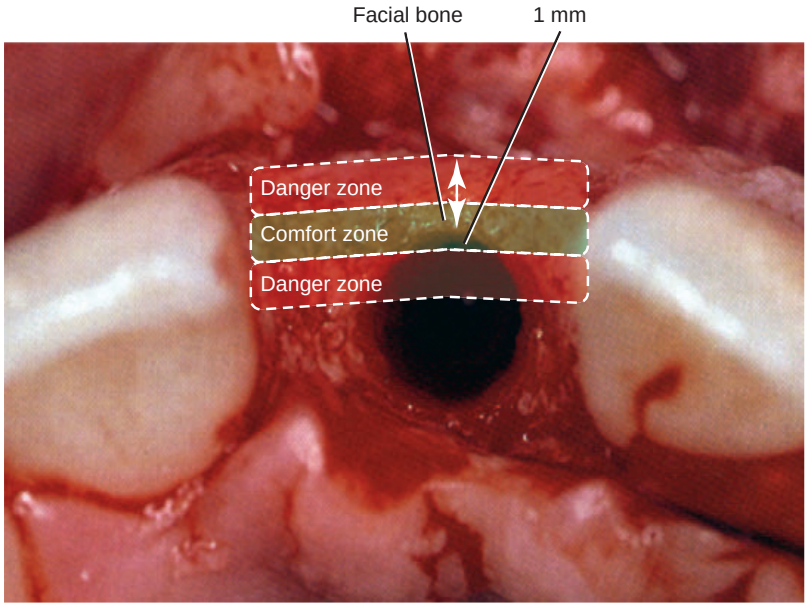

Figure 3-10 Outline of the comfort zone in the horizontal dimension. The comfort zone is the correct area for positioning of the implant platform in the horizontal dimension; the danger zone is the incorrect area for positioning of the implant platform.

- The implant platform is 1 to 2 mm palatal to the profile of the two adjacent teeth (Figure 3-10).
- The implant platform is placed in the bone so that it is 1.5 mm from the adjacent teeth (Figure 3-11).

After the implant has been properly placed, the empty space between the implant and the buccal bone should be filled with autogenous bone or other bone-filling materials to support the buccal osseous plate; this minimizes secondary resorption of the buccal bone. At this stage, if the insertion

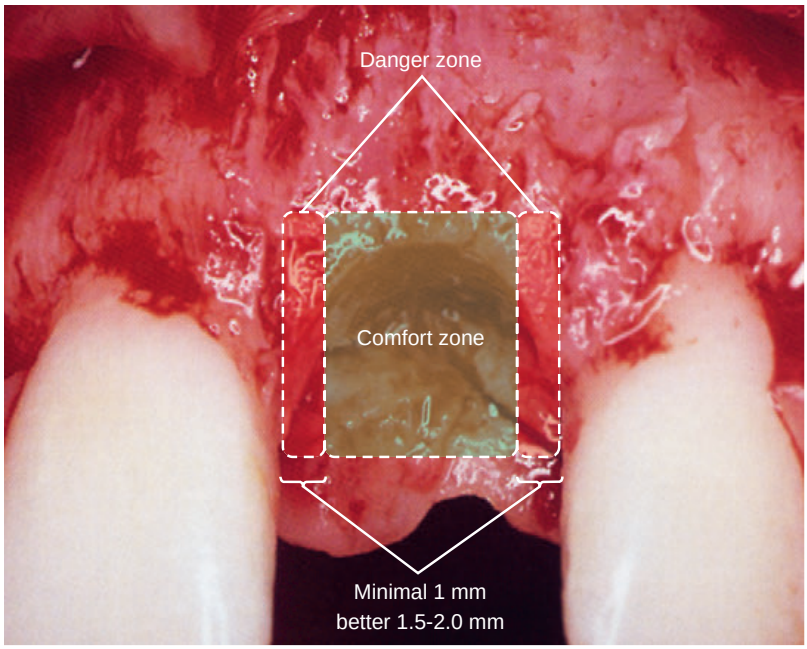

Figure 3-11 Outline of the comfort zone in the mesiodistal dimension. The comfort zone is the correct area for positioning of the implant platform in the mesiodistal dimension; the danger zone is the incorrect area for positioning of the implant platform.

torque value is at least 35 N, the implant can be placed and a provisional prosthesis can be manufactured to support and preserve the soft tissue position in the area. Otherwise, the implant should be submerged, the second surgical procedure should be performed, and the prosthesis should be manufactured at the proper time (Figure 3-12).

If the conditions that warrant surgery without flaps are not present, a flap surgical procedure should be performed. A mucoperiosteal flap is elevated so that the tooth can be removed less aggressively. The implant then is properly placed by observing the three-dimensional implant path. If the buccal bone requires reconstruction and reinforcement through the GBR technique, the necessary procedures are carried out, with proper attention to all relevant surgical principles. The implant is submerged for 3 to 4 months to better preserve the graft; then, the second surgical procedure is carried out, and the prosthesis is manufactured (Figure 3-13).

Implant Placement 6 to 8 Weeks After Tooth Extraction

Placement of an implant 6 to 8 weeks after extraction of the tooth has the following advantages:

- It increases the amount of keratinized gingiva at the implant site without displacing the mucogingival junction.
- It eliminates acute and chronic infections in the extraction socket.
- It preserves the crest width in the interproximal area of the extraction site after 6 to 8 weeks.

The disadvantage of this procedure is that after implant placement, the facial bone is very thin and requires a GBR procedure.

The procedure is advocated in the esthetic zone, because the risk of bone resorption is much less than with the immediate technique. It is advisable for premolar areas but is not recommended for molar areas.

Surgical Technique

The implant is placed in proper position after evaluation of a mucoperiosteal flap, which may also have vertical releasing incisions. The buccal bone should be reinforced, using the GBR technique, to prevent secondary bone resorption, and the implant then can be submerged. After 3 to 4 months, a second surgical procedure is performed, and the final prosthesis is manufactured.

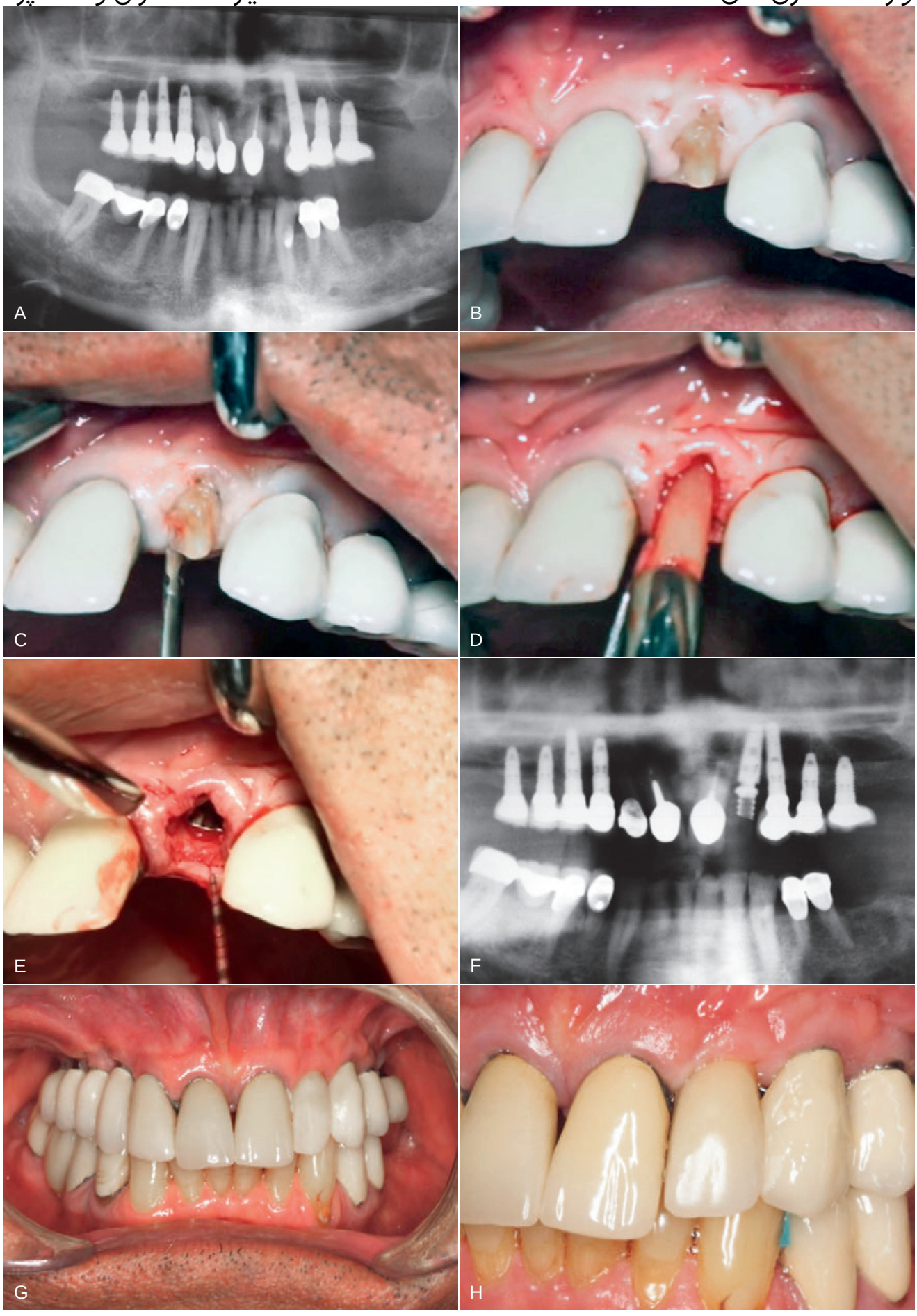

Figure 3-12 **A,** Radiographic view of the maxillary left lateral incisor. **B,** Clinical view of the same tooth as in **A. C** to **E,** Atraumatic extraction of the tooth using a periotome. **F,** Radiographic view of implant placement in correct three-dimensional position. **G** and **H,** Immediate provisional prosthesis.

During surgery, if the buccal bone has adequate thickness (approximately 1 mm); if the patient has a thick gingival biotype; and if the prosthesis is fixed in place with an insertion torque of at least 35 N, the healing abutment or main abutment can be placed for manufacture of a provisional prosthesis (Figure 3-14).

Implant Placement 12 to 16 Weeks After Tooth Extraction

Twelve to 16 weeks after extraction of a tooth, the hard tissues in the socket and the soft tissues are completely mature and bone resorption is expected in the vertical and horizontal dimensions. Placement of an implant in such cases is carried out in the esthetic zone only when uncertainty exists over whether the implant would be sufficiently stable in the site 8 weeks after tooth extraction. The surgical procedure is postponed so that the bone further matures to achieve implant stability during surgery.

This procedure is advocated in patients with extensive periapical or periodontal lesions. It also is advisable for mandibular and maxillary molar areas, because these areas have sufficient buccolingual width, and a minimum of 8 mm of bone can be guaranteed in the horizontal dimension even after tooth extraction—a necessity for placement of an implant in these areas.

SINGLE IMPLANT SURGERY IN THE NONESTHETIC ZONE

Single implant surgery in the nonesthetic zone can be classified as single implant surgery in the

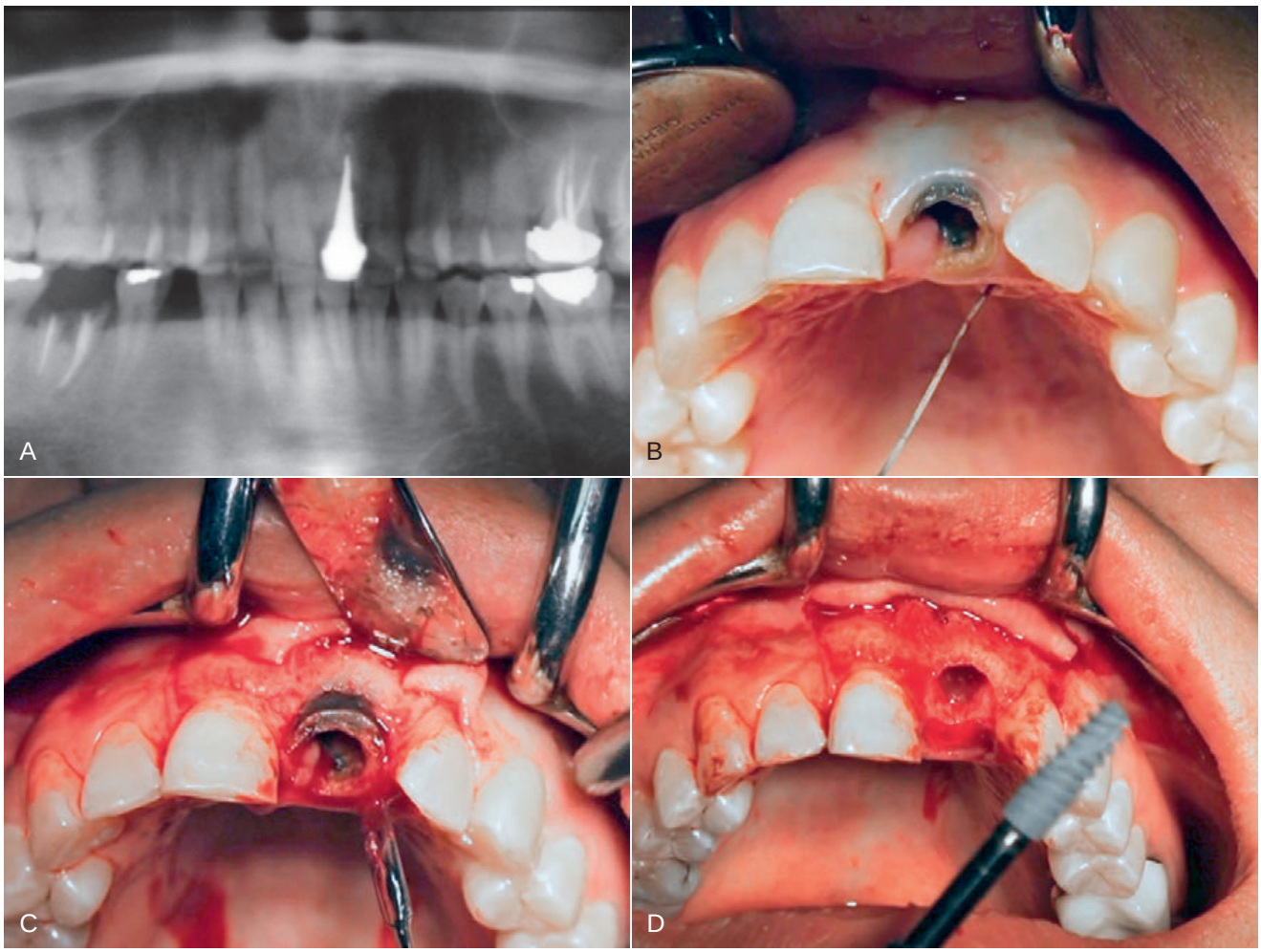

Figure 3-13 **A,** Radiographic view of the maxillary left central incisor. **B,** Clinical view of the same tooth as in **A. C,** After mucoperiosteal flap. **D,** After extraction and site preparation.

Continued

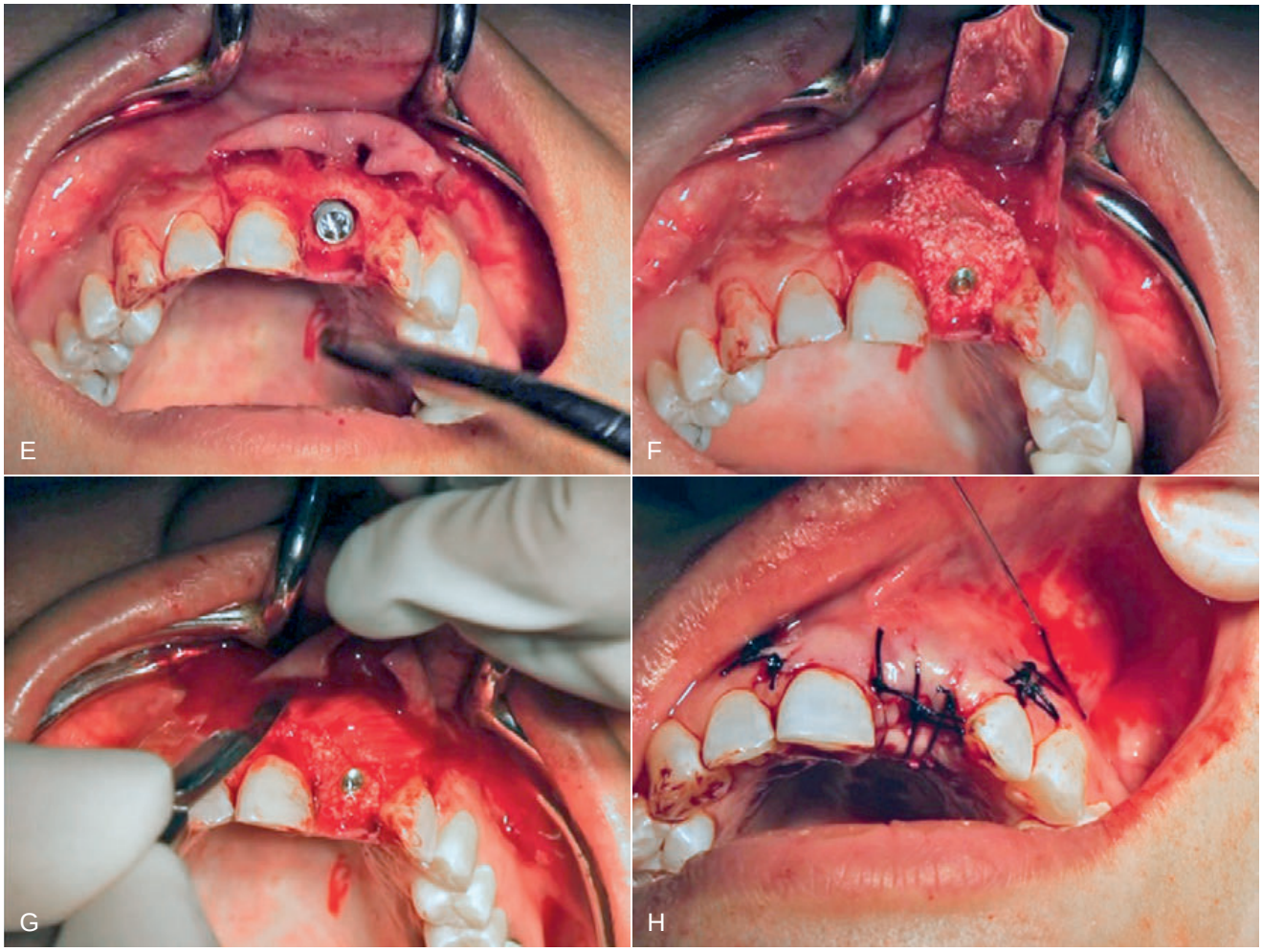

Figure 3-13, cont'd **E,** Implant placement in correct three-dimensional position. **F** and **G,** Guided bone regeneration (GBR) technique with particulate bone graft and collagen membrane. **H,** Suturing and implant submerged.

posterior maxilla, single implant surgery in the posterior mandible, or single implant surgery in the anterior mandible.

The first molars of both arches are the first permanent teeth to erupt into the oral cavity. They play an important role in the growth and development of the dental arch and occlusion. These teeth are prone to caries and trauma, and they are extracted earlier than other teeth in adult life. They can be replaced by removable partial dentures, fixed prostheses, and implant-supported fixed prostheses. Because the longevity of fixed prostheses is almost 10 years, based on existing data,[5] dental practitioners and patients prefer implants to replace these teeth.

Single Implant Surgery in the Posterior Maxilla

Single implants are usually used to replace single teeth up to the first molars; when the mandibular second molar is present, reconstruction of the maxillary second molar is also recommended.

The following factors should be taken into account when replacing single teeth in the posterior maxilla:

- The mesiodistal width of the edentulous area
- The distance between the alveolar crest and the floor of the maxillary sinus
- The buccolingual dimension of the bone

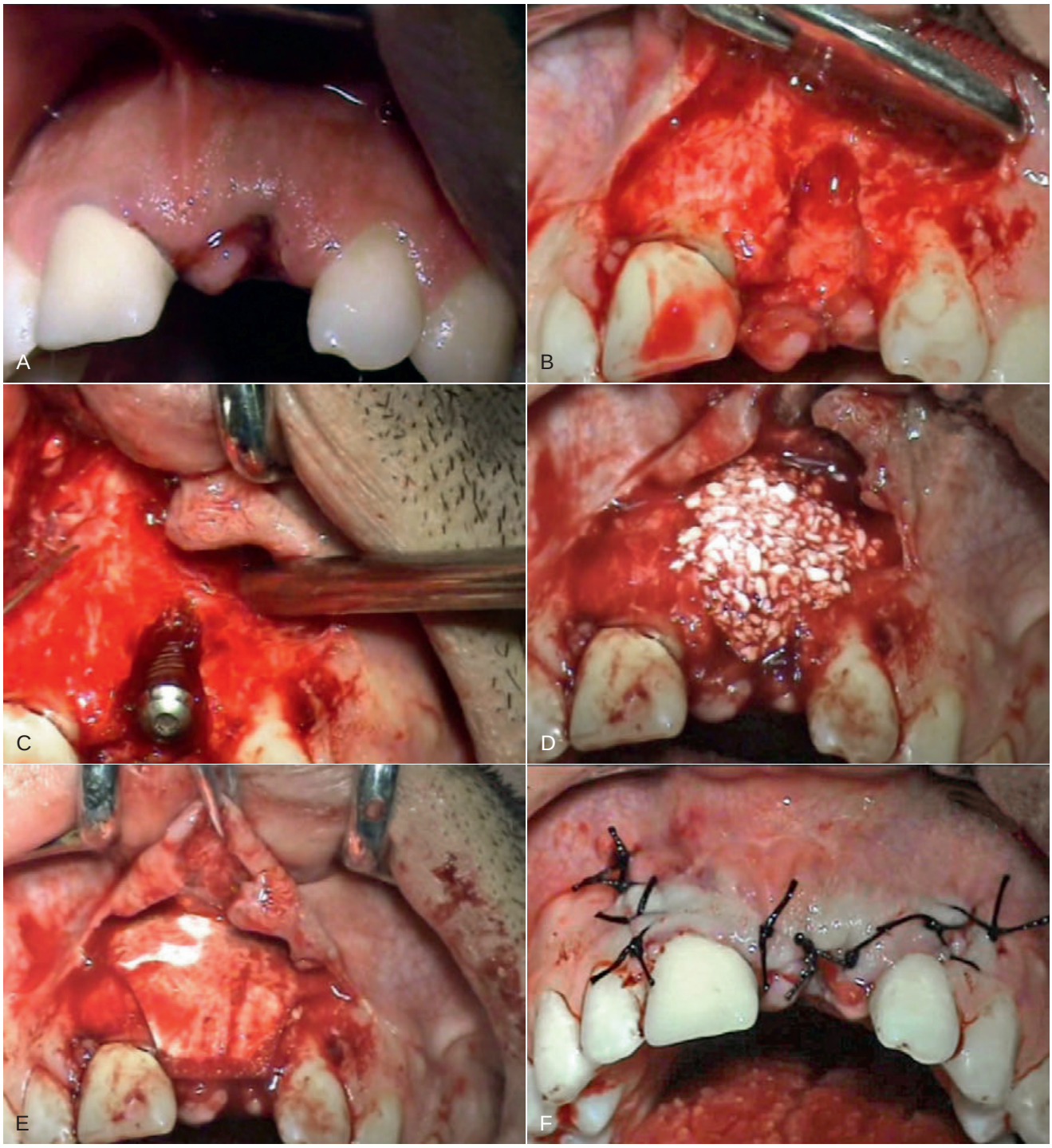

Figure 3-14 **A,** Clinical view of central incisor 8 weeks after extraction. **B,** Mucoperiosteal flap and site preparation for implant placement. **C,** Implant placement; note large dehiscence defect. **D** and **E,** Guided bone regeneration (GBR) with particulate bone graft and collagen membrane. **F,** Suturing and implant submerged.

Large-diameter implants should be used to form an appropriate and molarlike occlusal table when reconstructing first and second molars. In most implant systems, the diameter of wide implants is approximately 5 mm; therefore, at least a buccolingual dimension of 8 mm is required to place such implants. In addition, a mesiodistal width of 10 mm is required to reconstruct a crown similar to the crown of a permanent molar.

Currently, the minimum required implant length is 8 mm; therefore, to place such an implant, a distance of 8 mm is required between the alveolar crest and the floor of the maxillary sinus in the first molar areas. If insufficient bone is available in the area sinus, reconstruction techniques can be used to provide the minimum amount of bone necessary. Based on the references available, if the distance between the alveolar crest and the floor of the maxillary sinus is 5 mm, the dental practitioner can place the implant and perform the sinus-lifting surgery, using the osteotomy technique, in a single-stage procedure. If the distance is less than 5 mm, the procedure should be carried out in two stages. First, the sinus is reconstructed using the "window" technique; then, the implant is placed.

A factor that can jeopardize implant surgery in this area is the quality of bone, which declines in moving toward the posterior maxilla. In such situations, achieving primary implant stability requires the expertise of a surgeon skilled in the use of conical implants. The practitioner should wait 12 to 16 weeks before initiating prosthetic procedures.

Single Implant Surgery in the Posterior Mandible

Similar to the maxillary first molar, the mandibular first molar is lost early and can be reconstructed by an implant. The mandibular first and second premolar and second molar can also be replaced by implants. Various studies have shown that posterior single implants have a success rate of more than 95% over 10 years.[6]

The following factors should be considered in the posterior mandible for reconstruction of single teeth:

- The mesiodistal dimension of the edentulous area
- The distance between the alveolar crest and the mandibular canal
- The buccolingual dimension of the bone

In numerous cases in which the tooth was extracted many years earlier (e.g., the first molar), the second molar moves toward the edentulous space, reducing the mesiodistal width of the edentulous space (Figure 3-15). In these patients, if an implant is placed, the space distal to the implant and the space mesial to the posterior tooth trap food and plaque, resulting in subsequent problems. In such situations the minor tooth

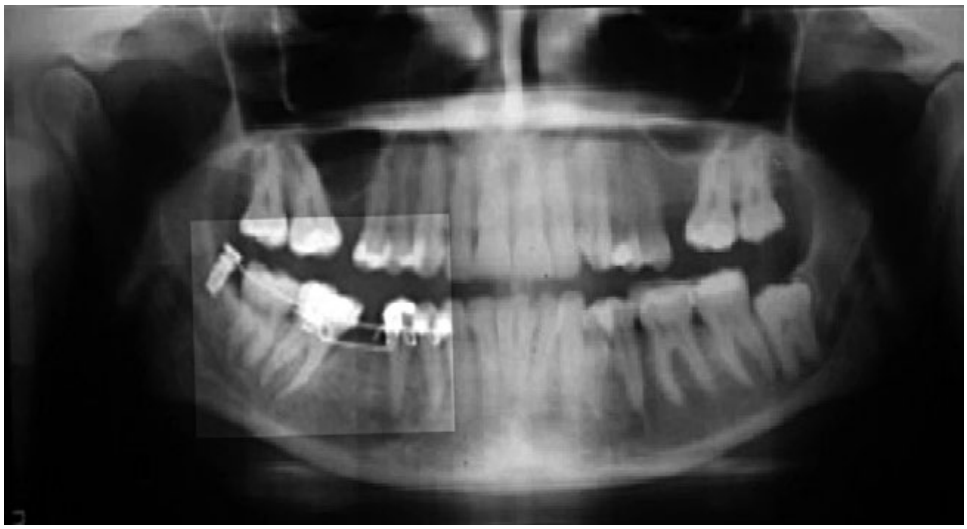

Figure 3-15 Radiographic view of minor tooth movement.

movement technique should be used to correct the problem, manage the space, and carry out the implant surgery. As discussed for the maxillary molars, the optimal mesiodistal width of the edentulous space for reconstruction of molars is 10 mm so that an occlusal surface similar to that of permanent molars can be reconstructed.

Another important consideration in implant surgery is the mandibular canal; inattention to it results in irreparable damage.

In the treatment plan, it is very important to determine the distance between the alveolar crest and the roof of the mandibular canal. This distance is determined using accurate diagnostic tools, such as a computed tomography (CT) scan. To prevent impingement on the mandibular canal, the dental practitioner should establish a safety margin of 2 mm from the canal. For example, if the distance between the alveolar crest and the mandibular canal is 14 mm, the implant placed in the area should not exceed 12 mm. A distance of 2 mm between the implant and the mandibular canal is an absolute necessity. If the distance between the alveolar crest and the mandibular canal is approximately 10 mm, an implant 8 mm long can be used. If the distance is less than 10 mm, no implant should be placed in that area; or, if the mandibular bone has undergone resorption, a vertical construction procedure should be performed.

Another surgical technique in such cases is nerve transposition, in which the inferior alveolar nerve is removed from the canal and then replaced in the canal after implant placement. Studies have shown that these procedures result in temporary anesthesia (and in some cases, permanent anesthesia) of the lower lip; therefore, this technique is not recommended.[7]

The recommended buccolingual dimensions of bone for wide and regular implants are 8 and 7 mm, respectively.

Generally, the immediate implant technique is not recommended for replacement of molars in both arches, because the position of the roots reduces the odds of placing implants in prosthetic-driven areas, resulting in subsequent prosthetic problems such as malposition of the implant, which will complicate restoring the implant. In such cases, implant surgery should be carried out 12 to 16 weeks after tooth extraction. However, this does not hold for premolars. If the position of the maxillary sinuses and the mandibular canal allows, the immediate implant technique can be used to replace premolars.

Another consideration during placement of single implants in posterior areas is management of the edentulous space. If the mesiodistal dimension of the edentulous area is 8 to 12 mm, a wide implant should be placed. If this dimension is 14 mm and an ideal space cannot be created by minor tooth movement, two regular implants, each with a diameter of 4 mm, can be used instead of one wide implant. In such cases care should be taken to provide a distance of 3 mm between the two implants and a distance of 1.5 mm between the implant and a natural tooth.

Single Implant Surgery in the Anterior Mandible

Placement of single implants in the central and lateral areas of the mandible is among the more difficult single implant surgeries. The mesiodistal dimension of the area is 5 mm at most, and the buccolingual dimension also is minimal; this poses a risk of damage to adjacent teeth and to the buccal and lingual bony plates, as well as the creation of dehiscence, during surgery. Use of narrow implants in this area is inevitable. Narrow implants have a diameter of 3 to 3.5 mm. Even if implants with a diameter of 3 mm are used and the mesiodistal dimension of the edentulous area is 5 mm, the distance between the implant and the adjacent tooth is 1 mm at most; this thin bone is always prone to resorption. Therefore, single implants should not be used to replace mandibular incisors; other techniques should be used. However, this is not the case with mandibular canines; given the anatomy of the area, if these teeth are lost, regular implants can easily be used to replace them.

LONG-TERM PROGNOSIS

The following studies have found that single implant placement in different areas has a very good prognosis.

- In 2012 Degidi et al.[8] performed a retrospective study to assess the long-term buccal bone

plate changes in cases of single implants in the maxillary esthetic zone that were placed and restored immediately after extraction. In 12 patients who met the inclusion and exclusion criteria and agreed to follow-up, one implant failed because of severe peri-implantitis. The remaining 11 patients had cone beam computed tomography (CBCT) scans after a minimum of 7 years. Buccal bone plate measurements were carried out on CT and CBCT Dicom images and by in vivo records. The researchers concluded that the buccal bone plate of single implants placed and restored immediately after tooth extraction in the maxillary esthetic zone was subject to moderate vertical and horizontal resorption 7 years after surgery.

- Another investigation by Degidi et al.[9] in 2012 assessed the 10-year performance of TiUnite implants supporting fixed prostheses placed with an immediate loading approach in both postextraction and healed sites. Success and survival rates for restorations and implants, changes in marginal peri-implant bone levels, probing depth measurements, biologic or technical complications, and any other adverse events were recorded yearly for up to 10 years after surgery. Five of 210 implants (2.38%) were lost. Statistical analysis revealed that the implants placed in healed and postextraction sites achieved 98.05% and 96.52% cumulative survival rates, respectively.
- In 2012 Dierens et al.[10] retrospectively evaluated the survival and radiographic and peri-implant outcomes of single turned Brånemark implants after at least 16 years. Of 134 patients, 101 could be contacted about implant survival and 50 were clinically examined. Marginal bone level was radiographically measured from the implant-abutment junction at baseline and from 1 to 4, 5 to 8, and 16 to 22 years postoperatively. Probing depth and gingival and plaque indexes were measured. Thirteen of 166 implants in 11 of 134 patients failed. These researchers concluded that the single turned Brånemark implant is a predictable solution with high clinical survival and success rates. In general, a steady-state bone level can be expected over decades, with minimal signs of peri-implant disease. A minority (5%), however, presents with progressive bone loss.
- In 2011 Andersson et al.,[11] in a 17- to 19-year follow-up study, evaluated long-term function of single implant restorations. They also assessed the relationship between implant infraposition, the shape of the face, and patients' satisfaction. A total of 47 implants failed (an 18-year cumulative survival rate [CSR] of 96.8%), and eight original single crown restorations were replaced (CSR, 83.8%). About 40% of the patients showed signs of infraposition, similar in younger and older age groups but more frequently observed in females. The authors concluded that single implant restorations in the anterior upper jaw may present small degrees of infraposition in the long term, but patients seemed to pay less attention to the degree of infraposition in their esthetic assessments, compared with most of the clinicians.
- In 2011 Vozza et al.[12] compared endodontic and implant treatments to evaluate their predictability over an 8-year period. A group of 40 partially edentulous patients were selected for this study. Their teeth had been endodontically treated and rehabilitated using gold alloy and ceramic restorations. In these patients, 65 osseointegrated implants were restored with single gold alloy–ceramic crowns and monitored on a yearly basis for 8 years with standardized periapical radiographs. A total of nine patients who did not attend the yearly follow-up were excluded from the study. During the follow-up of the endodontically treated elements, seven failures were detected (83.34%), and the success rate of implants inserted in the same patients was 80.8%, with nine implants lost in 8 years. The authors noted that, in view of the superimposable results between the two therapies, the endodontically treated teeth could be influenced by different pathologic conditions, whereas the restoration of the atrophic edentulous ridge with an implant support is predictable when patients perform correct oral hygiene and when the occlusal loads are axially distributed in implant-protected occlusion.
- In 2010 Krennmair et al.[13] evaluated the long-term survival and success rates of

screw-type, root-shaped (Camlog) implants of various diameters and their implant-prosthodontic reconstructions for more than 5 years of clinical use. The cumulative implant survival, success rates, peri-implant conditions (marginal bone loss, pocket depth, plaque index, gingival index, bleeding index), and prosthodontic maintenance requirements were evaluated. Statistical analysis revealed that the overall cumulative 5-year survival and success rates were 98.3% and 97.3%, respectively. Prosthodontic maintenance needs for implants were classified as successful. The average peri-implant marginal bone resorption value was 1.8 (± 0.4) mm, with no differences between the different implant diameters evaluated. Peri-implant soft tissue conditions (e.g., plaque, bleeding, and pocket depth) were also satisfactory. All the prostheses were functional throughout the observation period, with no fractures of implants, abutments, or screws. For single tooth restorations requiring recementation, retightening of screws, and adaptation of removable prostheses, loosening of abutment screws (4.5%) and isolated crown loosening (9.8%) were the most frequent prosthodontic maintenance needs.

- In 2010 Koo et al.[14] studied the 1- to 5-year CSR for single implants placed in the second molar region and the effects of associated factors. The study included 489 patients who were treated with single implants in the second molar region. A 1- to 5-year CSR was calculated using a life-table analysis. A comparison was made of CSRs for maxillary and mandibular implants, one-stage and two-stage implants, short and long implants, and standard-diameter and wide-diameter implants. The 1- to 5-year CSR was 95.1%. Within the limitations of the study, the placement of single implants in the second molar region was an effective and reliable treatment modality. In addition, the authors found that associated factors, such as implant diameter, length, and location (the maxilla versus the mandible), may not affect the long-term success of implants.
- In 2010 Kim et al.[15] evaluated the short- and mid-term prognosis for maxillary and mandibular single molar implants, including prosthetic complications and factors mediating the effects seen on them. Eighty-seven patients were enrolled consecutively in the study, and 96 implants were placed into a single molar defect site. Primary osseointegration failure developed in two implants, and delayed implant failure occurred in four implants. The surviving interval was 97% to 100%; at the last follow-up observation, the CSR was 91.1%. Prosthetic complications showed a significant correlation with the mesiodistal cantilever. Based on the results, the risk of failure for single molar implants was high, and the possibility of prosthetic complications during loading was also high. To minimize the cantilever, implants must be placed precisely, followed carefully, and maintained for a long period.

SUMMARY

This chapter briefly covers surgical considerations, advantages, and limitations of surgeries for single implants in different areas of the oral cavity in an attempt to provide a brief guide for the readers.

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CHAPTER 4

Bone Physiology, Metabolism, and Biomechanics in Implant Therapy

W. Eugene Roberts, Clark M. Stanford

Chapter Outline

Osteology of the Maxilla and Mandible
Bone Physiology
Bone Tissue Responses to Dental Implant Placement
- Woven Bone
- Lamellar Bone
- Composite Bone
- Bundle Bone

Skeletal Adaptation: Modeling and Remodeling
- Cortical Bone Growth and Maturation
- Basic Multicellular Unit and Cutting and Filling Cones

Dental Implants and Bone Responses
- Implant Macroretentive Features
- Implant Microretentive Features

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the specific types of bone structure in the maxilla and mandible and the impact of these structure types on dental implant therapy.
- Understand the ways osseous physiology and the types of unique bones in the skull influence the placement, timing of loading, and role of implant therapy, depending on the anatomic site of placement.
- Understand the complex role of bone turnover (remodeling) in maintaining a functional dental implant interface.
- Understand the role of implant surface design in the healing and remodeling processes around dental implants.

The success of dental implants fundamentally depends on the anatomy, structure, physiology, and biochemistry of alveolar bone and the way it heals and then remodels around a loaded prosthesis. The outcome of implant therapy depends on osseous site development that may require hard tissue augmentation with various bone graft materials. Once this has been achieved, the treatment outcome depends on the process of osseous healing (Figure 4-1). This chapter reviews the type of dental implant–associated bone encountered in oral implant tooth replacement therapy and discusses the role of inflammation, implant biomaterials, and the complex remodeling process that maintains the implant-bone interface over the life span of the patient.

OSTEOLOGY OF THE MAXILLA AND MANDIBLE

To understand the outcomes of implant therapy, the dental practitioner must understand the bone morphology (osteology) of the craniofacial complex. A frontal section of an adult skull shows

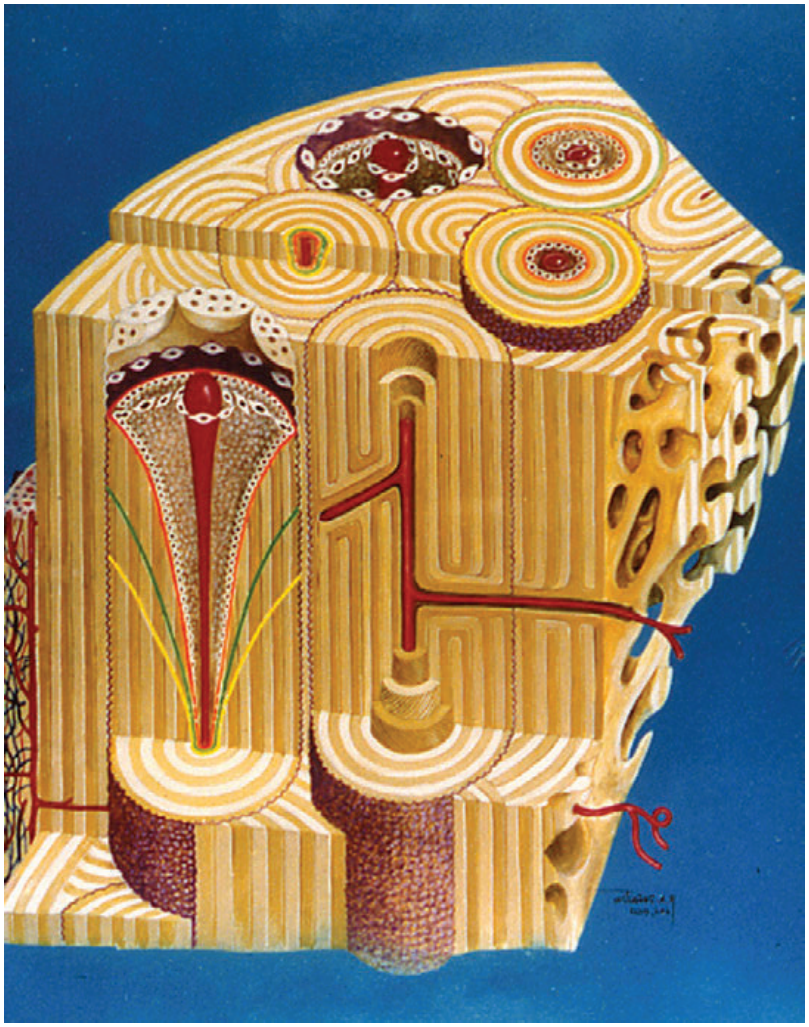

Figure 4-1 Dynamic principles of cortical bone remodeling. Remodeling is a vascularly mediated process of bone turnover that maintains the integrity of structural support and is a source of metabolic calcium. Osteoblasts are derived from preosteoblasts circulating in the blood, and perivascular mesenchymal cells give rise to osteoblasts. Note the three colored chevrons (yellow, green, and orange), which progressively mark the mineralization front of the evolving second osteon moving superiorly on the left. (From Roberts WE, Arbuckle GR, Simmons KE: What are the risk factors of osteoporosis?: assessing bone health, *J Am Dent Assoc* 122:59-61, 1991.)

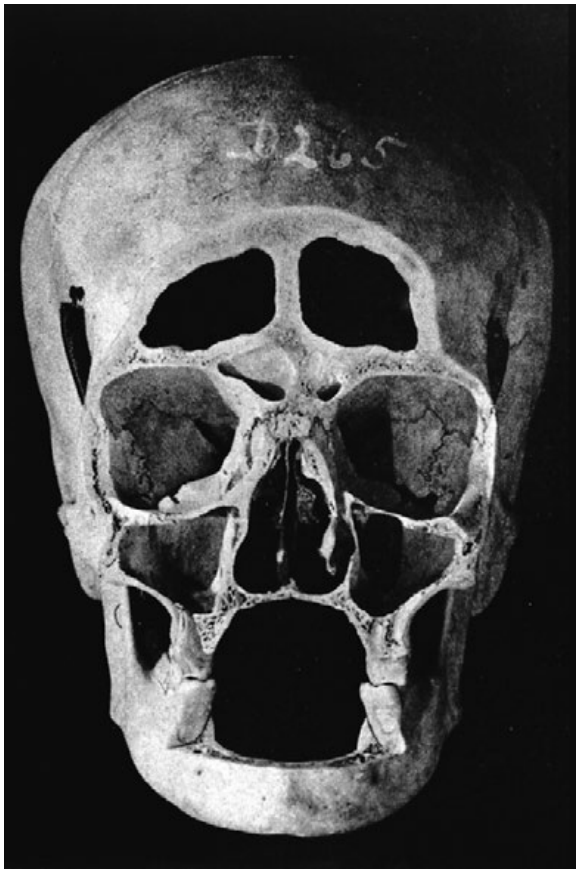

Figure 4-2 Frontal section of a human skull in the plane of the first molars. (From Atkinson SR: Balance: the magic word, *Am J Orthod* 50:189, 1964.)

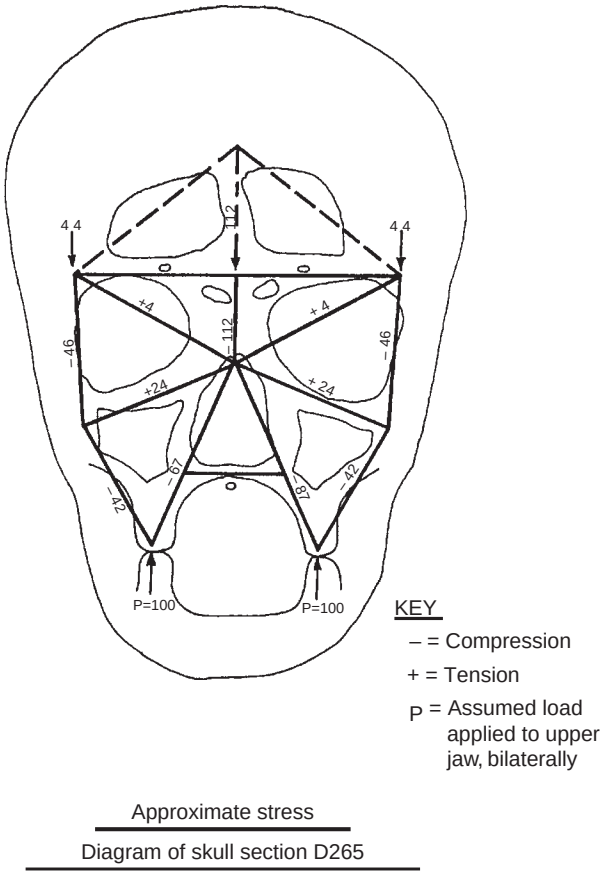

Figure 4-3 Two-dimensional vector analysis of stress in the frontal section of the human skull depicted in Figure 4-2. Relative to a bilateral biting force of 100 arbitrary units, the load is distributed to the vertical components of the midface as compressive (negative) stress. The horizontal structural components are loaded in tension. In a nongrowing individual, the stress across the midpalatal suture is zero. During mastication, loads increase and the midpalatal suture is subjected to a tensile load, resulting in an increase in maxillary width. (From Atkinson SR: Balance: the magic word, *Am J Orthod* 50:189, 1964.)

the bilateral symmetry of bone morphology and functional loading (Figures 4-2 and 4-3). As shown in Figure 4-3, the vertical components of the cranium tend to be loaded in compression (conveyed as a negative stress, by convention in engineering), and the horizontal components are loaded in tension (positive stress). This is one of the most efficient structures for achieving maximal compressive strength with minimal mass in a composite material.

As Figure 4-3 shows, no net tension exists across the palate in an adult. During the prenatal and early postnatal period, the palate grows in width through the posterior palatal synchondosis (primary growth center).[1] This is one important reason implant placement should be delayed until skeletal maturity has been reached. Otherwise, an implant becomes positioned too far from the palatal aspect of the occlusal plane.

Although equal and opposite functional loads are delivered to the maxilla and mandible, the maxilla transfers stress to the entire cranium, whereas the mandible absorbs the entire load. Consequently, the mandible is stiffer than the maxilla. A midsagittal section through the incisors (Figure 4-4) and a frontal section through the molar region (Figure 4-5) show the distinct differences in the osseous morphology of the maxilla and mandible. This should be carefully evaluated with regard to implant placement, because the type of bone contact and proximity to the cortical plates influence when the implants can be safely loaded.

The maxilla has relatively thin cortices interconnected by a network of trabeculae (see Figures

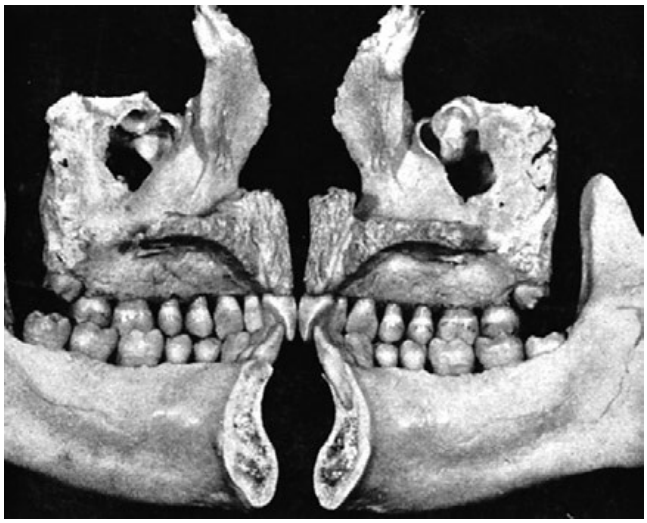

Figure 4-4 Midsagittal section of a human skull shows that the maxilla is composed primarily of trabecular (spongy) bone. The opposing mandible has thick cortices connected by relatively coarse trabeculae. (From Atkinson SR, Balance: the magic word, *Am J Orthod* 50:189, 1964.)

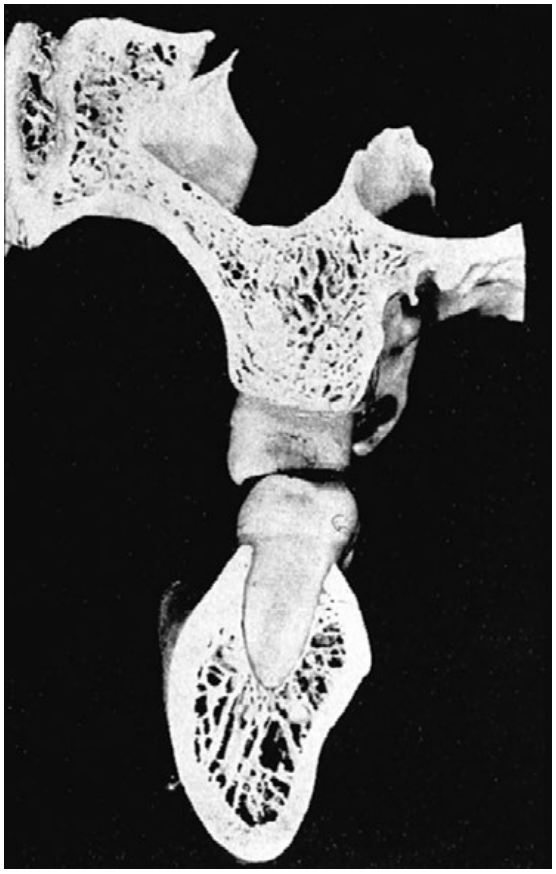

Figure 4-5 Frontal section of the maxilla and mandible in the plane of the first molars. Because it transmits masticatory loads to the entire cranium, the maxilla has thin cortices connected by relatively fine trabeculae. The mandible, however, is loaded in bending and torsion; it therefore is composed of thick cortical bone connected by coarse, oriented trabeculae. (From Atkinson SR: Balance: the magic word, *Am J Orthod* 50:189, 1964.)

4-2, 4-4, and 4-5). Because it is loaded primarily in compression, the maxilla is structurally similar to the body of a vertebra. The mandible, however, has thick cortices with radially oriented trabeculae (Figures 4-4 and 4-5). The structural array is similar to that for the shaft of a long bone, indicating that the mandible is loaded predominantly in bending and torsion. For this reason, mandibular flexure often influences implant prosthesis design. This biomechanical impression based on osteology is confirmed by in vivo strain gauge studies in monkeys. Hylander[2,3] demonstrated substantial bending and torsion in the body of the mandible associated with normal masticatory function (Figure 4-6). This is an important issue in implant treatment planning, because implant prostheses that cross the mandibular midline or extend into the molar area undergo torsional stress. This mechanical overload can lead to prosthesis fracture, material failure, and possibly implant or implant abutment fracture.

BONE PHYSIOLOGY

The physiology of bone has proven elusive for investigators because of the technical limitations inherent in the study of mineralized tissues. Accurate assessment of the response of bone to mastication requires time markers (bone labels) and physiologic indexes (e.g., deoxyribonucleic acid [DNA] labels, histochemistry, and in situ hybridization) of bone cell function. Systematic investigation with these advanced methods has defined new concepts of clinically relevant bone physiology, such as mineralized sectioning, birefringence analysis, fluorescent labeling (often with tetracycline-based markers to determine rates of bone growth), microradiography, cell morphology measurements, finite elemental modeling of bone stress and strain, and electron microscopy to evaluate bone density and microarchitecture.[4-19]

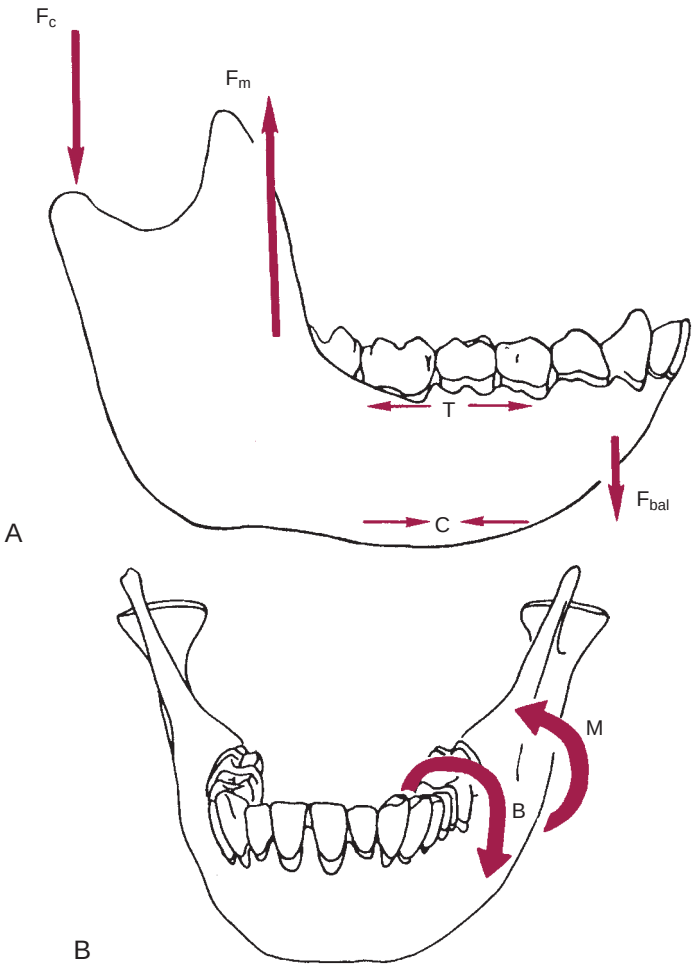

Figure 4-6 Stress patterns in the primate mandible during unilateral mastication. F_c and F_m are the condylar reaction and the resultant muscle forces on the balancing side, respectively. F_{bal} is the force transmitted through the symphysis from the balancing to the working side. *T* and *C* indicate the location of tensile stress and compressive stress, respectively. **A,** During the power stroke, the mandibular corpus on the balancing side is bent primarily in the sagittal plane, resulting in tensile stress along the alveolar process and compressive stress along the lower border of the mandible. **B,** On the working side, the corpus is twisted primarily about its long axis (it also experiences direct shear and is slightly bent). The muscle force on this side tends to evert the lower border of the mandible and invert the alveolar process *(curved arrow M)*. The twisting movement associated with the bite force has the opposite effect *(curved arrow B)*. The portion of the corpus between these two twisting movements experiences maximal twisting stress. (From Hylander WL: Patterns of stress and strain in the macaque mandible. In Carlson DS, editor: *Craniofacial biology,* Ann Arbor, Mich, 1981, Center for Human Growth and Development.)

BONE TISSUE RESPONSES TO DENTAL IMPLANT PLACEMENT

After implant placement, relatively immature new bone forms rapidly at the implant interface; this bone is later replaced by a more complex but stronger bone along the interface. In general, there are four types of bone established during normal healing and remodeling phases: woven bone, lamellar bone, composite bone, and bundle bone.

WOVEN BONE

Woven bone varies considerably in structure but is often described as a rapidly forming, cell-rich but matrix-poor tissue that forms immediately after placement of the implant. It is weak, disorganized, and poorly mineralized. However, woven bone plays a vital role in wound healing, because it (1) rapidly fills osseous defects around the implant interface, (2) provides initial continuity for fractures and osteotomy segments and also around bone grafts, and (3) strengthens bone weakened by surgery or trauma. Woven bone is the first bone formed in response to implant placement and is not found elsewhere in the adult skeleton under normal conditions. It is compacted to form composite bone, remodeled to lamellar bone, or rapidly resorbed if prematurely loaded.[6,20]

LAMELLAR BONE

Lamellar bone is a strong, highly organized, well-mineralized tissue that makes up more than 99% of the adult human skeleton. When new lamellar bone is formed, a portion of the mineral component (poorly apatite mineral) is deposited by osteoblasts during primary mineralization (Figure 4-7). Secondary mineralization, which completes the mineral component, is a physical process (based on crystal growth in the c-axis of the apatite mineral

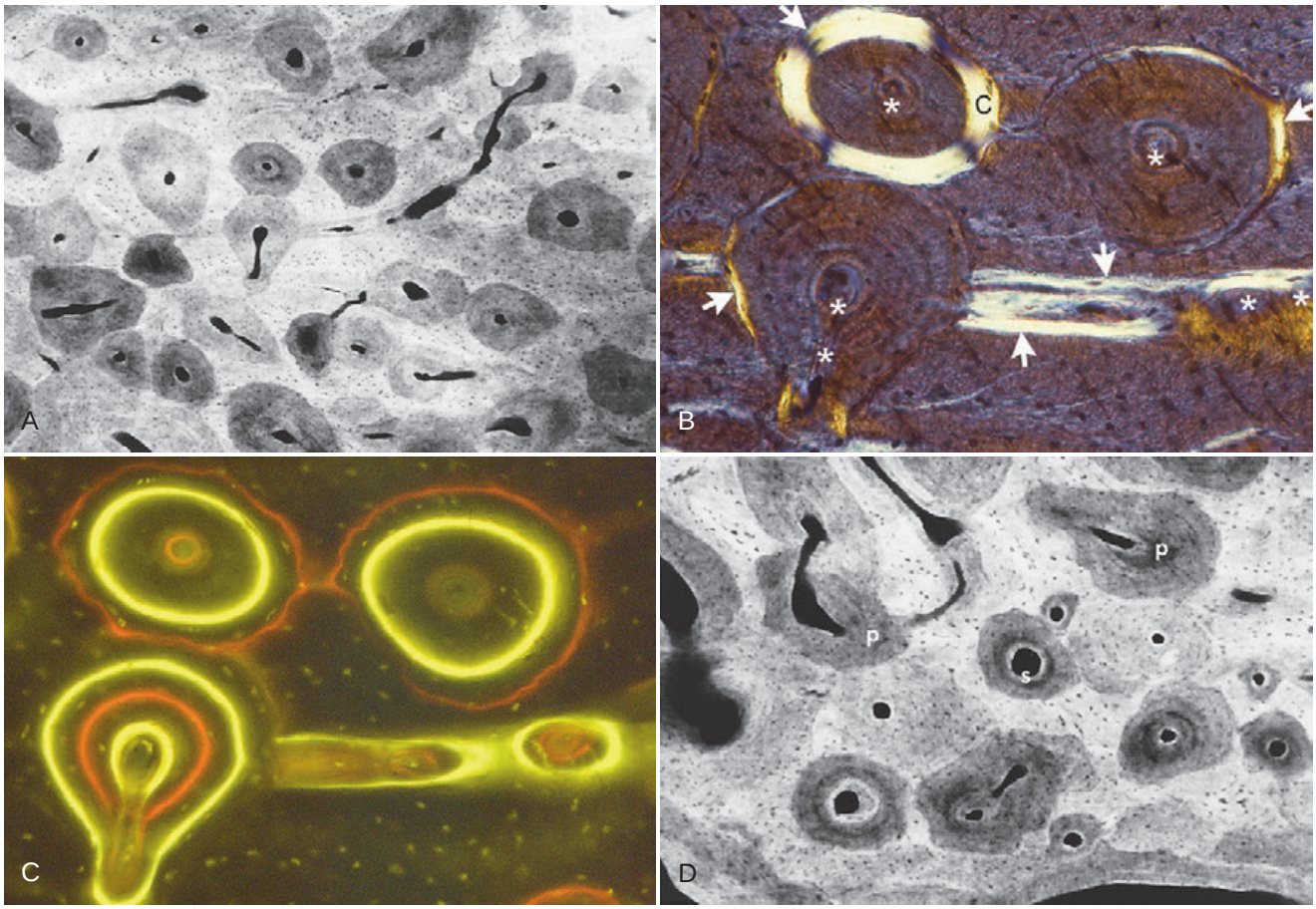

Figure 4-7 **A,** Microradiograph provides a physiologic index of bone turnover and relative stiffness. The more radiolucent *(dark)* osteons are the youngest, the least mineralized, and the most compliant. Radiodense *(white)* areas are the oldest, most mineralized, and most rigid portions of the bone. **B,** Polarized light microscopy shows the collagen fiber orientation in bone matrix. Lamellae with a longitudinally oriented matrix *(C)* are particularly strong in tension, whereas a horizontally oriented matrix *(dark)* has preferential strength in compression (*arrows* mark resorption arrest lines, and *asterisks* mark vascular channels). **C,** Multiple fluorochrome labels administered at 2-week intervals demonstrate the incidence and rates of bone formation. **D,** This microradiograph shows an array of concentric secondary osteons (haversian systems) characteristic of rapidly remodeling cortical bone. Primary *(p)* and beginning secondary *(s)* mineralization are more radiolucent and radiodense, respectively. (From Roberts WE et al: *Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series,* vol 27, Ann Arbor, 1991, University of Michigan Press.)

phase) that requires many months. Within physiologic limits, the strength of bone is related directly to its mineral content.[21,22] The relative strengths of different histologic types of osseous tissue can be stated thusly: woven bone is weaker than new lamellar bone, which is weaker than mature lamellar bone.[23] Adult human bone is almost entirely of the remodeled variety: secondary osteons and spongiosa.[5,22,23] The full strength of lamellar bone to support a dental implant is not achieved until about 1 year after completion of loading (completion of the full cycle of bone resorption, woven bone formation, remodeling, and maturation of the new implant-bone interface).[24,25]

COMPOSITE BONE

Composite bone is an osseous tissue formed by the deposition of lamellar bone within a woven bone lattice, a process called *cancellous compaction*.[4,26] This process is the quickest means of producing relatively strong bone.[27] Composite bone is an important intermediary type of bone in the physiologic response to loading (Figure 4-8), and it is usually the predominant osseous compact bony tissue formed along the implant interface as it passes through a marrow space. When the bone is formed in the fine compaction configuration, the resulting composite of woven and lamellar bone forms structures known as *primary osteons*.

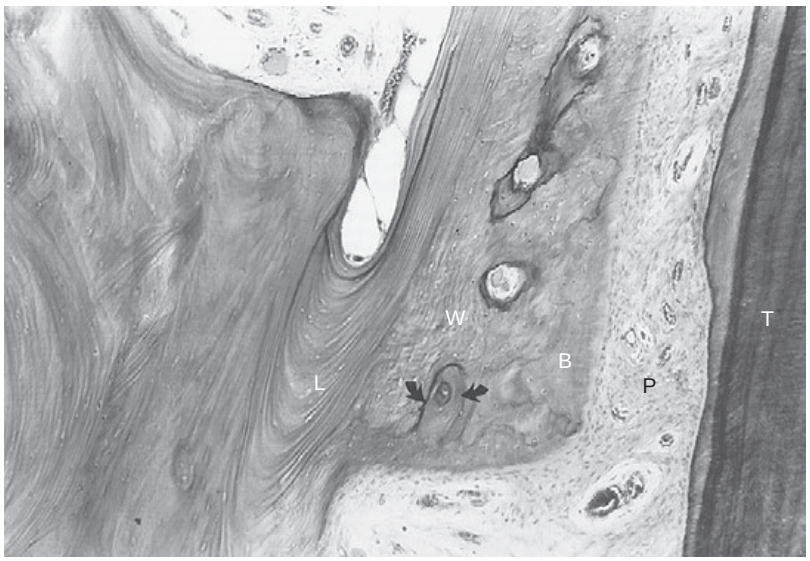

Figure 4-8 A section of human periodontium from the lower first molar region shows a typical histologic response to orthodontic tooth movement. With respect to the mature lamellar bone *(L)* on the left, the tooth *(T)* is being moved to the right. The first bone formed adjacent to the periodontal ligament *(P)* is of the woven type *(W)*. Subsequent lamellar compaction forms primary osteons of composite bone *(arrows)*. Bundle bone *(B)* is formed where ligaments, such as the periodontal, are attached. (From Roberts WE et al: Implants: bone physiology and metabolism, *Calif Dent Assoc J* 15:58, 1987.)

Although composite bone may be high-quality, load-bearing osseous tissue, it is eventually remodeled into secondary osteons.[5,23]

BUNDLE BONE

Bundle bone is a functional adaptation of lamellar structure that allows the attachment of tendons and ligaments. Perpendicular striations in histologic sections, called *Sharpey fibers*, are the major distinguishing characteristics of bundle bone associated with dental alveolar bone. Distinct layers of bundle bone are usually seen adjacent to the periodontal ligament (PDL) (see Figure 4-8) along physiologic bone-forming surfaces.[28] It is important to recall that bundle bone does not form, nor is it maintained by, dental implant placement.[29]

SKELETAL ADAPTATION: MODELING AND REMODELING

Skeletal adaptation to the mechanical environment is achieved through changes in (1) bone mass, (2) geometric distribution, (3) matrix organization, and (4) collagen orientation of the lamellae. In addition to these adaptive mechanisms, which influence bone formation, the mechanical properties of osseous structures change as a result of maturation, function, aging, and pathologic processes. Examples of physiologic and pathologic factors include secondary mineralization, mean bone age, fatigue damage, and loss of vitality (pathologic hypermineralization).[28]

Trabecular bone and cortical bone grow, adapt, and turn over by means of two fundamentally distinct mechanisms, modeling and remodeling. In bone modeling, independent sites of resorption and formation change the form of a bone (i.e., net shape or size, or both). In bone remodeling, a specific coupled sequence of resorption and formation replaces previously existing bone without a net change in size or shape. The mechanism for internal remodeling (turnover) of dense compact bone involves axially oriented cutting and filling cones composed of a coordinated set of osteoclasts and osteoblasts (Figure 4-9).[4] In implant healing the initial modeling process, which is driven by inflammatory mediators, establishes the implant-bone interface.[30] Later, ongoing remodeling mobilizes and deposits calcium apatite mineral by means of coupled resorption and formation: bone is resorbed and deposited at the same site.

Osteocytes, osteoblasts, osteoclasts, and possibly their precursors are thought to communicate by a complex set of growth factors.[31] Transforming

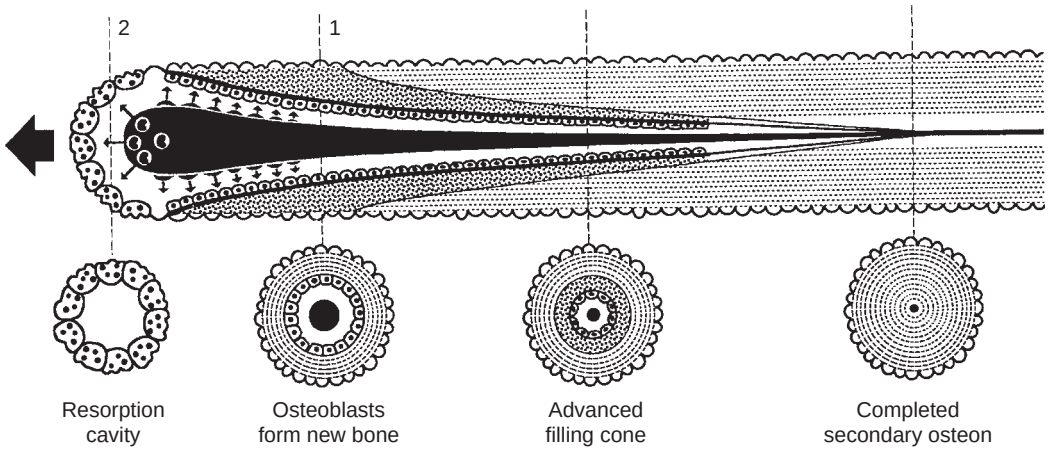

Figure 4-9 The cutting and filling cone has a head of osteoclasts that cuts through the bone and a tail of osteoblasts that forms a new secondary osteon. The velocity through bone is determined by measuring between two tetracycline labels (*1* and *2*) administered 1 week apart. (Modified from Roberts WE et al: Osseous adaptation to continuous loading of rigid endosseous implants, *Am J Orthod* 86:95-111, 1984.)

growth factor beta, released from bone during the resorption process, helps to stimulate subsequent bone formation to fill resorption cavities.[32] Currently, growth factors released from bone are thought to mediate the coupling process through a genetic mechanism for activating and suppressing osteoclasts (*RANK, RANKL,* and *OPG* are gene products that assist in the control of remodeling). This genetic mechanism appears to be involved in the inflammatory induction of bone resorption and the coupling of bone formation at the same site (Figure 4-10).[33,34]

CORTICAL BONE GROWTH AND MATURATION

The manner in which craniofacial bones develop and the implications for implant placement are important concepts. Some investigators sectioned human skulls and histologically identified areas of surface apposition and resorption.[26] The overall patterns of bone modeling (the formation of net new bone or net loss of bone) defined the mechanisms of facial growth. Melsen[35] used microradiographic images of mineralized sections to extend the capability of the osseous topography method. Patterns of primary and secondary mineralization (see Figure 4-7) identified active appositional sites and provided an initial index of rates of bone formation.

Roberts et al.[4,5,36] introduced simultaneous use of multiple fluorochrome labels and microradiography to assess modeling and remodeling patterns over extended periods. Noorda[37] subsequently applied these methods for a three-dimensional assessment of subcondylar growth of the mandible of adolescent rabbits. Rabbits in early adolescence (20 weeks) were labeled every 2 weeks with a series of six different multifluorochrome labels for 18 weeks. Cross sections of the subcondylar region (Figure 4-11, *A*) were superimposed on the original, oldest labeled, and newest labeled bone according to fluorescent time markers (Figure 4-11, *B*). All three sections were at the same relative level at a point in time; superimposition on original (unlabeled) bone and the oldest labeled bone (Figure 4-11, *C*) provided an index of the relative amounts of bone resorbed and formed as the mandible grew superiorly (Figure 4-11, *D*). This method provided the most accurate assessment to date of cortical bone modeling over time.

The Noorda study also produced important quantitative data on the rates of surface modeling (apposition and resorption) of primary bone (Figure 4-12). During the last 18 weeks of growth to adult stature, the surface apposition rate decreased from more than 25 mm/day to less than 5 mm/day (Figure 4-13, *A*). The secondary osteon "census" peaked at about 8 to 10 weeks (Figure 4-13, *B*). Therefore, under conditions of relatively rapid growth, primary cortical bone is remodeled into secondary osteons (haversian bone) in about 2 months.[4,5]

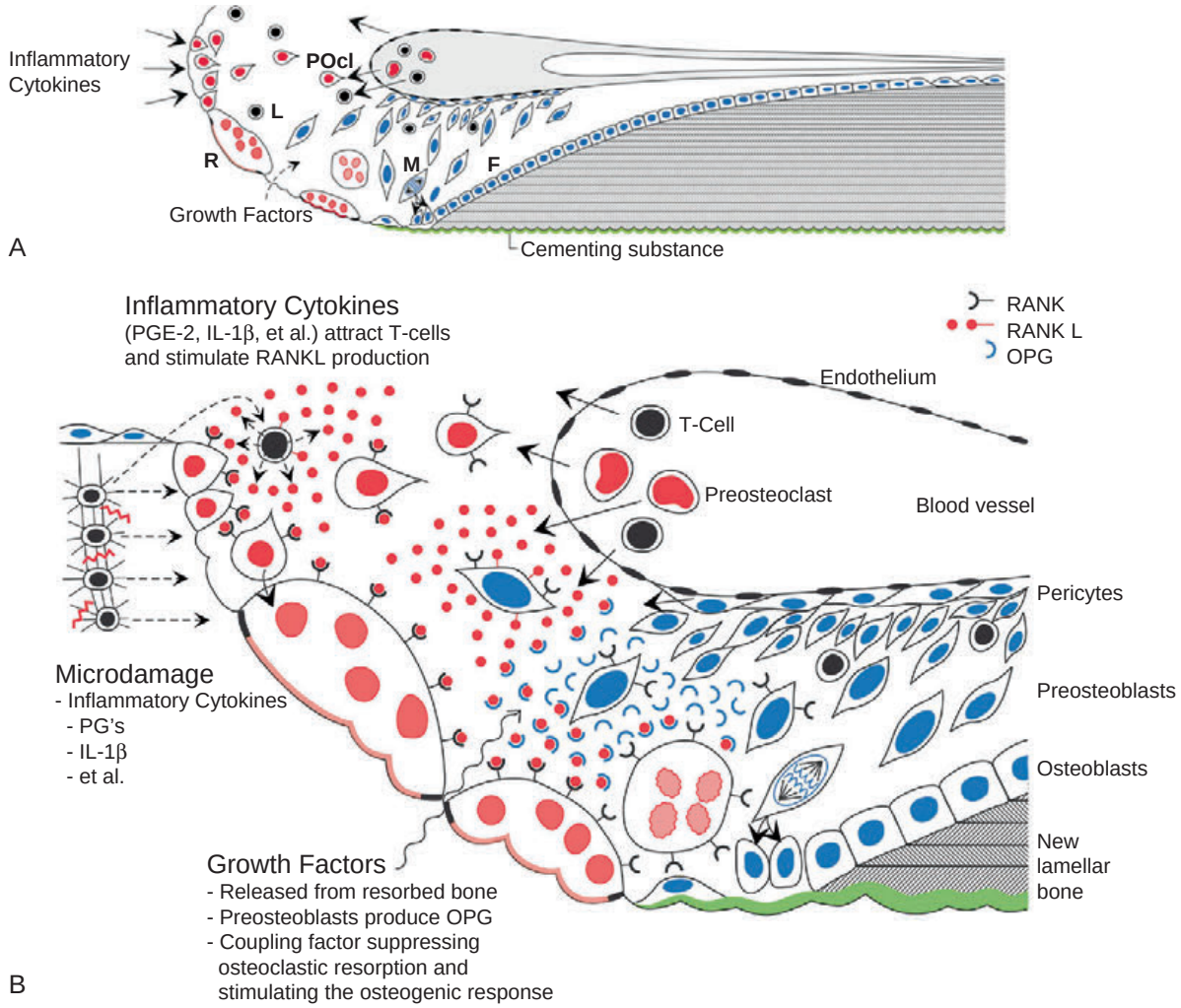

Figure 4-10 **A,** Hemisection of a cutting and filling cone moving to the left demonstrates the intravascular and perivascular mechanisms for coupling bone resorption *(R)* to formation *(F)* during the remodeling process. Lymphocytes *(L)* are attracted from the circulation by inflammatory cytokines. They help recruit preosteoclasts *(POcl)* from the circulation (see text for details). **B,** Magnified view of the head of a hemi–cutting and filling cone illustrates the proposed mechanism for coupling bone resorption to formation through the genetic *RANK/RANKL/OPG* mechanism. The cutting head is stimulated by inflammatory cytokines produced by osteocytes in damaged bone *(left).* Preosteoclasts have *RANK* receptors that are bound and activated by *RANKL,* probably produced or mediated by T cells (lymphocytes) near the resorption front. Growth factors from resorbed bone *(bottom)* stimulate production of preosteoblasts, which produce *OPG* to block the *RANK* receptors on osteoclasts; the latter withdraw from the scalloped surface and degenerate. Relatively flat mononuclear cells *(bottom center)* form a cementing substance to form a resorption arrest line. Osteoblasts *(bottom right)* produce new lamellar bone to fill the resorption cavity. (From Roberts WE et al: Remodeling of mineralized tissues. II. Control and pathophysiology, *Semin Orthod* 12:238-253, 2006.)

BASIC MULTICELLULAR UNIT AND CUTTING AND FILLING CONES

Bone remodeling around implants is guided by a complex spatial and temporal relationship between osteoclasts and osteoblasts, which Frost[39] described as a basic multicellular unit (BMU). It consists of a set of osteoclasts at the head of the unit (consider the analogy of an oil drilling bit) followed immediately by a set of newly differentiated osteoblasts that fill the resorbed area.

The rate of cutting and filling through compact bone is an important determinant of turnover. The progression is calculated by measuring the distance between initiation of labeled bone formation sites along the resorption arrest line in longitudinal sections.[4] Using two fluorescent labels administered 2 weeks apart in adult dogs, investigators[36] recorded

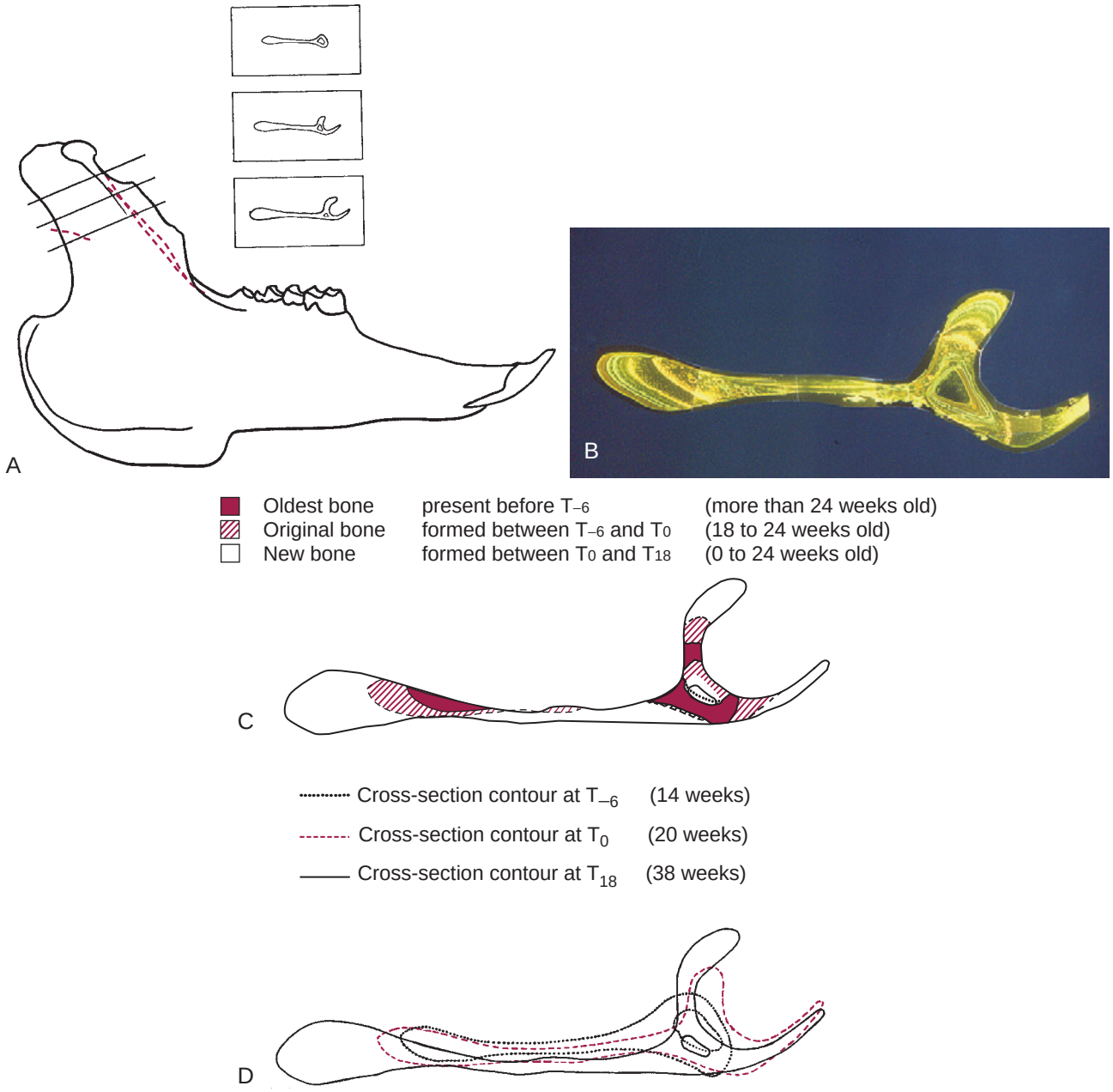

Figure 4-11 **A,** Schematic drawing of a rabbit mandible showing the plane of sectioning in the subcondylar region of the ramus. **B,** Fluorescent light photomicrographs of the most inferior section are arranged in a composite. The weekly deposition of bone labels over 4 months shows the patterns of bone modeling and remodeling associated with the growth and development of the subcondylar region. **C,** Based on the uptake of bone labels, the age of specific areas in a given cross section can be determined accurately. **D,** Because the subcondylar region of the ramus is growing superiorly, superimposition of the three sections on the oldest bone gives an estimation of the patterns of bone resorption (catabolic modeling) associated with growth of the mandibular ramus. (From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)

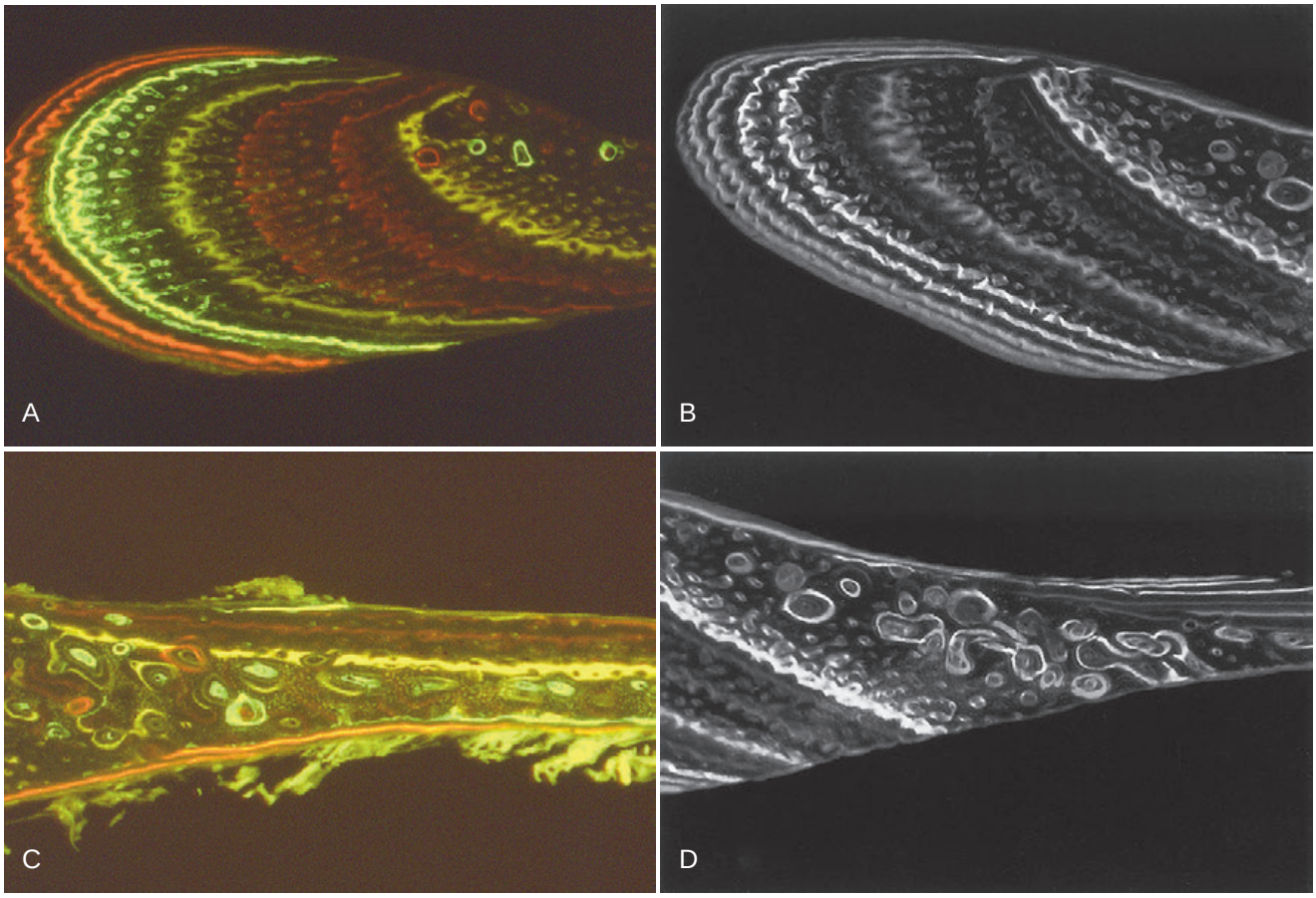

Figure 4-12 **A,** Fluorescent microscopy of weekly bone labels shows the patterns of anabolic modeling (bone apposition) in a rabbit. Note the diminishing space between the labels as growth slows and the animal achieves an adult skeletal form. **B,** A similar section from another rabbit in the same study shows the consistency of the growth pattern. **C,** In the first rabbit, the adjacent microscopic field shows several sites of bone remodeling in primary cortical bone formed about 6 to 12 weeks earlier. **D,** In the second rabbit, the adjacent microscopic field shows a consistent pattern of remodeling of new cortical bone at about 6 to 12 weeks after formation. (From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)

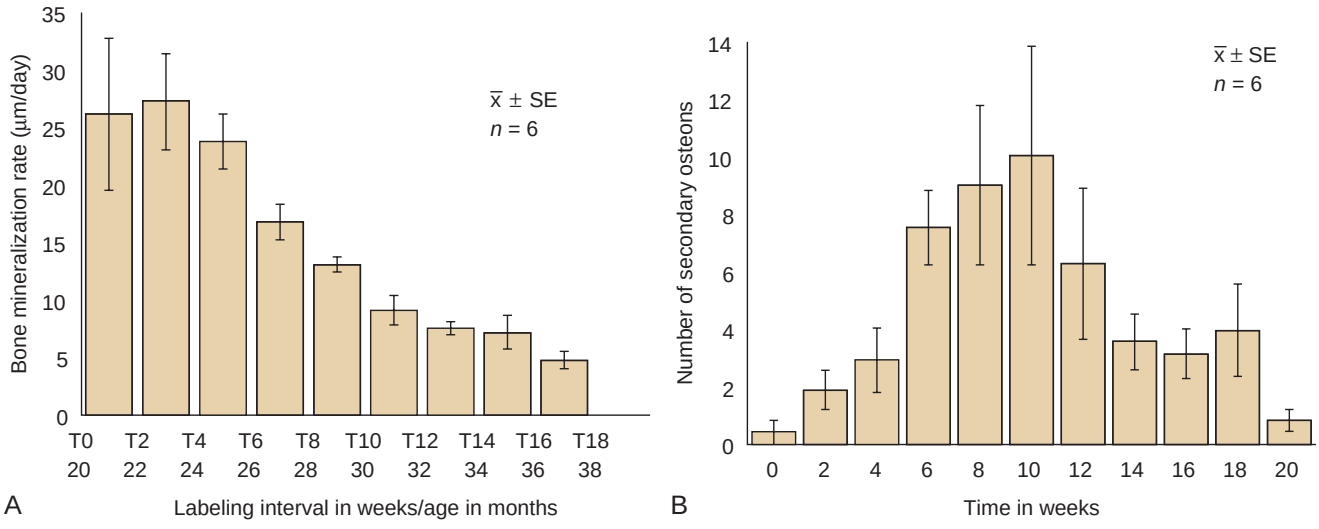

Figure 4-13 **A,** Age-related changes in the rate of periosteal apposition that occur in the posterior border of the mandibular ramus of the rabbit. Note the progressive decrease in the rate of periosteal bone apposition as the adolescent animals mature. **B,** Remodeling of new cortical bone. The highest incidence of remodeling to secondary osteons occurs when new cortical bone is 6 to 12 weeks old. (From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)

a velocity of 27.7 ± 1.9 mm/day (mean ± standard error of the mean [SEM], $n = 4$ dogs, 10 cutting and filling cones sampled from each). At this speed, evolving secondary osteons travel about 1 mm in 36 days. Newly remodeled secondary osteons (formed within the experimental period of the dog study) contained an average of 4.5 labels (administered 2 weeks apart). The incidence of resorption cavities was about one third of the incidence of labeled osteons.

These data are consistent with a remodeling cycle of about 12 weeks in dogs,[36] compared with 6 weeks in rabbits[4] and 17 weeks in human beings.[5,23] This relationship is useful for extrapolating animal data to human applications, but it is limited by the fact that the labeling technique itself (tetracycline) also alters remodeling kinetics. More recent experimental studies have shown that new secondary osteons may continue to fix bone labels for up to 6 months, indicating that terminal filling of the lumen is slow.[38]

Traumatic or surgical wounding usually results in intense but localized modeling and remodeling responses. After an osteotomy or placement of a dental implant, callus formation and resorption of necrotic osseous margins may be observed. However, a cartilage callus is rarely observed in endosseous bone of the skull. Internal replacement of devitalized cortical bone surrounding traumatic sites activates remodeling activity. Furthermore, a gradient of localized remodeling disseminates through the bone adjacent to any invasive bone procedure. This process, called a *regional acceleratory phenomenon,* is an important aspect of postoperative healing.[23,39]

Modeling and remodeling are controlled by an interaction of metabolic and mechanical signals. Bone modeling is largely under the integrated biomechanical control of functional applied loads. However, hormones and other metabolic agents have a strong secondary influence, particularly during periods of growth and advanced aging. Paracrine and autocrine mechanisms, such as local growth factors and prostaglandins, can override the mechanical control mechanism temporarily during wound healing.[40] Remodeling responds to metabolic mediators (e.g., parathyroid hormone [PTH] and estrogen) primarily by varying the rate of bone turnover.

Bone scans with ^{130}Te-bisphosphate, a marker of bone activity, indicate that the alveolar processes (not including the basilar mandible) have a high remodeling rate.[41,42] Uptake of the marker in alveolar bone is similar to uptake in trabecular bone of the vertebral column. The latter is known to remodel at a rate of about 20% to 30% per year compared with most cortical bone, which turns over at a rate of 2% to 10% per year.[43] Metabolic mediation of continual bone turnover provides a controllable flow of calcium to and from the skeleton.

The structural fraction of cortical bone is the relatively stable outer portion of the cortex; the metabolic fraction is the highly reactive inner aspect (Figure 4-14, *A*). The primary metabolic calcium reserves of the body are found in trabecular bone and the endosteal half of the cortices. The stiffness and strength of a bone are related directly to its cross-sectional area. Diaphyseal rigidity is quickly enhanced by adding circumferential lamellae at the periosteal surface. Even a thin layer of new osseous tissue at the periosteal surface greatly enhances bone stiffness, because it increases the diameter of the bone. In engineering terms, cross-sectional rigidity is related to the second moment of the area. The same general relationship of round wire diameter and stiffness (strength) is well known. For example, the rigidity of a wire increases as the fourth power of diameter.[44] Therefore, when a relatively rigid material (bone or wire) is doubled in diameter, the stiffness increases by 16 times.

The addition of new osseous tissue at the endosteal (inner) surface has little effect on overall bone strength. Structurally, the long bones and mandible are modified tubes, an optimal design for achieving maximal strength with minimal mass.[21] The inner cortex can be mobilized to meet metabolic needs without severely compromising bone strength (Figure 4-14, *B*). This is the reason patients with osteoporosis have bones with a normal diameter but thin cortices. Even under severe metabolic stress, the body follows a cardinal principle of bone physiology: maximal strength with minimal mass.[45]

DENTAL IMPLANTS AND BONE RESPONSES

Endosseous (also called *internal bone*) dental implants have created a revolution in the routine

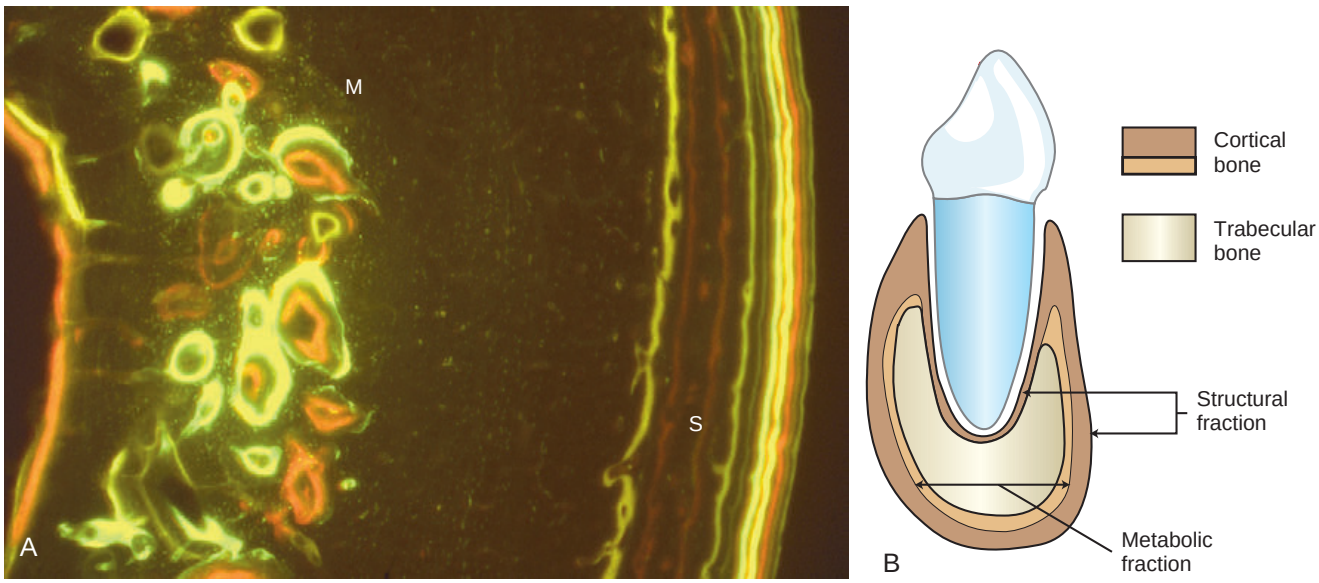

Figure 4-14 **A,** The structural *(S)* and metabolic *(M)* fractions of cortical bone are revealed by multiple fluorochrome labeling of a rabbit femur during the late growth and early adult periods. Continuing periosteal bone formation *(right)* contributes to structural strength, and high remodeling of the endosteal half of the compacta provides a continual supply of metabolic calcium. **B,** Structural and metabolic fractions of bone in the mandible. (Modified from Roberts WE et al: *Bone dynamics in orthodontic and orthopedic treatment: craniofacial growth series,* vol 27, Ann Arbor, Mich, 1991, University of Michigan Press.)

approach to dental care for patients missing one or more teeth. The remarkable success of this tooth replacement therapy is based on a series of clinical and biologic steps starting with initial implant primary stability in the bone provided by the amount, quality, and distribution of bone in the proposed implant site.[46] Bone adaptation or integration of an implant is characterized by a series of biologic reactions that start with bone turnover at the interface (a process of localized necrosis) followed by rapid repair, as previously discussed.[25] Success rates are high for certain anatomic regions; however, the bony response in the thin cortical plates and diminished cancellous bone (i.e., the type IV bone described by Lekhom and Zarb[47]) is considerably less successful with conventional machined-surface implants (e.g., 65% to 85%).[48]

The long-term success of implant therapy does not depend solely on enhanced osseous stability. Recently, greater attention has been paid to the transmucosal dental implant or implant abutment interfaces. The mechanical and biologic stability derived from the design and surfaces in this connective tissue and junctional epithelial environment is critical to maintaining a sufficient volume of connective tissue that has minimal inflammatory infiltrate. Chronic inflammation in this transmucosal region can be influenced by the implant's design, materials, or surface roughness and can lead to long-term tissue recession and even peri-implant disease years after completion of the tooth replacement therapy.[49-55] To increase the predictability of dental implant therapy, significant efforts have been made to develop implant biomaterials that hold the promise of improving clinical success.

IMPLANT MACRORETENTIVE FEATURES

Implants have one of three major types of macroretentive features: (1) screw threads (tapped or self-tapping), (2) solid body press-fit designs, or (3) sintered bead features. These devices enhance initial implant stability and create volumetric spaces for bone ingrowth (Figure 4-15). An important biologic principle of bone is that it responds favorably to compressive loading (without the presence of a ligament) but not to shear forces.[24] Therefore, buttress screw-thread implant designs have been adapted to achieve compressive loading of the surrounding cortical or cancellous bone.

IMPLANT MICRORETENTIVE FEATURES

Upon placement of an implant into a surgical site, a cascade of molecular and cellular processes result in new bone growth and maturation along the

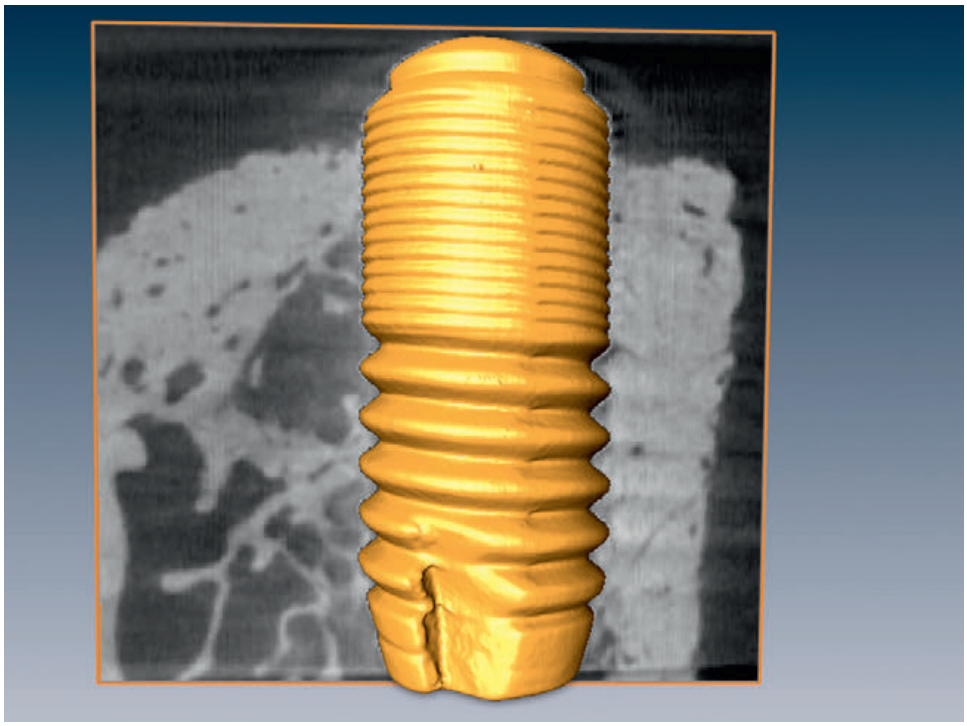

Figure 4-15 Micro-CT imaging of a cpTi implant after 8 weeks in vivo in an animal model.

biomaterial surface. The surrounding bone undergoes an initial necrosis during the first 2 weeks after placement. About 1 mm of bone all around the healing implant is replaced with woven bone, which is subsequently replaced with mature haversian bone through the process of remodeling (using the BMU system previously described).[56,57] The goal of a number of current strategies is to provide enhanced osseous stability through microsurface-mediated events. These strategies can be divided into two groups: those that attempt to enhance the migration of new bone (e.g., osteoconduction) onto the implant surface by way of surface topography and (2) those that use the implant as a vehicle for local delivery of a bioactive coating (adhesion matrix or growth factor, such as bone morphogenic protein 2 [BMP-2]).[58,59]

One means of improving implant success is to increase the amount of bone contact along the body of the implant. In dental implant design, a greater surface area (per unit of bulk metal surface) is considered a design objective. This may be created by various means of surface roughness and surface energy of the implant (Figure 4-16). This enhanced surface allows a greater area to be used for load transfer of bone against the implant surface.[60-63]

Micromechanical features also influence the process of secondary integration (bone growth, turnover, and remodeling).[25] An advantage of acid etching, a commonly used cleaning technique, is that it increases the roughness of the grit-blasted surface, allowing bone to adapt to the surface under elevated shear forces.[64,65] Implant design features conventionally were thought to require surface pores, or "pits," of 100 μm or greater in diameter for ingrowth of bone, although clinically relevant surface roughness may actually be much finer (on the nanoscale level).[66]

Wound healing around a dental implant placed into a prepared osteotomy follows three stages of repair. Initial formation of a blood clot occurs through biochemical activation, followed by cellular activation and, finally, a cellular response. These initial rapid changes during the surgical phase of implant therapy lead to the activation of key biochemical pathways: the clotting system (fibrinogen to fibrin), complement activation, kinin cascade activation (vascular dilation), and plasminogen activation of plasmin. Adhesion of platelets to the assembled fibrin scaffold and to the surface topography of an implant leads to platelet activation.

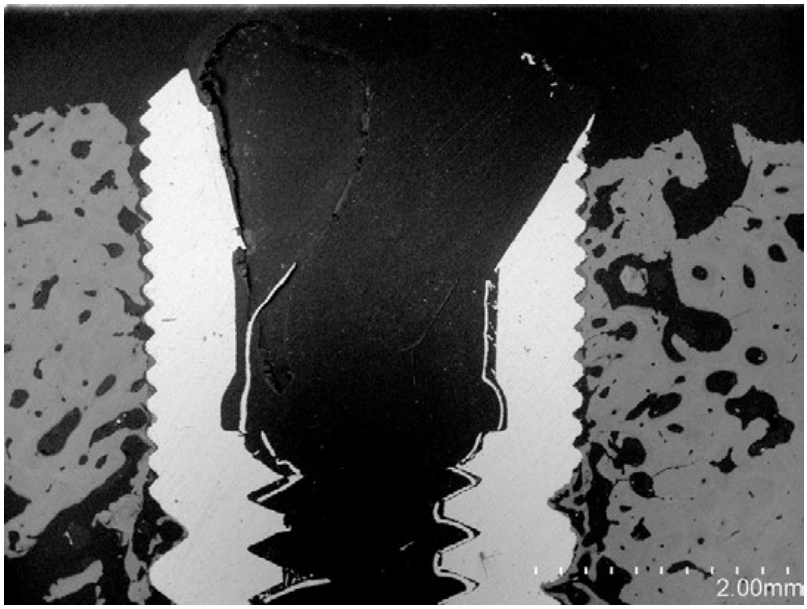

Figure 4-16 Dental implant at 8 weeks in an animal model. This transcortical section was imaged with secondary electron diffraction (backscatter mode) to show continuous adaptation of bone along the small threaded portion on the cortical region.

The interaction between the implant's surface and serum proteins appears to create the primary effect of implant surface topography.[67] Platelet activation has also been elevated on etched titanium surfaces. When platelet adhesion and activation were compared for machined and blasted/etched titanium surfaces, the smoother machined surfaces demonstrated higher adhesion of platelets but reduced activation. The rougher surfaces demonstrated reduced platelet adhesion but nearly 100% platelet degranulation.[68]

During the initial remodeling steps, a number of immune cells (e.g., platelets, polymorphonuclear neutrophils [PMNs]) mediate the early tissue response, followed by migration of phagocyte macrophages.[69] Biomaterials research recently has focused on macrophages not just as mediators of debris removal, but also as mediators of new bone formation on the implant surface.[70,71] Mosser and Edwards[69] suggest that a continuum exists for the functions of various forms of macrophages, including wound healing. An initial role for these cells is to remove the necrotic debris created by the drilling process. This material is laced with DNA fragments, histones, nuclear proteins, and heat shock proteins, all of which lead to physiologic changes in the macrophages. This, in turn, leads to the expression of cell surface proteins (CD135) and the production of cytokines and proinflammatory mediators through the nuclear factor kappa B (NF-κB) pathway.[69,72]

Dental implants are typically placed from a cortical surface of the dental alveolus into the medullar cavity. Interestingly, when histologic studies are performed on clinically healed implants, bone contact exceeding 50% of the implant surface area is seen along the portion of the device that passes though the medullar cavity, a feature that is not seen in the absence of implants.[73-76] This allows for rapid contact of the implant surface with marrow-derived monocytes and may be one reason for the extensive adhesion of macrophages to retrieved implant surfaces.[70]

The subsequent formation of a mineralized matrix during osteogenesis, bone remodeling, or osseointegration of dental implants involves the recruitment of multipotent mesenchymal stem cells and the progressive differentiation of these cells into osteoblasts.[77] Osteoblast differentiation and skeletal formation during embryonic development are mediated by an essential transcription factor protein called *core binding factor alpha 1* (Cbfa1) or RUNX-2.[78] Belonging to the Runt family of transcription factors, Cbfa1 regulates osteoblast differentiation and expression of bone extracellular matrix protein genes.[79-81] A second transcription factor, Osterix, has been suggested to play a key role downstream from

RUNX-2, where its expression is necessary for ongoing differentiation in the osteogenic pathway (as opposed to shifting to a chondrogenic pathway).[82]

Various studies have addressed the issue of surface roughness through different means of grit blasting followed by surface etching or a coating procedure. Such techniques include titanium plasma spray (TPS),[60] abrasion (titanium dioxide [TiO_2] blasting or the use of soluble abrasives), combinations of blasting and etching (e.g., aluminum dioxide with sulfuric acid/hydrochloric acid [Al_2O_3 with H_2SO_4/HCl]),[60] thin apatite coating,[83] and sintered beads.[84] Laboratory and clinical evidence has shown that commercially available roughened surfaces with a large grit-blasted and acid-etched surface (e.g., Straumann's SLA surface) have higher success rates in areas of the posterior maxilla.[85-89] The role of the roughened surface is complex, because the actual strength of bone contact against the titanium oxide surface is quite low (4 MPa or less), weak enough that little bone contact occurs without the surface.[64]

Various titanium surfaces have surface roughness created by grit blasting, etching, or blasting of the surface alone using tightly controlled conditions to obtain a predefined optimal surface topography. One such optimization criterion has already been proposed.[90,91] The titanium oxide grit-blasted surface then is further modified with a mild hydrofluoric acid etching to create surface pitting on the blasted surface. The optimization criterion calls for maintaining the macroroughness derived from the blasting process for primary implant stability but with a surface etching (acid etching) to influence the secondary osseointegration process (the process of wound healing after implant placement).

Masaki et al.[92] and Isa et al.[93] used a human mesenchymal cell culture model and demonstrated a rapid increase in the expression of key genes involved in the differentiation of bone that was unique to the fluoride-modified and etched titanium surface; this increased expression was not evident on a blasted surface alone or in a comparison group of large grit–blasted and dual acid–etched surfaces.[92,93] Follow-up evaluation of the fluoride-modified and etched titanium surface demonstrated enhanced bone adaptation in a wound healing model (Figure 4-17).[30,68]

SUMMARY

The complexity of the bones in the upper and lower jaws affects implant treatment planning and sequencing, as well as the outcome of therapy. The maxilla tends to be loaded in compression, leading to thinner vertical cortical plates as a function of a complex anatomy with horizontal members (e.g., hard palate) loaded in tension. The effect is often thinner and less dense bone in the maxilla, especially with tooth loss. The mandible, in contrast, undergoes complex torsional loading that leads to thicker cortical plates and minimal trabecular bone; this provides an osseous structure in which an implant can often be placed.

Before placing an implant, the dental practitioner must recognize that the immediate postoperative support for the implant will be dead bone, devitalized to a depth of about 1 mm by the surgical procedure. The exposed endosseous surface, not in contact with dead lamellar bone, is a site for new woven bone formation. Therefore, during the early stages of healing, the osseous interface of the implant is a composite of either dead lamellar bone or poorly mineralized woven bone. As healing advances, the entire osseous interface will be remodeled into lamellar bone. Because the interface at first may be weak, the dental practitioner must have a clear understanding of loading, healing time, and control of occlusion both during the initial healing period and over the long term. However, if the implant is placed in high-quality lamellar bone, the initial dead bone interface may be able to sustain immediate loading, because the implant remains stable as the interface undergoes step-wise remodeling.

The dental practitioner also must exercise caution in placing implants into extraction sockets, especially in a thinner biotype, because the bundle bone present is lost in time. After placement the implant interface undergoes a progressive remodeling or turnover process guided by an interaction between a set of osteoclasts, which remove damaged bone tissue, and a highly organized set of osteoblasts, which subsequently lay down replacement bone. This complex interaction, or basic multicellular unit, is vital to maintaining the functional dental implant interface.

The preparation of the implant's surface plays a key role both in the initial healing process and in

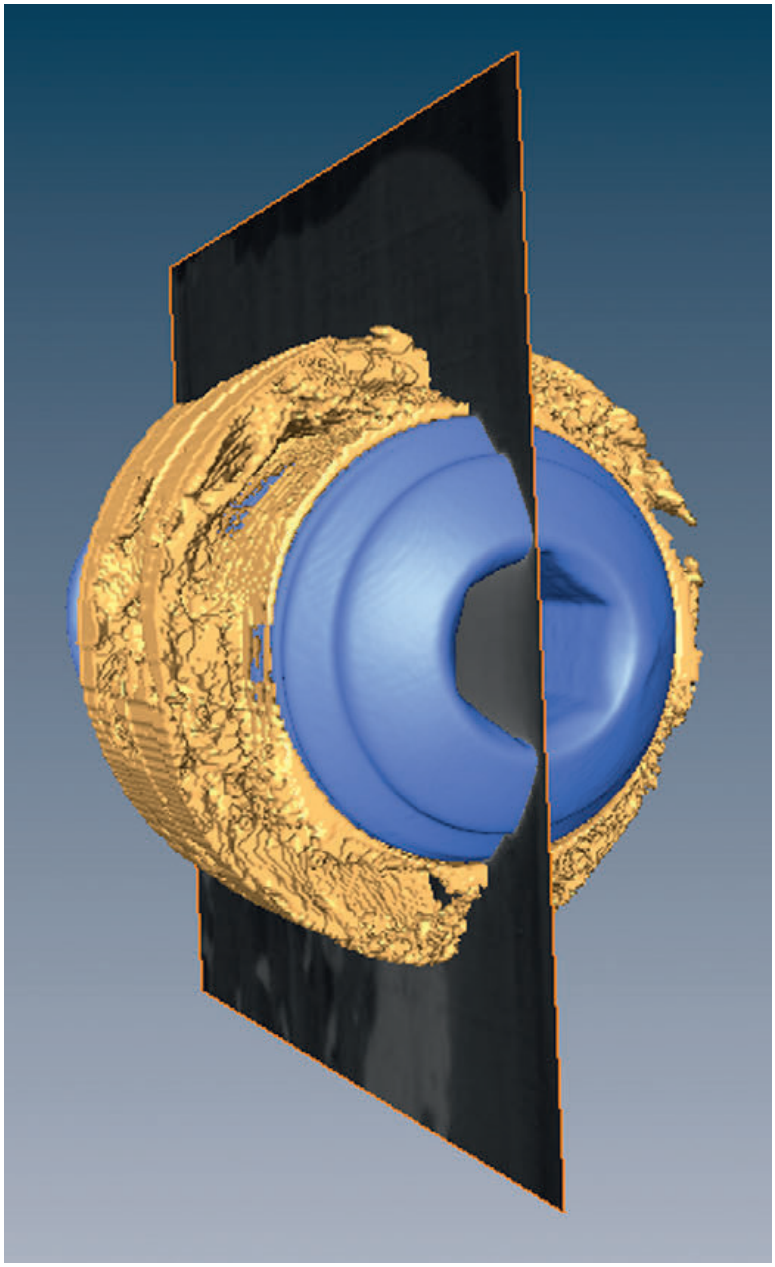

Figure 4-17 Dental implant in an animal model with a wound healing chamber consisting of a 1-mm peri-implant defect that originally was 4 mm deep. The defect was allowed to fill with clot, and new bone was imaged with micro-CT at 8 weeks after placement. An 80% fill of the defect was noted, compared with 50% for the blasted but nonetched control surfaces.

the long-term turnover process. The microscopic topographic features created by various additive and subtractive oxidation, blasting, and etching processes are an important factor. These features manipulate the normal healing processes around the implant. Secondarily, they can lead to important nanotopographic changes that influence fundamental tissue formation and subsequent remodeling.

Dental practitioners must have a clear understanding of the fundamental changes that occur in bone tissue after dental implant placement so that they can communicate these important facts to their patients and their restorative colleagues.

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CHAPTER 5

Bone Grafts and Bone Substitute Materials

Alan S. Herford, Enrico Stoffella, Clark M. Stanford

Chapter Outline

Overview of Different Types of Biomaterials
Autogenous Bone
- Features
- Donor Sites
- Advantages and Disadvantages

Allografts and Alloplasts
- Features
- Advantages and Disadvantages

Xenografts
- Features
- Advantages and Disadvantages

Osteoinductive Materials
- Features
- Advantages and Disadvantages

Summary of Surgical Procedures for Grafting
- Ridge Socket Preservation After Extraction
- Onlay Block Grafting
- Guided Bone Regeneration
- Sinus Elevation

Management of Complications

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the commonly used techniques for bone augmentation.
- Understand the advantages and disadvantages of various types of bone grafts.
- Discuss the limitations of nonautogenous grafts.
- Identify and manage complications associated with grafting.

Alveolar defects resulting from loss of teeth or trauma often require bone augmentation before dental implants are placed. Attempting to place implants in locations with significant bone loss or lack of bone formation may lead to implant failure or a comprised position of the implant and patient dissatisfaction. The process of grafting involves a combination of biomaterials and clinical procedures, both of which affect the outcomes of the grafting procedure. Several types of grafts and materials are used for grafting (Table 5-1). These materials are classified in a general sense as *autogenous* (from the same person) or *nonautogenous*. Common surgical techniques include guided bone regeneration (GBR), onlay block grafting, and interpositional grafting. In choosing the technique or grafting material to use, the dental practitioner must evaluate characteristics such as the size and geometry of the anatomic location to be grafted.[1]

OVERVIEW OF DIFFERENT TYPES OF BIOMATERIALS

Autologous (or autogenous) bone is often referred to as the "gold standard" for regenerative and reconstructive procedures. However, performing a bone harvest, either intraorally or extraorally, may lead to significant morbidity for the patient. To overcome this problem, alternative materials have been developed; these materials are known collectively as *biomaterials*.[2,3] Ideally, a biomaterial is able to:

- Form bone by transplanting osteoblastic cells to the site (i.e., it is osteogenic)
- Induce bone formation (i.e., it is osteoinductive)
- Act as a scaffold for the creation of new bone (i.e., it is osteoconductive)

Only autologous bone and certain growth factors have all these characteristics. Bone substitutes have principally osteoconductive properties.

AUTOGENOUS BONE

FEATURES

Autogenous bone is often favored over other nonautogenous grafts because it is osteogenic, osteoconductive (it can act as a scaffold to support the ingrowth of new tissues and cells), and osteoinductive (it can induce stem cells into the osteoblastic pathway). Autologous bone provides mechanical support to the vessels and cellular elements that colonize the grafting site; it stimulates bone formation at the graft site; and it contains

Table 5-1 Types of Bone Grafts and Grafting Materials

TYPE OF GRAFT/MATERIAL	DESCRIPTION
Autogenous graft	• Transferred from one location to another in the same individual • Intraoral or extraoral donor sites
Allogenic graft	• Transferred between genetically dissimilar members of the same species • Mineralized bone allograft • DFDB commonly used ◦ Freeze-drying reduces antigenicity of material and exposes BMPs
Xenogenic graft	• Taken from a donor of another species • Bovine bone mineral commonly used
Alloplastic materials	• Inorganic, synthetic, biocompatible bone graft substitutes • Hydroxyapatite, beta tricalcium phosphate, polymers, bioactive glasses
Growth factors	• Specific factors obtained from the patient (PRP), or • Molecular biologic technique used to produce large quantities of growth factors (BMPs, PDGF, PepGen)

BMPs, Bone morphogenetic proteins; *DFDB,* Demineralized freeze-dried bone; *HA,* hydroxyapatite; *PDGF,* platelet-derived growth factor; *PRP,* platelet-rich plasma.

mature cellular elements that can directly create new bone.

The graft is harvested from the patient using either extraoral sites (e.g., the iliac crest or tibia) or intraoral donor sites (e.g., the mandibular symphysis, maxillary tuberosity, or mandibular ramus). The size of the defect helps determine which site is chosen. For isolated defects intraoral grafts have advantages over extraoral grafts, such as ease of access, proximity of the donor site and alveolar defect, ability to harvest in the office, decreased cost, and avoidance of morbidity associated with extraoral harvest sites.[4,5]

The inorganic component of bone (hydroxyapatite) contributes to the rigidity of the graft; the organic component (collagen) provides strength, durability, and stability. Autologous bone grafts may be the cortical, cancellous, or corticocancellous type.

Cortical Bone Grafts

Cortical bone grafts are blocks composed predominantly of cortical bone. They provide a very dense, compact bone that offers great structural support. A cortical bone graft is suitable for reconstruction of both horizontal and vertical defects and is usually placed as a block graft secured with screws to the underlying ridge (Figure 5-1). This type of graft takes longer to revascularize than a cancellous graft.

Cancellous (Particulate) Bone Grafts

Cancellous bone grafts consist predominantly of trabecular bone tissue. Cancellous bone has higher osteogenic and osteoinductive properties than cortical bone and a larger number of progenitor cells and osteoblasts.

The structure of cancellous bone allows rapid revascularization of the graft. It also reduces the number of cells that undergo necrosis, allowing more rapid neoangiogenesis, with early incorporation of the graft. These grafts often exhibit greater resorption than block grafts because of their lower density. A limitation of cancellous bone grafts is their instability immediately after placement. This type of graft requires a rigid biologic scaffold provided by barriers or walls of bone. Cancellous bone grafts are suitable for covering peri-implant osseous defects and periodontal fenestrations, for obtaining small alveolar reconstructions in GBR, for filling the spaces between cortical bone grafts, and for sinus lift and split-crest procedures (Figure 5-2).[6]

Corticocancellous Bone Grafts

Corticocancellous bone grafts are composed partly of compact (cortical) tissue and partly of spongy (trabecular) tissue. Ideally they have the best features, because they are cellular; they have a large number of osteoblasts and osteoprogenitor cells; and they also give good structural support.

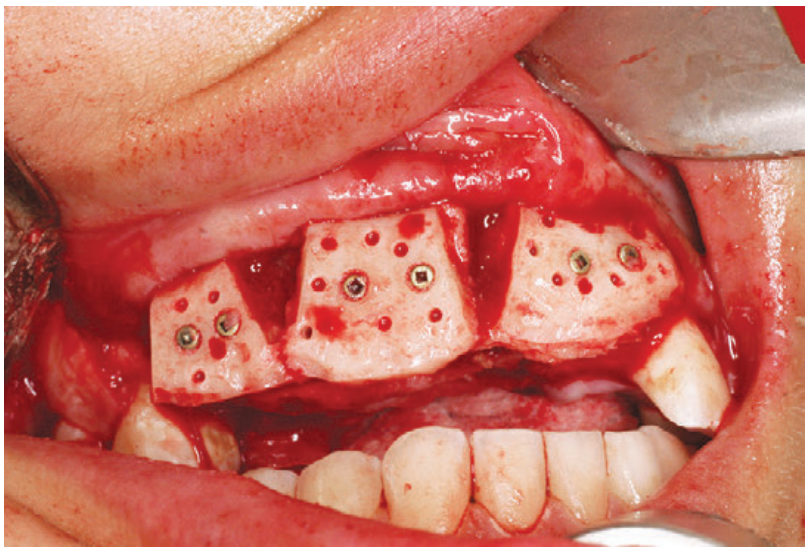

Figure 5-1 Block grafts harvested from the iliac crest are secured in place with titanium screws.

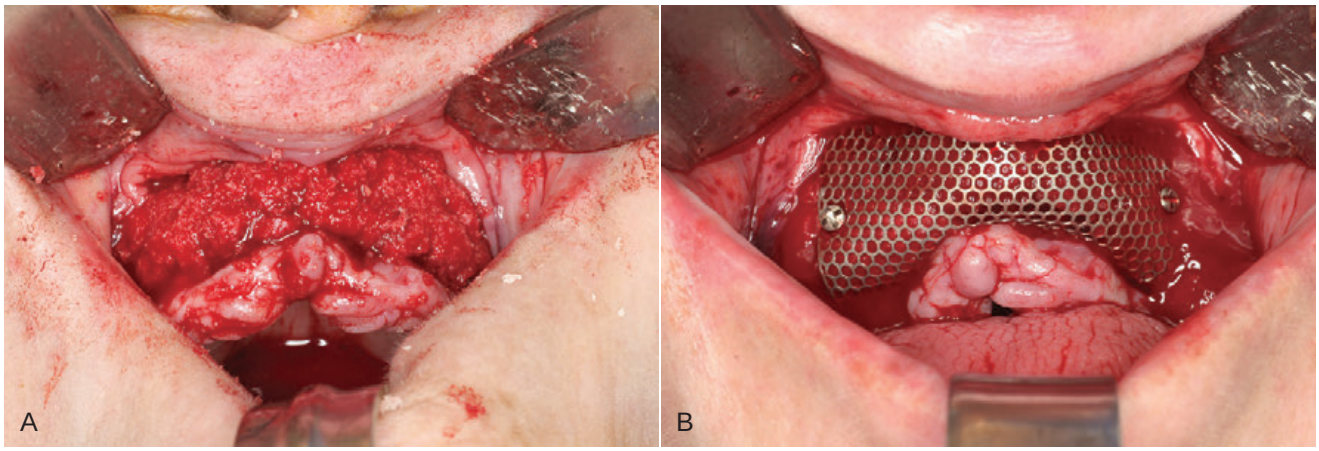

Figure 5-2 **A,** Cancellous bone graft is harvested from the iliac crest for anterior maxillary reconstruction. **B,** Titanium mesh is adapted to secure the graft in place and guide bone growth.

DONOR SITES

The choice of the site for bone harvesting depends on the quantity and quality of bone needed to restore the proper morphology of the alveolar ridge. The choice also is influenced by the conditions at the recipient site, the patient's expectations, and the dental practitioner's capabilities and preferences. The available literature is a good reference source for determining specific sites according to an evidence-based approach to the grafting of various defects.[7,8]

Intraoral Donor Sites

Intraoral bone samples are indicated for reconstruction of bone defects that affect edentulous areas of one to three teeth or, alternatively, to provide enough bone to fill a sinus, because the amount of bone harvested is limited (Figure 5-3). A major advantage of an intraoral donor site is that the harvest site is close to the defect[9,10]; this translates into reduced operating and anesthesia time and often accelerated healing because of the rapidity of mucosal healing in the oral cavity. In addition to their reduced postoperative morbidity compared with extraoral sites (and the use of transcutaneous access), intraoral sites leave less scarring. Generally, this grafting procedure can be performed using local anesthesia or intravenous sedation, which reduces costs.

The most commonly used intraoral donor sites from which bone is harvested for reconstruction of alveolar defects before placement of dental implants are:

- The mandibular ascending ramus (third molar region)
- The mandibular symphysis
- The maxillary tuberosity

Extraoral Donor Sites

An advantage of extraoral sites is that a large amount of bone can be harvested for reconstruction of large defects.[11] A disadvantage of all extraoral sites is the need for a surgical site in addition to the intraoral site and the possibility of postoperative morbidity associated with the donor site. General anesthesia and hospitalization are often required for patients undergoing extraoral bone harvest. The main extraoral harvest sites are:

- The iliac crest
- The proximal tibia
- The cranium

ADVANTAGES AND DISADVANTAGES

The use of autogenous bone grafts has several advantages. The greater osteogenic ability of autogenous bone, compared with that of xenografts and allografts, results in more efficient release of osteoinductive growth factors and a better osteoconductive surface for cell attachment and growth. Autogenous bone also is highly biocompatible with the recipient grafting site and has the economic benefit of low cost.

Despite its advantages, autogenous bone has some disadvantages, such as the risk of donor site

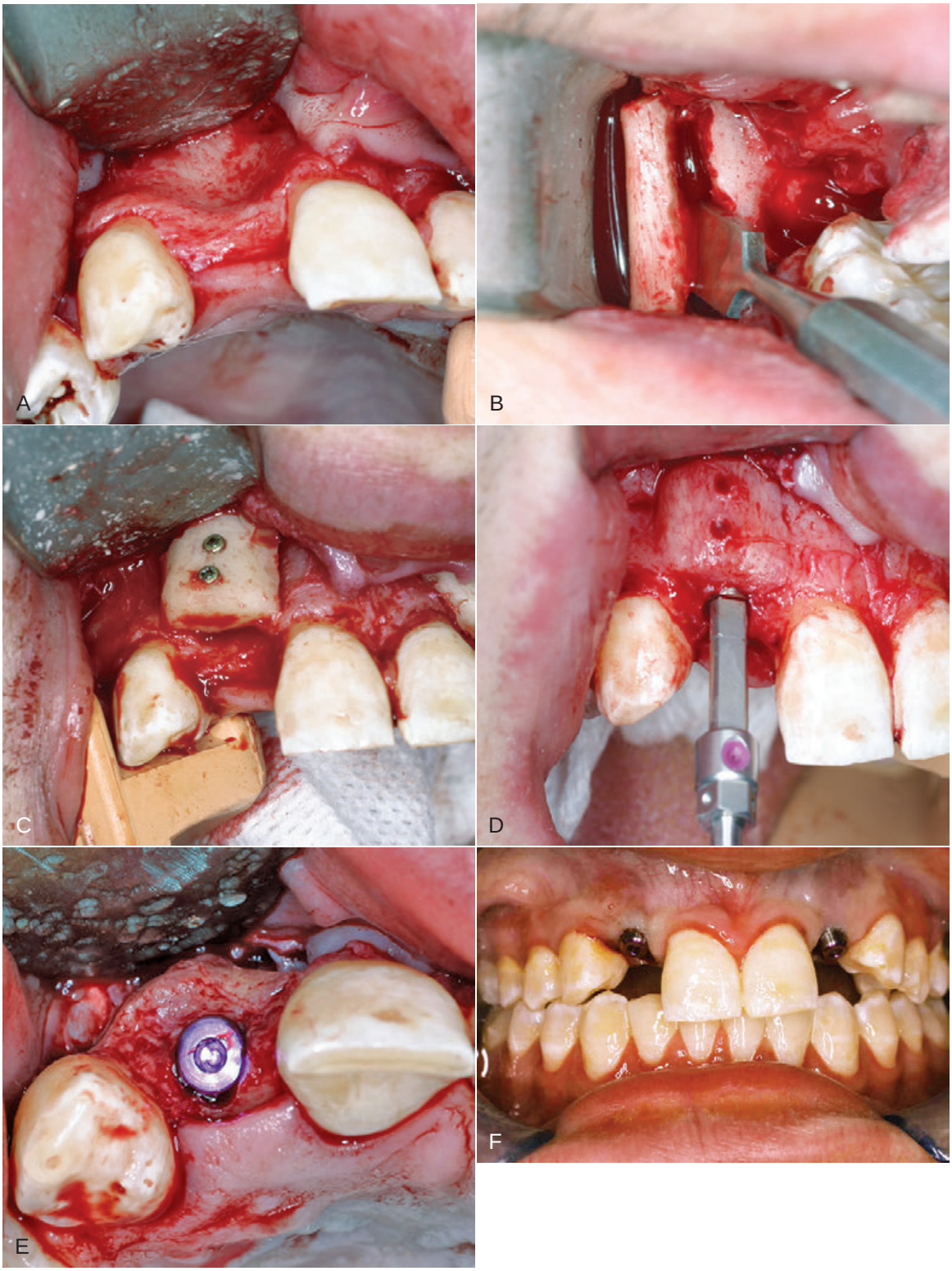

Figure 5-3 **A,** Bone defect in the area of a congenitally missing lateral incisor. **B,** An intraoral graft is harvested from the mandibular ramus. **C,** The graft is secured in place with titanium screws. **D,** An implant is placed in the grafted site. **E,** Implant in place. **F,** Implants are placed to restore missing teeth.

morbidity and the need for two surgical sites. The use of two surgical sites can increase both postoperative stress and the risk of infection. Additionally, the patient has a longer recovery time.

ALLOGRAFTS AND ALLOPLASTS

FEATURES

Allografts are obtained from other individuals of the same species but different makeup. The grafting tissues typically are processed from cadaver materials under sterile conditions. To prevent an immune reaction in the recipient, homologous bone is often freeze-dried (freeze-dried bone [FDB]) or demineralized and freeze-dried (DFDB).[12]

Alloplasts are grafts made of inert synthetic materials, usually calcium phosphate. Depending on their construction, alloplasts may be resorbable or nonresorbable.[13,14]

ADVANTAGES AND DISADVANTAGES

The use of homologous bone for grafts has many advantages, including osteoconductive ability, a physical structure similar to that of the recipient, and the availability of large amounts of donor bone. The two main advantages over autogenous bone are the elimination of the risk of donor site morbidity and the reduced surgical time.

The use of homologous bone also has numerous disadvantages. In rare cases it can cause an immune reaction, and the risk exists that it could transmit a viral infection from the donor to the recipient. Although large amounts of bone are available, the clinician still must depend on a bone bank as a source. In addition, success with large defects has been limited (especially in gaining adequate height); significant resorption or limited resorption (hydroxyapatite [HA]) has been noted; and the graft material is not osteoinductive.[15]

XENOGRAFTS

FEATURES

Heterologous grafting materials are derived from species other than the recipient (e.g., coral [HA], cattle, horses, and swine). These materials are inert and slowly resorbed. Natural hydroxyapatite is obtained from the calcium carbonate ($CaCO_3$) skeleton of corals. It has the three-dimensional microstructure of bone with a natural porosity of 60%, an average pore diameter of 200 μm, and a calcium-to-phosphate ratio of 10:6.

HA is highly biocompatible and immediately binds with the adjacent hard and soft tissues. With its well-organized porous and permeable structure, the newly formed bone graft is reshaped in response to the same chemical and biomechanical forces that remodel the native bone. Disadvantages of this type of material include brittleness and difficulty in handling. Also, it may migrate in the connective tissues during the healing period.

Another heterologous material, inorganic, deproteinized bovine bone, is chemically treated to remove all organic components. A thermal process that differs, depending on the material to be obtained, is used for this purpose.

OsteoGraf N (Ceramed Dental, Lakewood, Colorado) uses a sintering process at high temperature (1100° C), which causes fusion of bone crystals and reduced porosity. Another chemical process uses a lower temperature (300° C), which preserves trabecular architecture and porosity. When the graft is processed at a low temperature (e.g., BioOss; Geistlich AG, Wolhusen, Switzerland), it maintains the natural crystalline structure of apatite, a characteristic important for remodeling. The material is then sterilized, and antigens are removed (Figure 5-4).

These materials have micropores and macropores that promote both the stability of the clot and the apposition of new bone within the graft's structure. These grafting materials can be used alone or can be mixed with autologous bone to improve the osteoinductive capacity of the graft.[16]

Apatite inorganic bovine bone integrates well into the recipient site, histologically shows direct contact with the parent bone, and undergoes slow resorption.[17,18]

ADVANTAGES AND DISADVANTAGES

Xenografts are similar to autogenous bone grafts in that both are osteoconductive and relatively inexpensive. Additionally, they do not lengthen the healing time, and the need for a second surgical site for bone harvesting is eliminated. Unlike

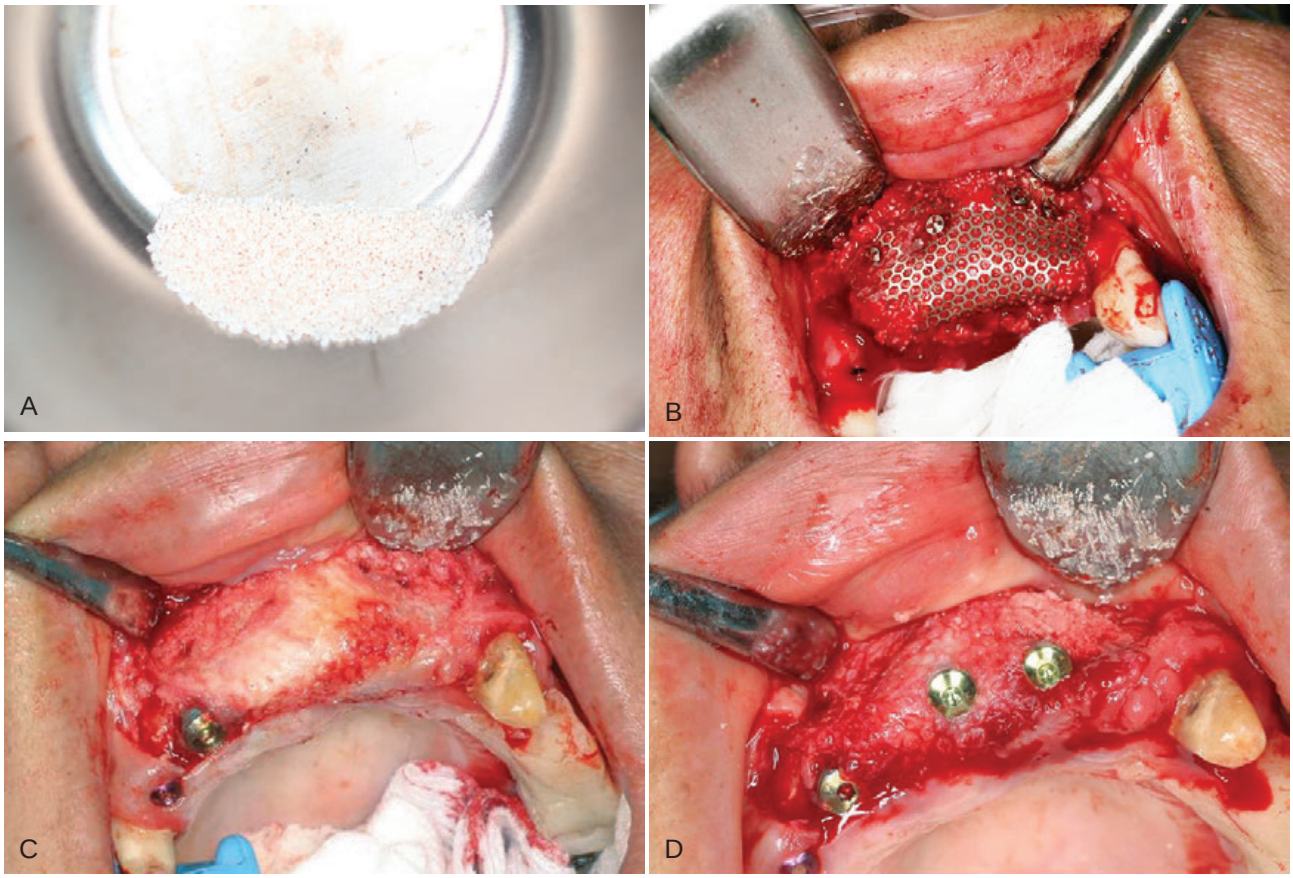

Figure 5-4 **A,** Bovine bone graft. **B,** The graft is secured in place with titanium mesh. **C,** The mesh is removed, showing the healed bone graft. **D,** Implants placed in grafted bone.

with homologous bone, the clinician is not dependent on bone banks, and the material is readily available.

However, much like their homologous counterparts, xenografts carry a rare risk of causing an immune reaction, and they have demonstrated an inability to gain adequate height and width for large defects. Also, they are not always available in formulations that allow easy adaptation or modeling.

OSTEOINDUCTIVE MATERIALS

FEATURES

With the introduction of recombinant human bone morphogenetic protein 2 (rhBMP-2) and recombinant human platelet-derived growth factor (rhPDGF), clinicians now have another option for reconstructing isolated alveolar defects.

Bone morphogenetic proteins (BMPs) is the generic name for a family of proteins that can form bone de novo, for which they are considered osteoinductive. These growth factors have been shown to cause differentiation of stem cells toward different cell lines (adipose tissue, cartilage, and bone). Specifically, BMP-2 influences stem cells to differentiate into bone-forming cells (osteoblasts). rhBMP-2 has been shown to be clinically effective both for isolated alveolar defects and for sinus augmentation (Figure 5-5).[19,20]

ADVANTAGES AND DISADVANTAGES

Growth factors have several advantages, such as the possibility of inducing new bone formation using a bone substitute without autogenous bone, a reduced healing time, and reduced total surgical time. In addition, the need for graft harvest sites (with the possible associated morbidity) is eliminated.

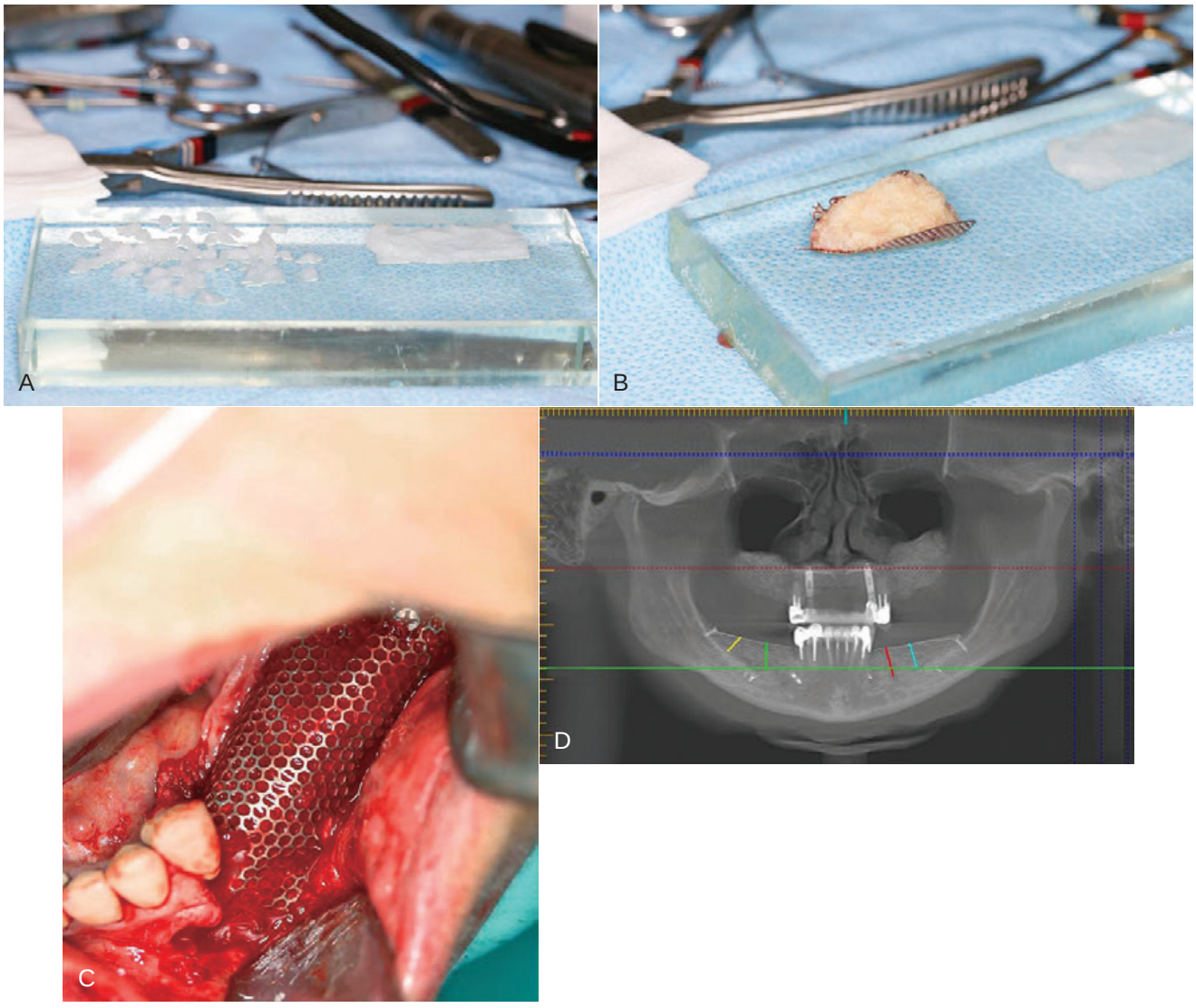

Figure 5-5 **A,** Recombinant human bone morphogenetic protein 2 (rhBMP-2) combined with collagen sponge. **B,** Titanium mesh filled with rhBMP-2. **C,** Titanium mesh secured in place. **D,** Titanium mesh in place; bilateral sinus lifts.

Some disadvantages of growth factors include the high cost, limitations on the scaffolding needed, and a risk of significant edema postoperatively.

SUMMARY OF SURGICAL PROCEDURES FOR GRAFTING

RIDGE SOCKET PRESERVATION AFTER EXTRACTION

After a tooth is extracted, physiologic resorption occurs in the socket as a result of lack of function and loss of the facial plate because of its primary composition as bundle bone. This physiologic alveolar resorption may be minimized by using regeneration techniques and biomaterials.[21]

ONLAY BLOCK GRAFTING

The harvesting of bone blocks from inside the mouth is often the preferred technique for correcting a severely narrow ridge. When a larger amount of bone is needed, the autogenous block can be harvested from extraoral sites. It is important to perforate the underlying cortex at the recipient site to stimulate bleeding before securing the graft

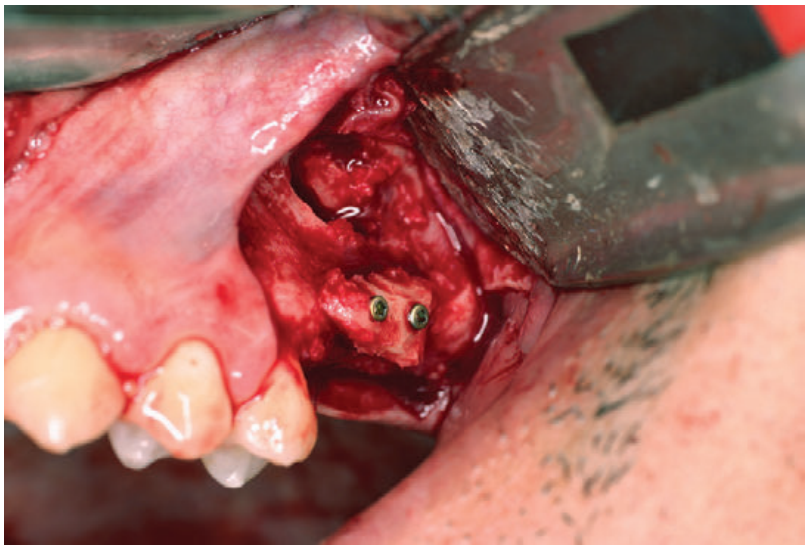

Figure 5-6 Maxillary osteotomy for sinus elevation.

in place. A minimum of two screws should be placed to prevent mobility of the graft during healing. It also is important to perform tension-free flap closure to prevent postoperative exposure of the graft during the healing period. The grafts should be allowed to heal for approximately 6 months before an implant is placed to allow sufficient incorporation of the graft.

GUIDED BONE REGENERATION

Guided bone regeneration is a surgical technique that uses barrier membranes to direct, or guide, the growth of new bone at the site of the defect. The principle underlying GBR is that the barrier membranes create and maintain a space above the bone defect; this allows the slower mesenchymal cells with osteogenic potential to populate the defect and regenerate without interference from the more quickly proliferating overlying soft tissues. Protection of the clot in the defect, exclusion of gingival connective tissue cells, and preparation of an enclosed space in which osteogenic cells can migrate from the bone are three essential elements of a successful outcome.[22]

Many types of grafts have been used as space maintainers between the membrane and the bone defect. Autografts, allografts, and xenografts have all been used successfully, either alone or in combination, for bone regeneration using particulate materials.

SINUS ELEVATION

A condition of enlarged maxillary sinuses and reduced residual maxillary posterior bone height often requires augmentation procedures before dental implant placement. Internal augmentation of the maxillary premolar and molar region was introduced in 1980 to provide an appropriate amount of bone in a severely resorbed maxilla.[23] The technique involves creating an osteotomy into the maxillary sinus and gently elevating the schneiderian membrane. The bone graft is then placed along the floor of the sinus beneath the sinus membrane (Figure 5-6).

Grafting of the maxillary sinus with different materials, including autogenous and nonautogenous bone, has proved clinically successful. The performance of sinus grafting procedures either before or simultaneously with implant placement has been proposed. Many allogenic, xenogenic, and alloplastic materials have been developed for use alone or in combination with autogenous bone in sinus grafting. Many recent works support the finding that bone substitute materials, used alone or in combination with autogenous bone, may be at least as effective as autogenous bone alone.[24,25]

MANAGEMENT OF COMPLICATIONS

Bone grafting is not without the risk of complications (Figure 5-7 and Box 5-1).[26] Ideally a

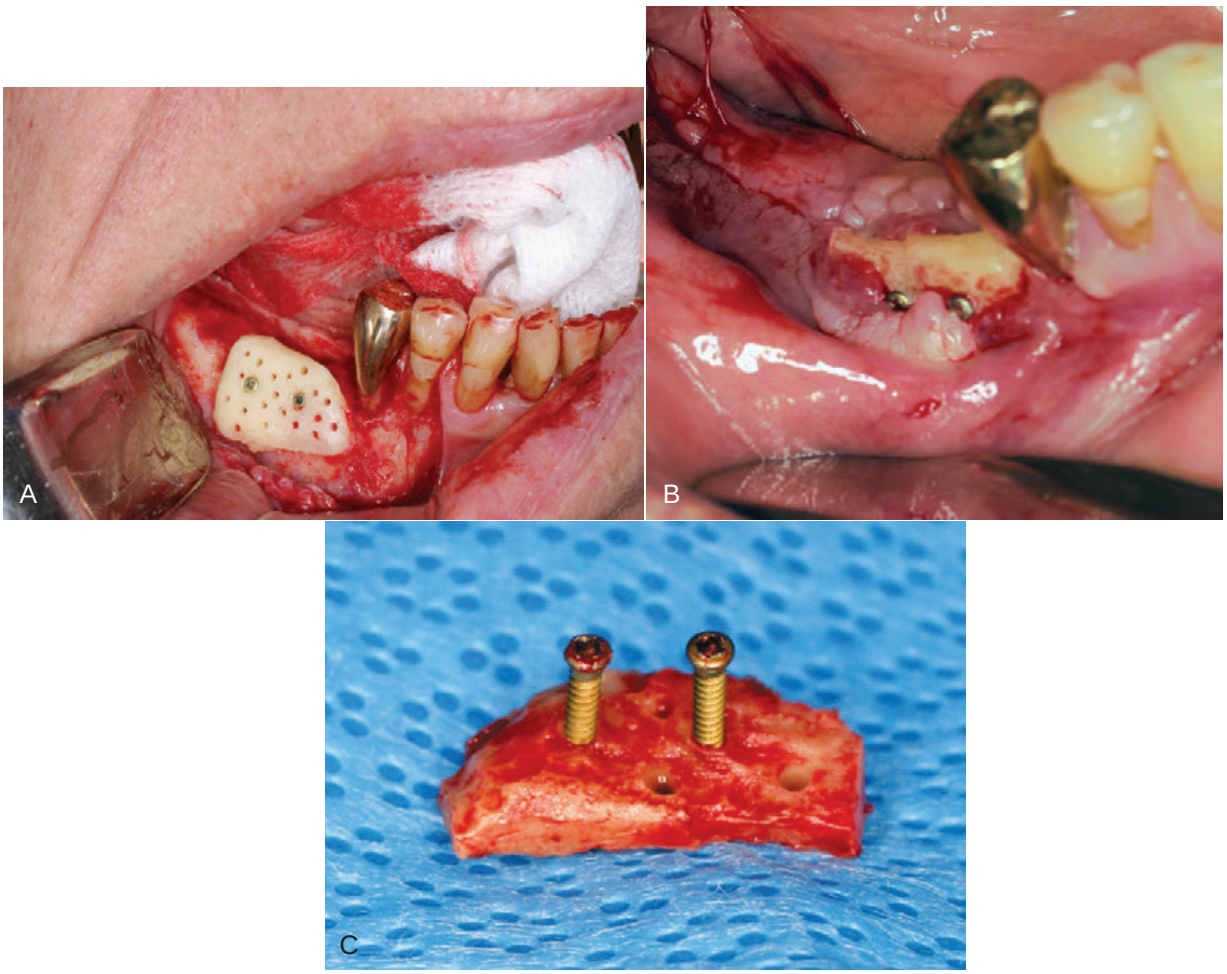

Figure 5-7 **A,** Cortical onlay graft secured in place. **B,** Exposed bone graft. **C,** Loss of graft.

Box 5-1 Bone Grafting Complications

- Exposure of the graft, resulting in loss of part or all of the graft material
- Injury to adjacent teeth during the procedure
- Surgical morbidity associated with the graft site
- Premature exposure of resorbable and nonresorbable membranes
- Infection of the graft

complication should be identified early. If the bone is exposed, it should be gently irrigated to prevent infection and antibiotics should be prescribed. If the graft becomes exposed to the oral environment during the early postoperative period, the likelihood of complete loss of the graft is high. Injury to adjacent teeth can be prevented by proper imaging before surgery to identify the root anatomy. The mortality of the recipient site varies based on the location and quantity of bone harvested. Intraoral grafts are associated with decreased morbidity. Exposure of nonresorbable membranes may lead to infection, and these membranes may need to be removed prematurely.

SUMMARY

Before implant placement, many patients can benefit from augmentation of the alveolar ridge, which can optimize reconstruction. Although autogenous bone remains the gold standard in the field of regenerative surgery, other biomaterials

have demonstrated usefulness and reliability. The choice of which surgical technique and graft material to use should be made after careful consideration of the benefits and risks associated with the procedures. Every attempt should be made to achieve the highest chance for success while minimizing possible morbidity.

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CHAPTER 6

Tooth Extraction and Site Preservation

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Chapter Outline

Alveolar Bone Healing After Tooth Extraction
Scientific Validation for Site Preservation
Surgical Techniques for Minimally Invasive Tooth Extraction
- Esthetic Evaluation
- Biotype Analysis
- Anesthesia
- Minimally Traumatic Exodontia
- Curettage
- Extraction Defect Sounding (EDS) Classification

Surgical Techniques for Site Preservation
- Biomaterials
- Regenerative Potential
- Surgical Protocols
- Complications Management

Prosthetic Manipulation of Soft Tissues During Healing
Clinical Outcome Analysis of Alveolar Preservation Techniques
- Limitations of Site Preservation
- Indications for Site Development

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the basic physiology of extraction defect healing and the benefits of site preservation in altering that response.
- Describe the surgical techniques and biomaterials needed to perform atraumatic tooth removal and site preservation.
- Explain the extraction defect sounding classification system and the associated treatment algorithms.
- State the limitations of site preservation and the circumstances in which advanced surgical procedures are necessary.

Dental implants are quite often the treatment of choice for the replacement of lost or missing teeth. Implant treatment is extremely predictable for partially as well as completely edentulous clinical conditions, and long-term survival rates of 85% to 100% have been reported.[1] The challenge today in implant dentistry is no longer just to achieve osseointegration, but also to attain balance and harmony between the implant restoration and the surrounding soft tissues (Figure 6-1). This is especially true in the esthetic zone.

The loss of a tooth commonly leads to hard and soft tissue alterations that challenge ideal implant placement, soft tissue esthetics, and long-term peri-implant tissue management. Tooth extraction is a traumatic surgical procedure that can result in immediate loss or fracture of alveolar bone. Soft and hard tissues are commonly traumatized during tooth extraction, compromising tissue esthetics. Damage to marginal bone may lead to recession of the marginal gingiva and coronal elongation of an implant restoration (Figure 6-2). Damage to the interproximal bone may lead to papilla shrinkage and the formation of interproximal "black triangles" (Figure 6-3) or force alteration of the restorative contact points, making restorations look bulky.

Physiologic wound healing after extraction is associated with morphologic alteration of the alveolar bone and soft tissue. Clot contraction in the socket leads to a reduction of alveolar bone width and height. An experimental study that evaluated morphologic changes in the alveolar process after tooth extraction showed an average loss of 2 mm of bone width. Soft tissue invagination in the socket leads to incomplete bone fill and reduction of alveolar bone height.[2-4] The loss of crestal bone height ultimately leads to a vertical soft tissue deficit and a compromised esthetic result. In these situations the implant platform often must be placed more apically than is ideal for a proper emergence profile, which leads to the development of deeper peri-implant probing depths; this development compromises home care and long-term management of the peri-implant tissues and increases the risk of peri-implant disease.[5] However, the loss of alveolar bone height and width can be minimized and very often prevented through the

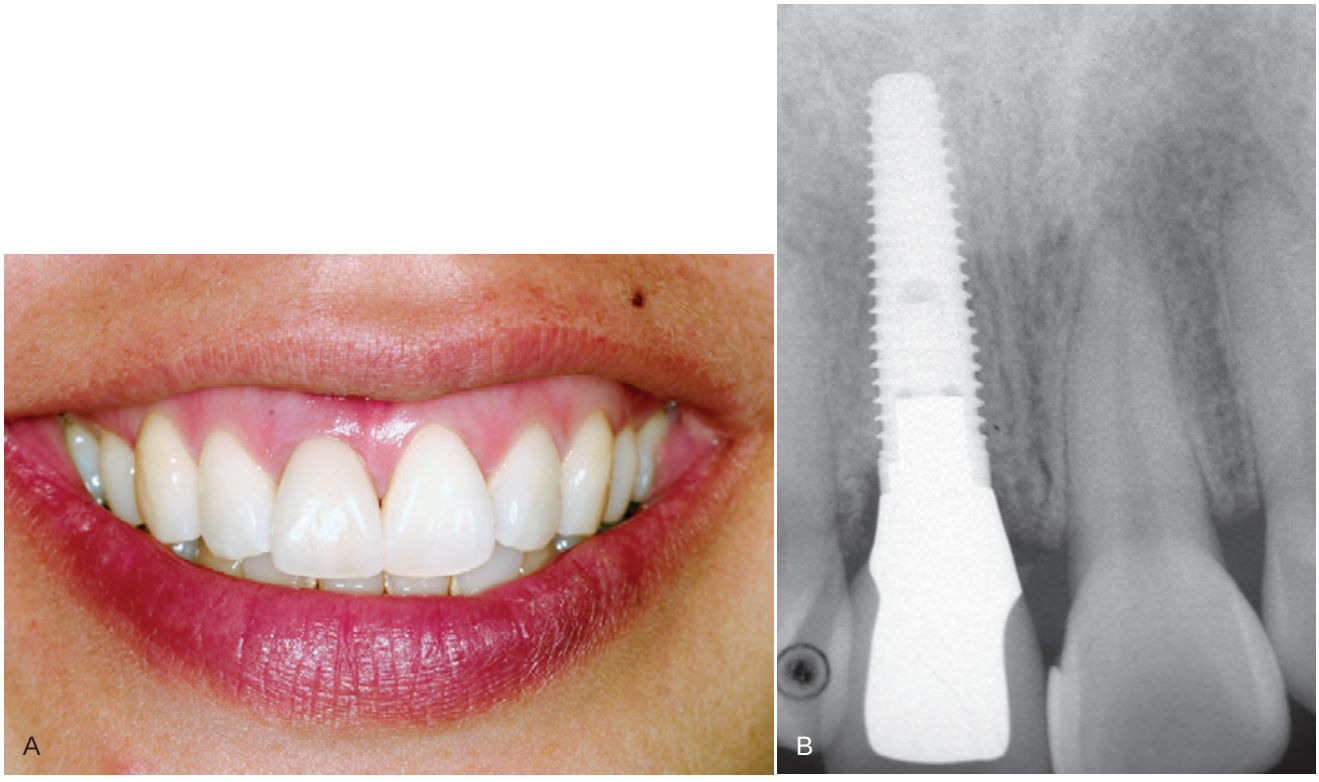

Figure 6-1 **A,** Implant restoration site #8 demonstrating balance and harmony with adjacent soft tissues. **B,** Radiograph of implant #8 depicting excellent bone condition.

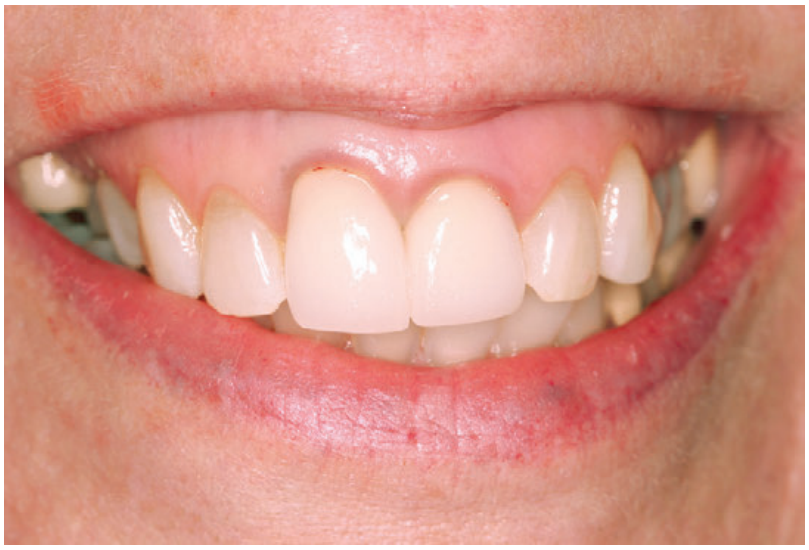

Figure 6-2 Marginal recession around implant restoration site #8.

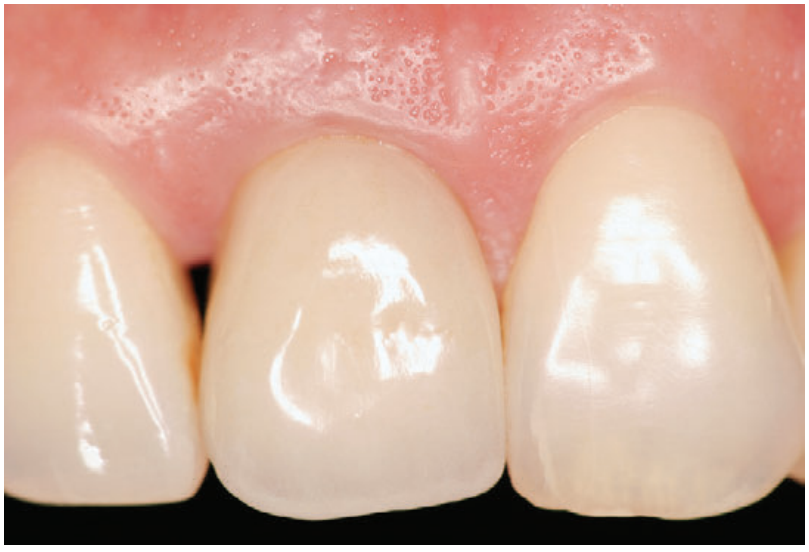

Figure 6-3 Interproximal papilla loss distal to implant site #8.

incorporation of site preservation procedures at the time of tooth extraction.

ALVEOLAR BONE HEALING AFTER TOOTH EXTRACTION

The healing of an extraction socket after tooth removal has been well studied in both animals and humans.[6] Studies in animals demonstrate that during the process of healing, a series of events occurs. It begins with the formation and maturation of a blood clot and proceeds to infiltration of fibroblasts to replace the coagulum and eventual establishment of a provisional matrix that allows for bone formation. In an experimental animal study, Araujo and Lindhe[2] noted that resorption of the buccal and lingual plates occurred after tooth removal. This resorption occurred in two phases. In phase I the bundle bone was resorbed and replaced with woven bone, leading to a substantial vertical reduction of the crest. In the second phase, resorption occurred from the outer surfaces of both bone walls. This ultimately led to a loss of ridge width. In a follow-up study by the same authors,[7] the effect of flap elevation on alveolar ridge dimension was examined. The authors

concluded that flap elevation had very little or no effect on the alveolar process. These studies suggest that alveolar ridge resorption is a physiologic outcome directly caused by tooth removal.

In a study by Schenk and Hunziger,[8] the alterations seen after tooth extraction were attributed to a decreased blood supply to the alveolus, which led to osteocyte cell death and necrosis of the surrounding tissue. In a further phase of healing, the necrotic bone may be gradually eliminated through surface resorption by osteoclasts in the periosteum. Additional factors related to these alveolar bone changes may be an adaptation to continued lack of function at the extraction site and tissue adjustment to meet genetically determined demands on ridge geometry in the absence of teeth. In a human study by Schropp et al.,[9] bone and soft tissue dimensions were examined after tooth extraction. The authors found that the width of the alveolar ridge was reduced by 50% during the 1-year observation period. Most of these changes (approximately two thirds), occurred within the first 3 months after tooth extraction.

These studies suggest a need for procedures that can minimize alveolar bone and soft tissue changes after tooth extraction when esthetics, function, and long-term maintenance require minimal changes. This is especially evident in the esthetic zone.

SCIENTIFIC VALIDATION FOR SITE PRESERVATION

In a 6-month randomized, controlled, blinded clinical and histologic study in humans, Iasella et al.[10] examined 24 patients who underwent extraction and then implant placement.[10] The aim of the study was to determine whether ridge preservation procedures would prevent postextraction resorption. Tetracycline-hydrated, freeze-dried bone allograft (FDBA) was placed in extraction sockets, and the grafts were covered with a collagen membrane. The authors concluded that ridge preservation improved ridge height and width dimensions compared with extraction alone. The mean width of preserved sites decreased by 0.8 mm, compared with a decrease of 2.7 mm in nonpreserved sites (a statistically significant finding). Most of the resorption was noted on the buccal aspects, and maxillary sites lost more width than did mandibular sites. Vertically, the preserved sites gained approximately 1 mm, compared with a loss of 1 mm in nonpreserved sites. A height difference of 2.2 mm was reported, which was statistically significant. However, the study also revealed a disadvantage of site preservation: the use of FDBA resulted in less bone by volume in the extraction defect, approximately 28% in the preserved sites compared with 54% in the nonpreserved sites. This was predominantly the result of the presence of residual graft particles.

In a 6-month split mouth study in the dog using bovine collagen (Bio-Oss), Araujo and Lindhe[11] histologically noted better dimensional integrity of the alveolar process compared with nonpreserved sites. The authors found that the bovine collagen served as a scaffold for tissue modeling. However, as in the study by Iasella et al., the procedure did not enhance bone volume. Araujo and Lindhe[11] concluded that placement of a biomaterial in an extraction socket may modify modeling and counteract marginal ridge contraction that naturally occurs after tooth removal.

In a histomorphometric evaluation of mineralized cancellous allograft (Puros) covered by a bioabsorbable collagen dressing in human extraction defects, Wang and Tsao[12] noted favorable bone growth in the extraction defects.

These studies suggest that the benefits of site preservation procedures are not material specific. Multiple graft materials have been used successfully for site preservation. However, some materials may work better than others.[13] The benefits of adding a graft material to a fresh extraction socket derive from an alteration in healing through the occupation of space by the graft material, which improves clot stability and reduces clot shrinkage and contraction.

SURGICAL TECHNIQUES FOR MINIMALLY INVASIVE TOOTH EXTRACTION

Site preservation has been shown to significantly improve alveolar ridge height and width by minimizing physiologic alveolar shrinkage associated with tooth removal.[14] However, the surgical procedure for removing a tooth can easily lead to a much more significant amount of tissue loss in a matter

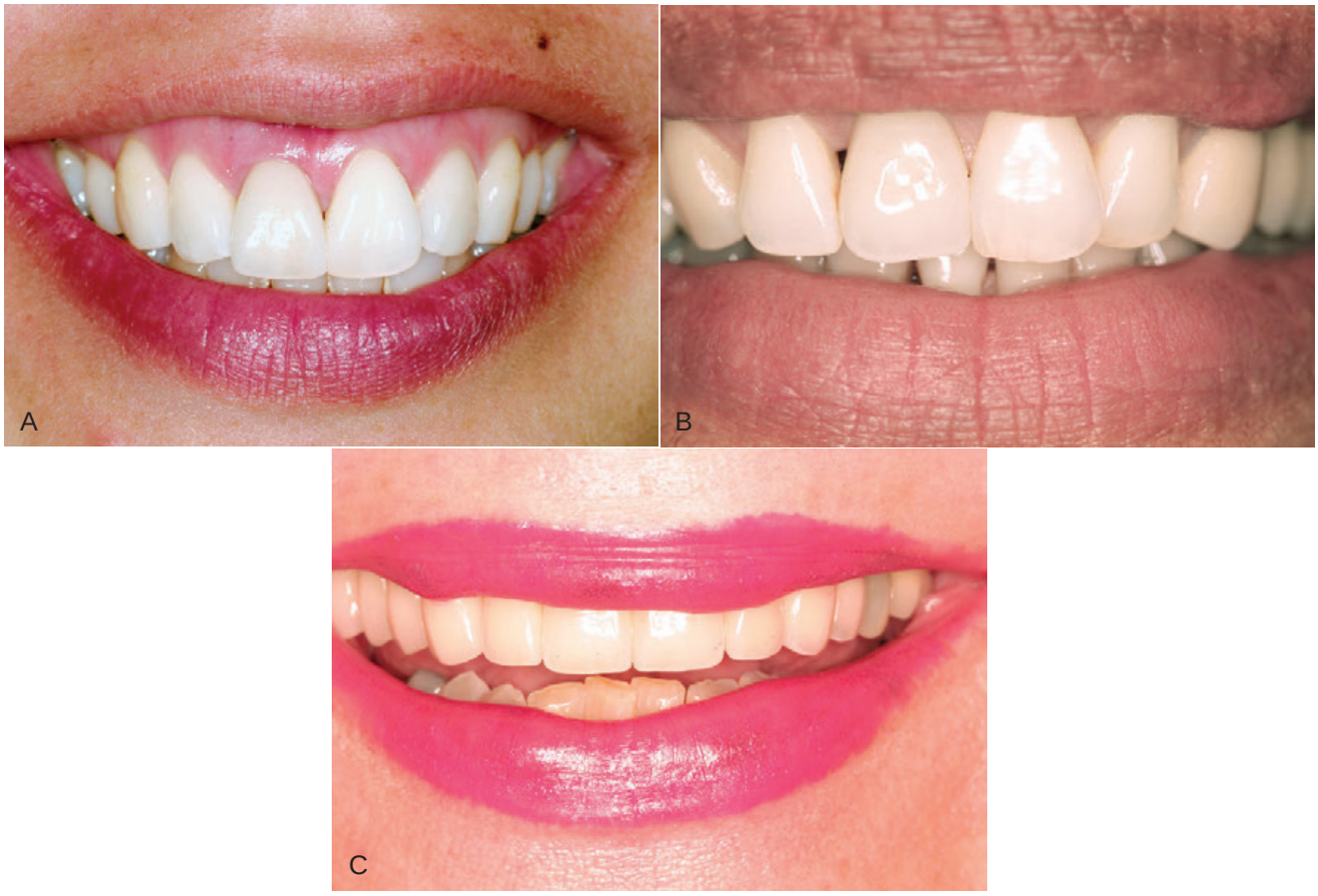

Figure 6-4 Smile line documentation is crucial to a proper esthetic evaluation. **A,** High smile line. **B,** Moderate smile line. **C,** Low smile line.

of minutes. Fracture of the alveolus, bone removal with the extracted tooth, and trauma to the soft tissues all are complications related to exodontia that can lead to significant hard and soft tissue deficits. This type of damage is also extremely difficult to repair predictably. Therefore, preventing such trauma and performing minimally invasive extractions are critical for sites that require minimal alveolar changes after tooth removal. Minimally traumatic tooth extraction should be considered the first step for successful site preservation. The following procedures are beneficial for all extraction sites but crucial in the esthetic zone[15]:

- Esthetic evaluation
- Biotype analysis
- Anesthesia
- Minimally traumatic exodontia
- Curettage
- Extraction defect sounding

ESTHETIC EVALUATION

Before removing a tooth, the dental practitioner should perform a soft tissue evaluation that focuses on esthetics and document the details. This is extremely important when dealing with extractions in the esthetic zone or any extraction in a patient who is esthetically demanding or particular. The evaluation should document the smile line (Figure 6-4) to determine the extent of gingival display; the gingival margin positions of the adjacent teeth, with notations of any asymmetries; and the condition of the interproximal papillae (Figure 6-5). The size, shape, and form of the papillae are important to recognize and document, because this can help preclude or minimize loss of interproximal papillae. Loss of the interproximal papillae often leads to the formation of interproximal spaces commonly referred to as "black triangles." A thorough esthetic evaluation

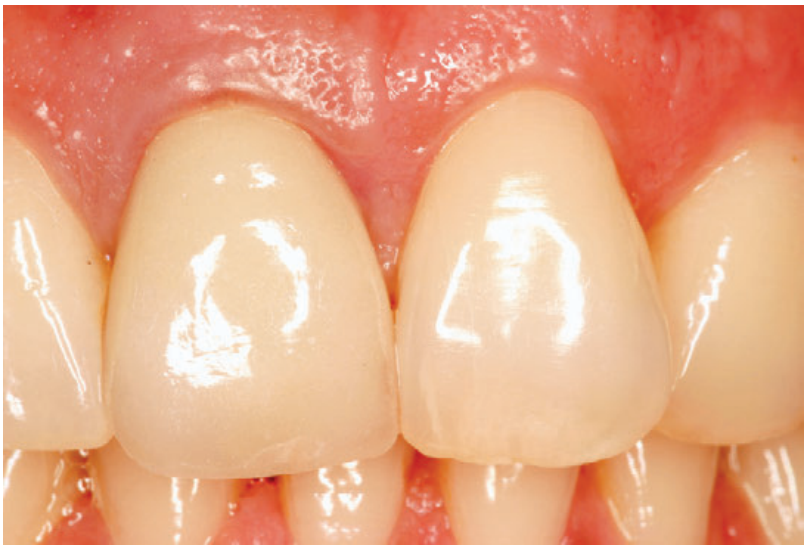

Figure 6-5 Recognition of the character of the papillae before surgery is crucial. Long, thin papillae, as seen here, are susceptible to recession after surgery.

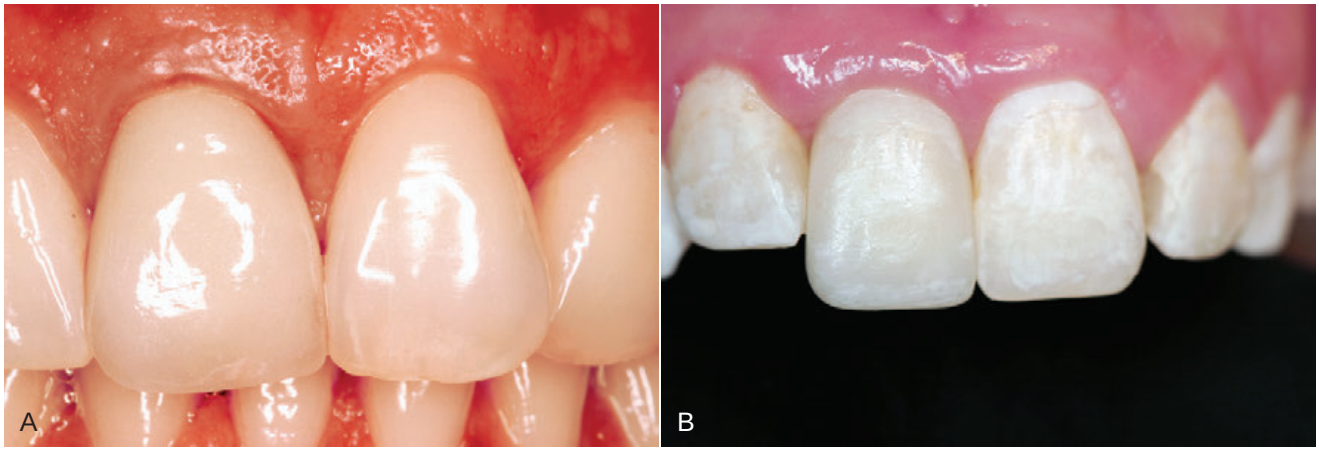

Figure 6-6 Biotype analysis. **A,** Thin biotype. **B,** Thick biotype.

before tooth removal allows the practitioner to discuss expected healing outcomes accurately with the patient and to predict the alteration to the soft tissues.

BIOTYPE ANALYSIS

Recognition and documentation of the patient's periodontal biotype are important for predicting hard and soft tissue healing; this also allows modification of the surgical procedure, when indicated, to enhance esthetics.[16] An understanding of the biotype is extremely important for patient communication and expectations. In a clinical study, two basic tooth forms were observed and correlated with various soft tissue clinical parameters, leading to the description of two discrete periodontal biotypes (Figure 6-6).[17]

The thick, flat periodontium is associated with short, wide tooth forms. This biotype is characterized by short, flat interproximal papillae; a thick, fibrotic gingiva that is resistant to recession; wide zones of attached keratinized tissues; and thick underlying alveolar bone that is resistant to resorption.[18] Wound healing is ideal in this type of periodontium, because bone resorption and soft tissue recession are minimal after surgical procedures, including extractions and dental implant surgery. Ideal implant soft tissue esthetics can be predictably achieved in patients with this biotype.

In contrast, the thin, scalloped periodontium is usually associated with long, narrow, triangular

tooth forms. This biotype is characterized by long, pointy interproximal papillae; a thin, friable gingiva; minimal amounts of attached keratinized tissues; and thin underlying alveolar bone that is frequently dehisced or fenestrated.[18] After surgical procedures, marginal and interproximal tissue recession in conjunction with alveolar resorption can be expected in patients with this biotype.[16] A careful, minimally traumatic extraction technique performed with microsurgical instruments is necessary in these patients to help preserve the alveolar architecture.

ANESTHESIA

A local anesthetic is minimally required. A small amount of vasoconstrictor (e.g., lidocaine 2% 1:100,000 epinephrine) can be used to aid visualization of the bone and surrounding soft tissues during surgery, which helps minimize trauma. Use of a vasoconstrictor also aids visualization of the extraction fundus immediately after tooth removal; this allows the practitioner to ensure adequate débridement of all tissue remnants, granulation tissue, and other debris, a critical step in promoting bone fill in the socket.

MINIMALLY TRAUMATIC EXODONTIA

The use of oversized and conventional elevators should be avoided when possible, especially in critical areas, such as the esthetic zone. Although these instruments are highly effective at tooth luxation, they are also associated with a high degree of hard and soft tissue trauma. Microinstruments can better achieve minimally traumatic tooth removal.

A periotome is an extraction instrument that is based on the mechanisms of wedging and severing with a thin, flat blade to facilitate tooth removal. Periotomes can be used to luxate the tooth in the depths of the gingival sulcus; this results in circumferential separation of the gingival attachment, preventing excess trauma to the interproximal papillae and marginal gingiva.

As continued apical pressure is exerted, the periotome is inserted into the periodontal ligament space along the root surfaces, severing the periodontal ligament directly below the alveolar crest. This process is continued until the periotome penetrates to a depth sufficient to initiate tooth mobility (Figure 6-7). Quite often a surgical mallet is used to facilitate the process. Once the tooth is sufficiently mobile, conventional extraction forceps can be used with rotational force to gently remove the tooth, without the need for further luxation and associated trauma. The use of a periotome is limited to the interproximal and palatal aspect of a tooth. To preserve the integrity of the buccal plate, the buccal tooth surface is avoided when a periotome is used; this helps maintain the integrity of the gingival margin, which is critical for an optimal esthetic result. The disadvantages of using a periotome include fatigue

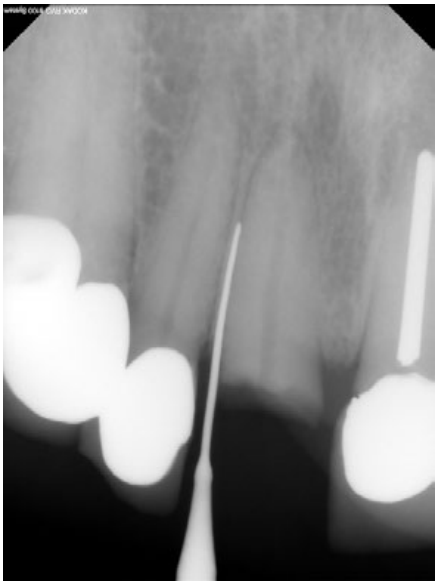

Figure 6-7 Periotome penetration into the periodontal ligament (PDL) space initiates tooth mobility.

and an increase in the time needed to accomplish the extraction procedure.

The Powertome (WestPort Medical, Salem, Oregon) is a mechanized periotome that provides the advantages of minimally traumatic extraction along with increased speed and decreased effort. The periotome blade is controlled by a solenoid in the handpiece. Power output to the handpiece may be adjusted to various settings. The instrument blade is inserted interproximally in the periodontal ligament space and activated with a foot switch. The blade is kept parallel to the long axis of the tooth and follows the contours of the root in a sweeping motion, slowly advancing apically in millimeter increments. The blade advances easily with minimal hand pressure, yielding much faster results with less effort compared with the traditional, nonmechanized periotome. After the Powertome has been used, the mobile tooth can be gently removed with forceps with minimal trauma (Figure 6-8).

The Easy X-TRAC system (Titan Instruments, Hamburg, New York) is another useful device for minimizing tooth extraction trauma, especially for severely decayed or fractured teeth. It minimizes trauma by completely avoiding mechanical luxation of a tooth and the need for luxation instrumentation and extraction forceps. The system uses a series of drills that enlarges the root canal space for placement of an anchor screw. Screws of various lengths allow the extraction of teeth in various clinical conditions. Once the anchor screw has been stabilized in the root canal space, a protector tray is used to brace the adjacent teeth and provide a fulcrum point to "lift" the tooth from the socket by pulling against the anchor screw. The extractor, which is somewhat like a pliers, is positioned between the protector tray and the head of the anchor screw. Expanding the extractor gently lifts the tooth or root fragment from the alveolar bone with minimal trauma (Figure 6-9).

CURETTAGE

After tooth extraction and in preparation for site preservation, the tooth socket should be thoroughly débrided to remove all remnants of the periodontal ligament and any other soft tissues and debris, including granulation tissue.[15] The practitioner should inspect the socket walls and fundus to make sure all soft tissues have been removed and a bleeding surface is present. Bleeding in the socket is necessary to promote healing. If bleeding inside the socket is inadequate, the cribriform plate is perforated with a periodontal curette or rotary instrument to promote bleeding and potentiate healing.

EXTRACTION DEFECT SOUNDING (EDS) CLASSIFICATION

When implant dentistry is anticipated after tooth extraction, the clinician is faced with many

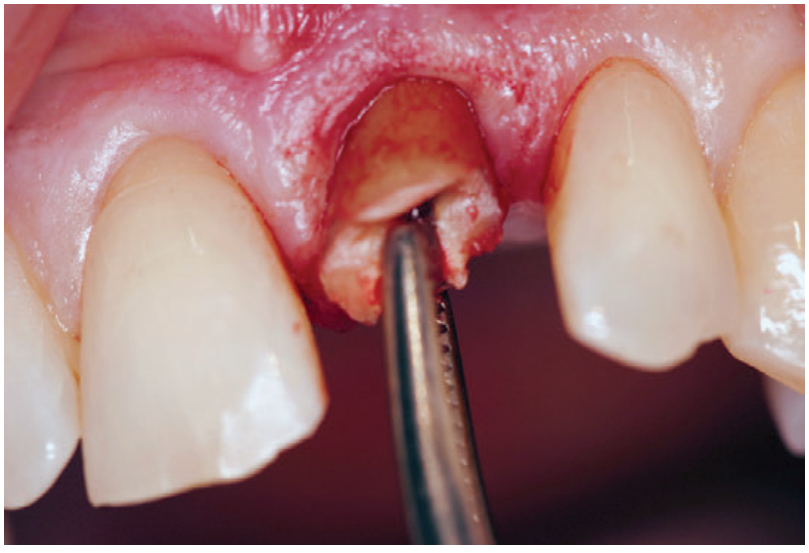

Figure 6-8 After use of a periotome, even difficult teeth can be easily removed with minimal trauma.

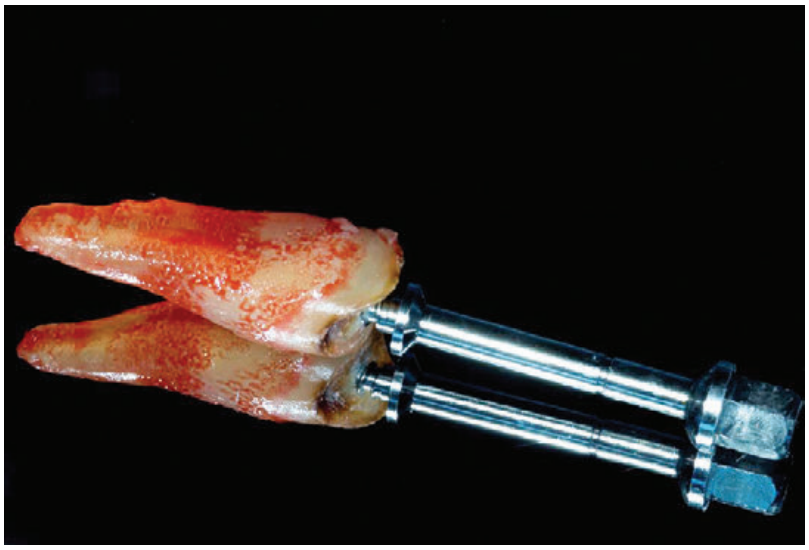

Figure 6-9 Easy X-TRAC system. (Courtesy Titan Instruments, Hamburg, NY.)

choices. One option is to place an implant immediately into the fresh extraction socket.[19] Another option is to perform site preservation and then place the implant in a secondary procedure after healing.[20] A third option is to allow the socket to heal naturally and then place the implant in a secondary procedure with associated fenestration or dehiscence-defect repair when necessary.[21] A final option is to perform site development to reconstruct the defect created by physiologic socket healing and re-enter the site for subsequent implant placement.[22]

The extraction defect sounding (EDS) classification system defines the condition of the hard and soft tissues immediately after tooth extraction; it attempts to predict the wound healing response and provides basic treatment guidelines for achieving predictable implant integration and esthetics. Treatment recommendations using this classification are conservative, focus on the predictability of implant integration, and provide realistic esthetic expectations.

With the EDS approach, a periodontal probe is used in a manner often described as *sounding,* in conjunction with a prosthodontically derived surgical template, which serves as a reference point (Figure 6-10).[15] This provides an objective method for evaluating hard and soft tissue integrity immediately after tooth extraction.

A classification of the extraction defect with associated treatment recommendations is outlined in Table 6-1 and depicted in DIAGRAM A.

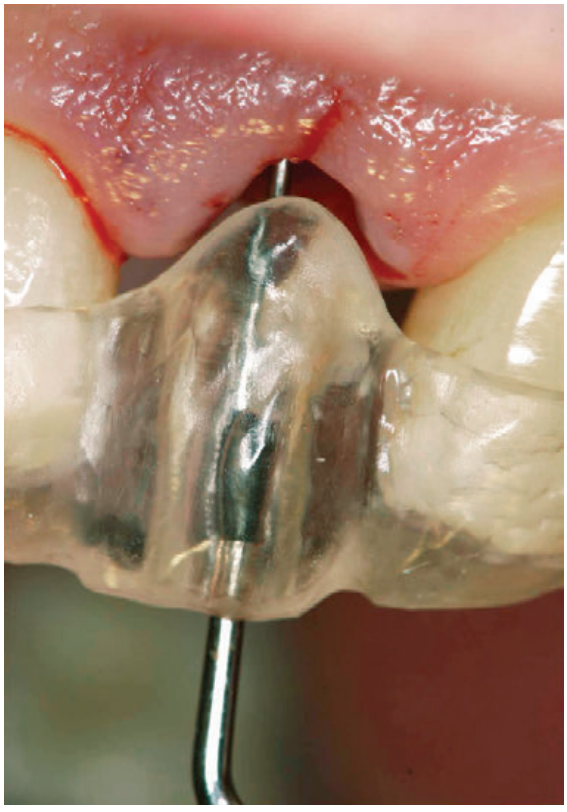

Figure 6-10 A prosthodontically derived surgical template is used as a reference point for measurements in the extraction defect sounding (EDS) classification system.

Table 6-1 Classification of Extraction Defects and Treatment Recommendations

DEFECT TYPE	GENERAL ASSESSMENT	NUMBER OF SOCKET WALLS AFFECTED	BIOTYPE	HARD TISSUE LOSS	DISTANCE TO REFERENCE POINT	IDEAL SOFT TISSUE ESTHETICS	TREATMENT RECOMMENDATIONS
EDS-1	Pristine	0	Thick	0 mm	0-3 mm	Predictable	Immediate implant (one stage)
EDS-2	Pristine to slight damage	0-1	Thin or thick	0-2 mm	3-5 mm	Achievable but not predictable	Site preservation or immediate implant (one or two stages)
EDS-3	Moderate damage	1-2	Thin or thick	3-5 mm	6-8 mm	Slight compromise	Site preservation, then implant placement (two stages)
EDS-4	Severe damage	2-3	Thin or thick	≥6 mm	≥9 mm	Compromised	Site preservation, then site development, then implant placement (three stages)

EDS, Extraction defect sounding classification.

After tooth removal, the socket's bony walls are inspected. Recognition of the number of remaining socket walls and their condition is vital. The gingival margin and interproximal papillae and their relationship to the underlying alveolus are also assessed. The classification of the periodontal biotype, with associated risk assessment for potential recession, is also determined. Extraction defect sounding is performed using the tip of a conventional periodontal probe; the entire socket is thoroughly explored. Initially, the crest of the extraction defect is evaluated. The prefabricated surgical template is used to note the position of the crestal bone in relation to the gingival margin and to the future restorative margin. The risk of soft tissue recession is proportional to the distance between the existing bone and soft tissue; the greater the distance between the alveolus and the soft tissues, the greater the risk of gingival recession.

Sounding of the bony crest includes the buccal and palatal plates and the interproximal bone peaks. The buccal plate is then further examined. While slight digital pressure is applied on the outer buccal plate, a periodontal probe is used to explore the inner aspect; this evaluation uncovers any fenestration or dehiscence-type defects. In addition, when the inner aspect of the socket is sounded with a probe, any vibrations felt digitally indicate a thin alveolar plate. The thickness of the buccal plate is evaluated visually, digitally using a probe, and also through manual palpation during sounding of the inner aspect. A thin buccal alveolar plate poses a greater risk of buccal plate resorption after healing (Figure 6-11).

Extraction Defect Sounding: Type 1

An EDS-1 defect is characterized by a pristine, undamaged, single-rooted socket and a thick periodontal biotype. This defect allows for predictable immediate implant placement in a prosthetically ideal position.[23] An EDS-1 defect has four intact bony walls and a crestal buccal plate thickness of 1 mm or more. With the surgical template in position and using the cervical margin of the future restoration as a reference, the gingival margin should be at the level of or above the reference point and the alveolar crest should be no more than 3 mm beyond.

The recommended treatment protocol for the EDS-1 defects is immediate implant placement after tooth extraction. Ideal soft tissue esthetics

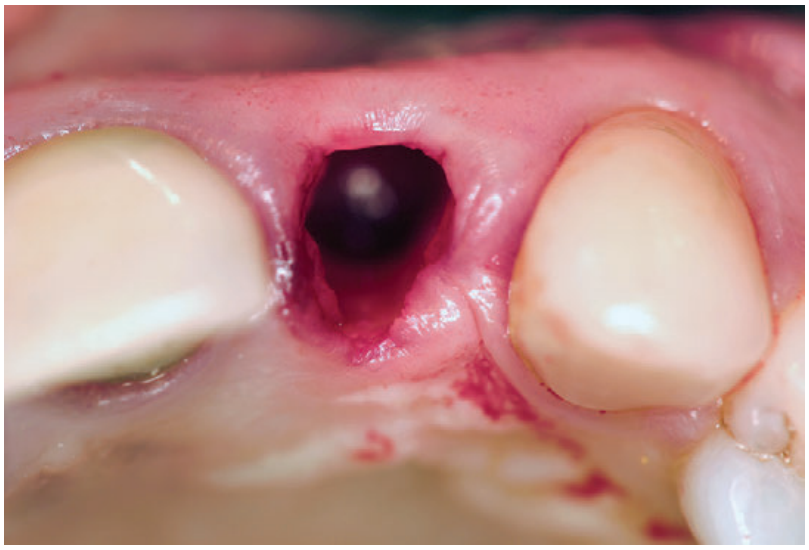

Figure 6-11 The risk of resorption is greater with a thin buccal plate.

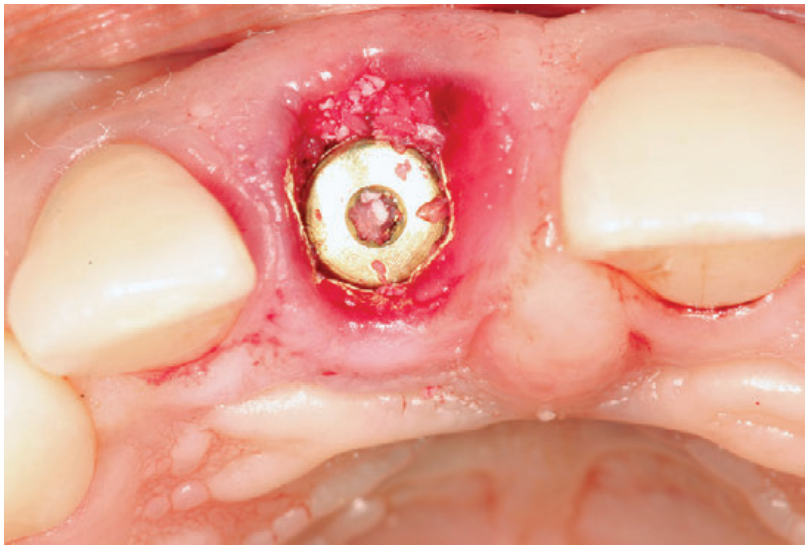

Figure 6-12 Immediate implant placement is recommended for an EDS-1 defect.

are predictable (Figure 6-12). When immediate implant placement is beyond the surgeon's level of expertise or when implant stability cannot be ensured, a two-stage approach is advised, as described for an EDS-2 defect.

Extraction Defect Sounding: Type 2

An EDS-2 defect is characterized by a mild degree of crestal bone loss or interproximal tissue loss of 2 mm or less, or a buccal plate thickness of less than 1 mm. No more than one socket wall is compromised. These defects have fenestrations that do not compromise the integrity of the crestal aspect of the buccal plate (e.g., apical endodontic damage). An EDS-2 defect also has an ideal socket, as defined by the EDS-1 criteria, except that it has a thin biotype instead of a thick one. All multiple-rooted sockets that are undamaged or have a mild degree of bone loss are classified as EDS-2.

The recommended treatment protocol for an EDS-2 defect is a two-step implant placement approach with site preservation performed at the time of tooth extraction (Figure 6-13). Immediate implant placement, with associated defect repair procedures when indicated, can also be

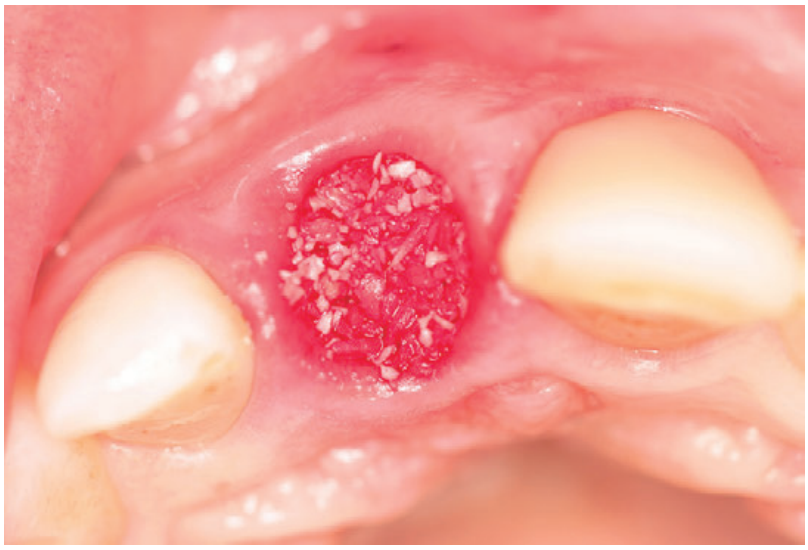

Figure 6-13 A two-step approach is recommended for an EDS-2 defect. Site preservation is initially performed, followed by implant placement at a later date. This technique allows for appropriate graft turnover.

considered; however, this poses a greater risk of recession and implant exposure.[21,24] Site preservation involves minimally traumatic tooth extraction performed with periotomes or other microsurgical extraction instruments; thorough débridement of the socket, including surgical manipulation to induce adequate bleeding; augmentation of the socket with appropriate biomaterials to minimize alveolar resorption; and the use of membranes to contain the graft and reconstruct missing bony walls, including the alveolar crest. Interpositional connective tissue grafts should be considered whenever a soft tissue deficit is present or the patient has a thin periodontal biotype so as to enhance soft tissue thickness or compensate for the thin biotype where recession is anticipated.[25] The implant is placed 3 to 6 months later, which allows for adequate wound healing and graft remodeling. Ideal soft tissue esthetics are frequently achievable but not always predictable for EDS-2 defects.

Extraction Defect Sounding: Type 3

An EDS-3 defect is generally characterized by moderate compromise of the alveolar bone and soft tissues. This includes a vertical or transverse hard and/or soft tissue loss of 3 to 5 mm, one or two compromised socket walls, or any combination of these conditions. With the surgical template in position and using the cervical margin of the future restoration as a reference, the gingival margin is positioned 3 to 5 mm from the cervical margin reference point and the crest is 6 to 8 mm away. This type of defect does not allow for routine immediate implant placement because of the greater risk of recession, implant exposure, implant malposition, inadequate initial implant stability, or reduced bone-implant contact. Examples of an EDS-3 defect include any socket with a buccal plate dehiscence of 7 mm from the reference point. Another example is a tooth with interproximal bone or soft tissue loss of 4 mm.

The recommended treatment protocol for the EDS-3 is a two-step implant placement approach with site preservation performed at the time of tooth extraction and implant placement 3 to 6 months later, as described for EDS-2 defects (Figure 6-14). A secondary procedure to increase the quantity of the hard and soft tissues, commonly referred to as *site development,* may be necessary in some situations. Ideal soft tissue esthetics are possible but not very predictable with EDS-3 defects. A slight esthetic compromise involving minor interproximal tissue loss or marginal recession can be expected with the final restoration.

Extraction Defect Sounding: Type 4

The EDS-4 defect is characterized by a severely compromised socket with greater than 5 mm of

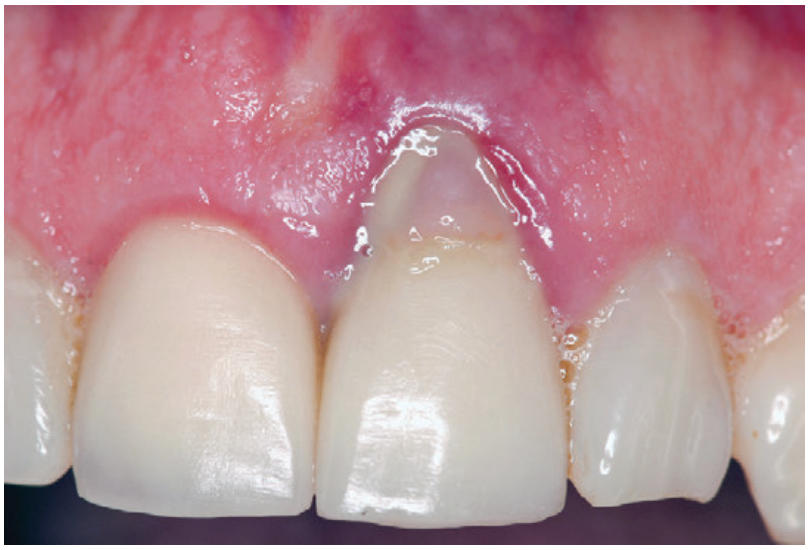

Figure 6-14 Two or three surgical steps are typically required for an EDS-3 defect. Initial site preservation is performed, followed by a secondary site development procedure, followed by implant placement.

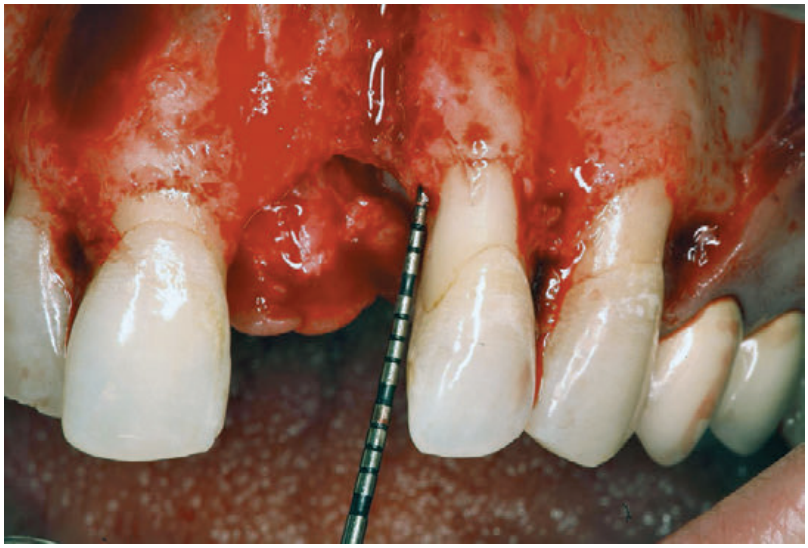

Figure 6-15 Three surgical procedures are often required to reconstruct an EDS-4 defect.

vertical or transverse loss of hard and/or soft tissue and two or more reduced socket walls. The periodontal biotype is either thick or thin. Immediate implant placement is not possible without compromised implant stability or significant exposure of the implant body. A site with an extensive history of periodontal disease that has led to a severely reduced alveolar housing and destruction of the buccal and palatal plates is an example of an EDS-4 defect. Sites with greater than 5 mm of interproximal bone loss between multiple-tooth extraction sockets are another example. With the surgical template in place, the distance between the gingival margin and the restorative cervical margin exceeds 5 mm. The alveolar crest is positioned greater than 8 mm from this reference point.

The recommended treatment protocol for an EDS-4 defect is usually a three-stage implant placement technique (Figure 6-15). At the time of tooth extraction, site preservation is performed as for an EDS-2 defect. Placement of a graft material preserves the existing alveolus. A resorbable membrane is used to contain the graft and provide

space for a modest regenerative response. Addition of a connective tissue graft helps enhance the soft tissue profile and facilitates primary closure during the subsequent second-stage site development procedure. Site development is performed approximately 3 to 4 months after site preservation to allow adequate wound healing. Before this procedure, the defect is a combination-type defect with a loss in both height and width, and multiple site development procedures may be necessary.[25] Alternatively, a defect repair procedure can be performed concurrently with implant placement, following the principles of guided bone regeneration (GBR).[26] However, the quantity of bone developed around the implant and the degree of implant integration of this regenerated bone may be less predictable when these complex procedures are combined than when a staged approach is used.[21,27]

The use of autogenous bone for site development in block or particulate form (or in combination) is preferable for these challenging defects.[22,28] When autogenous bone is used in particulate form, membranes are required to stabilize the graft, preclude soft tissue invagination, and provide space for regeneration. Connective tissue grafts should also be considered to enhance soft tissue esthetics and minimize the risk of premature wound dehiscence and graft or membrane exposure. A 3- to 6-month healing period is required before the subsequent third-stage surgical procedure is performed for implant placement. Ideal soft tissue esthetics are not achievable in an ED-4 defect. Minor to moderate compromise involving modest interproximal tissue loss and/or marginal recession can be expected.

SURGICAL TECHNIQUES FOR SITE PRESERVATION

BIOMATERIALS

Site preservation involves placement of a graft material in the extraction socket to stabilize the clot and minimize clot shrinkage. The graft is then covered with an appropriate barrier or "membrane" for containment to protect the regeneration space and to prevent the downgrowth of epithelium. A variety of graft materials are available to help preserve alveolar integrity and minimize bone shrinkage. However, some graft materials work better than others with regard to the quality of tissue regeneration in the socket and may provide a better substrate for dental implant placement. Some graft materials may adequately preserve the alveolar ridge after tooth extraction but may not allow for predictable dental implant placement.[12]

The choice of biomaterial, therefore, depends on the demands of the particular site (future pontic site or implant site). The dental practitioner must understand three characteristics of bone graft materials to select and use the material correctly. Bone grafts are characterized as osteogenic, osteoinductive, osteoconductive, or some combination of these.[29]

As discussed previously, an osteogenic material is capable of de novo bone formation. The graft itself retains cellular activity and properties that allow it to grow bone within itself as long as an adequate blood supply is provided. Currently, autogenous bone (bone procured directly from the patient) is the only osteogenic graft material. Autogenous bone also is thought to be osteoinductive. For these reasons, autogenous bone is considered the gold standard of bone graft materials.

An osteoinductive material is able to promote or induce bone formation by sending biochemical signals that promote differentiation of primordial or mesenchymal stem cells into osteoblast cell lineages. For an osteoinductive material to be effective, stem cells must be available. This is often the case in a bleeding extraction socket, but it underscores the importance of an adequate bleeding bed when an osteoinductive material is used for site preservation. Osteoinductive materials can promote bone growth in areas where no bone exists. For example, a pouch created in rodent muscle tissue is the classic model for osteoinduction experimentation.[30] When placed in muscle tissue, an osteoinductive graft material creates bone ectopically. In other words, an osteoinductive material can induce ectopic bone formation at a remote site from the host bone. Examples of osteoinductive materials include bone morphogenetic protein (BMP) and allografts (human tissue procured from another donor) known to contain inductive proteins in their matrix. Allografts are also considered osteoconductive.

An osteoconductive material simply provides a matrix for cellular migration and growth that leads

to bone formation. These materials can be thought of as "scaffolds" that facilitate bone growth. They are able to promote appositional growth from existing bone but cannot grow bone remotely, away from the existing bone.[31] All biocompatible bone graft materials are considered osteoconductive to some degree. Examples of osteoconductive grafts are autogenous bone, allografts, and alloplasts (synthetic graft materials), in addition to xenografts (tissue procured from another species), which are considered a subclassification of the alloplast group.

REGENERATIVE POTENTIAL

The potential for regeneration must be assessed for each surgical site and for the graft material to be used. For example, a site with a high regenerative potential (i.e., bone growth or repair occurs easily) requires a graft material with only a low or modest regenerative potential. A site with low regenerative potential (bone growth or repair is difficult) demands a graft material with a high regenerative potential.

In general, osteogenic materials (i.e., autogenous bone) are considered to have the highest regenerative potential, followed by osteoinductive materials (i.e., allografts and BMP) and then osteoconductive materials (i.e., alloplasts and xenografts).[29]

With regard to the extraction socket, a small defect with intact alveolar plates and four bony walls has a high regenerative potential. A larger socket or a socket that is missing bony walls has a decreased regenerative potential. Vertical bone loss with no adjacent bony walls is known to have the lowest regenerative potential, which is the reason vertical bone regeneration is still quite unpredictable. The need to incorporate autogenous bone increases as the regenerative potential of the site decreases. For example, complete loss of a buccal plate (from infection or trauma) often requires the incorporation of autogenous bone into the graft to obtain an adequate regenerative outcome for the extraction site. Luckily, most extraction defects have a relatively high regenerative potential, especially when minimally traumatic extraction techniques are used, because these help preserve the alveolar and interproximal bone walls. Allografts and alloplasts, therefore, are the most commonly used graft materials for site preservation.[10]

A membrane device is often required with site preservation. Membranes are used to contain the bone graft, provide space for regeneration, or prevent soft tissue invagination in the graft.[22] Membranes can either be resorbable or nonresorbable. Resorbable membranes can be further classified by their source. Some are allografts (human donor), alloplasts (synthetically derived), or xenografts (animal donor). Nonresorbable membranes are commonly derived from Teflon (Figure 6-16).

Similar to graft materials, membranes can be thought of as having varied degrees of regenerative

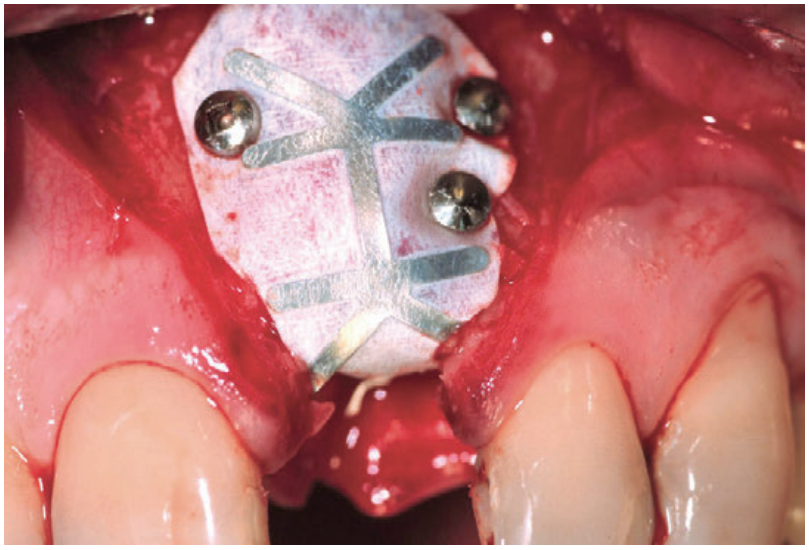

Figure 6-16 Nonresorbable membranes are commonly derived from Teflon and related materials.

potential. Membranes that last longer are considered to have higher regenerative potential compared with membranes that resorb quicker or those that must be removed sooner (some membranes have a higher incidence of developing infections). Membranes that are stiffer or have space-maintaining physical attributes are thought to have a higher regenerative potential than membranes that do not. Some types of membranes incorporate space-maintaining titanium mesh, which allows them to be shaped and helps maintain the space required for bone growth.[31]

As with bone graft material, the choice of a membrane depends on the regenerative potential of the surgical site. For example, an extraction defect with completely intact bony walls usually requires a membrane only for graft containment; therefore, a fast-resorbing collagen membrane is often adequate. In contrast, an extraction defect with complete loss of buccal and interproximal bone usually requires a slowly resorbing or nonresorbable membrane with stiffer physical properties or with titanium reinforcement to help maintain the space.[22] Because most extraction defects have a high regenerative potential, resorbable collagen membranes are most commonly used during routine site preservation.[10]

SURGICAL PROTOCOLS

After minimally traumatic tooth extraction (as outlined previously), the extraction defect is thoroughly explored and assessed. Based on the EDS classification, the appropriate graft and membrane are selected. Sterile surgical procedures are required when handling and preparing the graft and membrane. The bone graft is introduced into the extraction defect with a small periosteal elevator and packed into the socket defect with a condensing instrument. The graft is densely overpacked so that it extends slightly above the alveolar crest (1 to 2 mm) to compensate for graft shrinkage. The membrane is then sized and trimmed to cover the graft completely and extend onto the adjacent bone for better support and to contain the graft adequately. When the buccal plate is missing, the membrane must extend over the buccal surface of the graft. This often necessitates full-thickness flap elevation to expose and prepare the defect adequately and for subsequent placement of the graft and membrane.

After the graft and membrane have been placed, sutures are placed to secure the graft complex or to obtain primary closure. Collagen membranes typically do not require primary closure, because they are needed only to contain the graft; they quickly resorb and allow granulation tissue to close over the graft (Figure 6-17). Allograft, alloplast, and nonresorbable membranes typically require complete coverage to ensure adequate healing. The manufacturer's recommendations for suturing techniques and primary tissue closure should be followed.

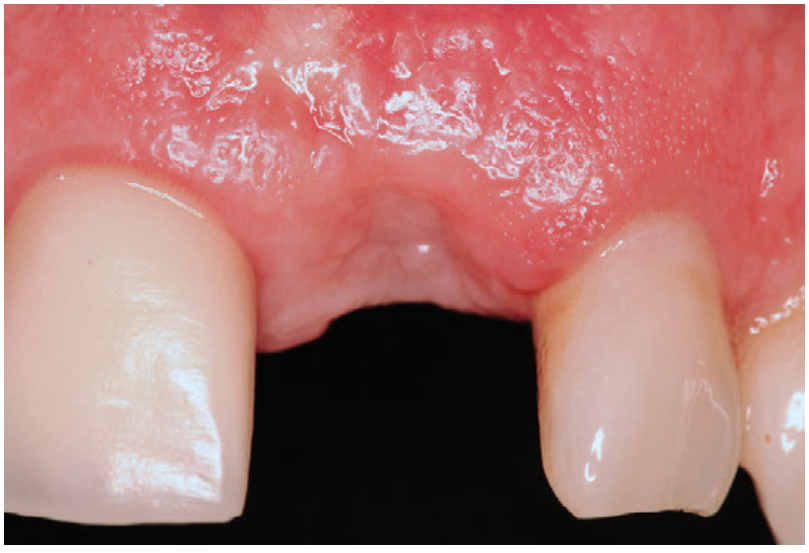

Figure 6-17 Collagen membranes used for site preservation quickly resorb and allow for granulation tissue coverage over the socket graft.

COMPLICATIONS MANAGEMENT

Complications after site preservation are rare. The most common complications are partial or complete graft loss with or without associated infection. The most effective way to manage these complications is to prevent them.

Overtly infected extraction sites with visible exudate must be thoroughly débrided and irrigated. Severe dental infections are relative contraindications to graft and membrane placement. When site preservation is performed in previously infected sites, socket detoxification procedures using antibiotics or antimicrobials should be considered.[33] Systemic antibiotics should be prescribed after site preservation, especially after extraction of teeth with acute and chronic dentoalveolar infections. After the surgery, oral rinsing twice daily for 1 to 2 weeks with 0.12% chlorhexidine gluconate is recommended (Figure 6-18).

The management of complications associated with site preservation is similar to the management of complications of tooth extraction. Palliative treatment, systemic antibiotics, oral antimicrobials, and débridement, when needed, are used to treat graft infection. Sites with compromised graft healing or graft failure are allowed to heal completely before retreatment. Residual defects can often be corrected through site development procedures after conventional GBR techniques.[22]

Figure 6-18 After surgery, twice a day rinsing with 0.12% chlorhexidine gluconate is recommended for 1 to 2 weeks.

PROSTHETIC MANIPULATION OF SOFT TISSUES DURING HEALING

Provisional prostheses can be used to help guide soft tissue healing after tooth extraction and site preservation procedures. The development and maintenance of normal gingival architecture after surgery is essential in creating biologically sound and esthetic implant restorations. Through minor selective pressure application, interim prostheses can help establish and maintain gingival margin positions and papilla form. These prostheses incorporate ovate pontic designs and can either be fixed or removable.[34] Customized or anatomically shaped healing abutments can be used for the same purpose.

Ovate pontic designs are beneficial in preserving or establishing esthetic soft tissue emergence profiles by applying minor selective pressure on the gingival margin and interproximal papillae. This minor selective pressure can minimize the collapse and flattening of the soft tissue that commonly occurs after tooth extraction. The ovate pontic surface should extend 1 mm within the extraction defect and apply facial but not apical pressure on the free gingival margin. It should apply slight lateral pressure on the existing interproximal papillae and also provide room for coronal enlargement of the papillae to accommodate swelling (Figure 6-19). Great care must be taken to prevent excessive pressure over preservation sites, because such pressure may compromise graft healing. Removable prostheses must incorporate positive rest seats to prevent excessive compression from occlusal forces. Adequate relief of the appliance is necessary to compensate for any expected tissue swelling.

Fabrication of these prostheses involves the creation of a master cast. The cast is then altered by removing the teeth slated for extraction and creating 1-2 mm deep concavities in the cast in the

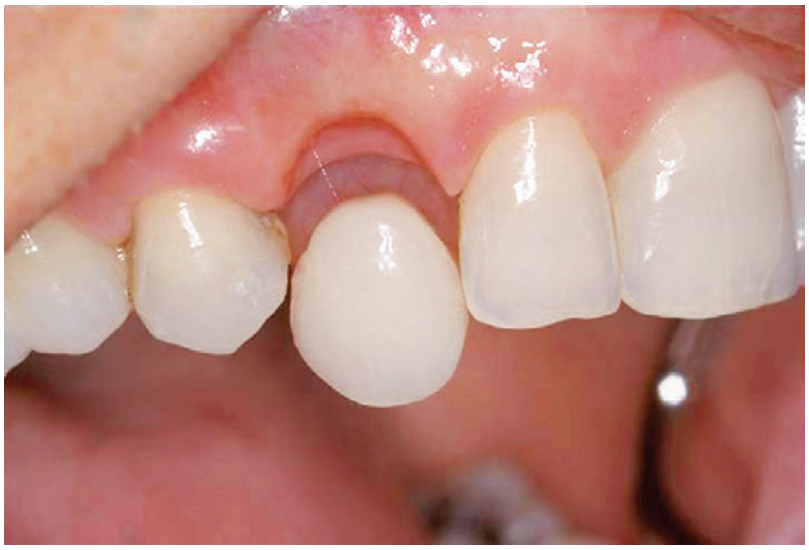

Figure 6-19 Ovate pontic designs help preserve and establish esthetic gingival architecture after tooth removal.

areas of the extractions, simulating the surgical procedure to be performed intraorally. The interim prosthesis is fabricated on the cast using acrylic or composite resin. The ovate pontic design can also be created or modified as needed chairside.

CLINICAL OUTCOME ANALYSIS OF ALVEOLAR PRESERVATION TECHNIQUES

LIMITATIONS OF SITE PRESERVATION

It should be clear that the main benefit of site preservation is to minimize the gross morphologic alterations that occur to the alveolar bone after tooth removal; this in turn minimizes visible soft tissue recession. Use of a bone graft and membrane appears to reduce shrinkage of both the alveolar width and height by approximately 2 mm.[10] These 2 mm are critical when dealing with implant tooth replacement in the esthetic zone. In nonesthetic areas, these 2 mm often allow for better home care and long-term peri-implant tissue maintenance. Therefore, when preparing for future dental implant placement, site preservation should always be considered. Site preservation can also be considered for pontic site development in preparation for conventional prosthodontics.

Site preservation as described in this chapter is not designed to repair or regenerate pre-existing defects. Significant defects of the soft and hard tissues (described previously as EDS-4 defects) require more complex surgical procedures for complete repair. Site preservation is the first of two or more surgical procedures required to correct any pre-existing deficiency predictably. This does not mean that site preservation should not be performed, but rather that the expectation for the clinical outcome from this first procedure needs to be tempered.[15]

It should also be clear that application of a bone graft in a socket clearly impedes the quality of bone formation in the socket. Histologic evaluation of bone removed from grafted sockets shows a decrease in bone tissue volume.[10,11] Therefore, application of a biomaterial in an extraction defect should be performed only when clinically indicated. Longer healing times are often required when such sites are re-entered for implant placement.

INDICATIONS FOR SITE DEVELOPMENT

With pre-existing hard or soft tissue deficiencies (or both) around a compromised tooth requiring extraction or when healing after site preservation is compromised, site development is often required. Advanced surgical techniques involving autogenous bone, BMPs, titanium mesh, or titanium-reinforced membranes and connective tissue grafts are used to reconstruct deficiencies in preparation for conventional prosthodontics or implant dentistry. The success of these advanced procedures depends on proper diagnosis of the defect, correct

selection of biomaterials, meticulous surgical technique, and the operator's training and experience.[22,28,35]

SUMMARY

The loss of a tooth commonly leads to hard and soft tissue alterations that present challenges for ideal implant placement, soft tissue esthetics, and long-term peri-implant tissue management. Physiologic wound healing after extraction is associated with morphologic alteration of the alveolar bone and soft tissue. However, the loss of alveolar bone height and width can be minimized and very often prevented through the incorporation of site preservation procedures at the time of tooth extraction.

Site preservation has been shown to improve alveolar ridge height and width significantly by minimizing physiologic alveolar shrinkage associated with tooth removal. The procedure begins with minimally traumatic tooth extraction, followed by placement of a graft material in the extraction socket to help stabilize the clot and minimize clot shrinkage. The graft is then covered with an appropriate barrier or membrane for containment to protect the regeneration space and to prevent the downgrowth of epithelium. A variety of materials can be used based on the principles of regenerative potential. Provisional prostheses are then used to help guide soft tissue healing.

Thorough evaluation of the extraction socket defect using the principles of the extraction defect sounding classification system, a thorough esthetic evaluation, and biotype analysis are paramount to proper diagnosis and treatment planning.

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CHAPTER 7

Implant Placement with Simultaneous Guided Bone Regeneration

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Chapter Outline

Criteria for Simultaneous Implant Placement and Guided Bone Regeneration
Clinical Evaluation of the Patient
Radiographic Examination
Guided Bone Regeneration for Implant Site Development
Flap Implant Surgery
- Flap Design
- Wound Closure

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Explain the basic clinical and radiographic evaluation of a potential implant patient
- Understand the advantage of three-dimensional tomography
- Describe the benefits of flapped implant placement
- Explain proper flap design and the importance of adequate periosteal release
- State the suture choice for flap closure

Since the first report of dental implant placement in a fresh extraction socket, interest in this concept of immediate tooth replacement has grown.[1-3] However, tooth removal is often accompanied by varying degrees of loss of alveolar bone. If not corrected, this loss tends to impede the ideal positioning of a dental implant replacement. Fortunately, this deficiency can be successfully overcome through the use of barrier membranes and bone grafts for guided bone regeneration (GBR). The GBR procedure can be performed before or at the time of dental implant placement to preserve the width and height of the existing alveolar ridge or to regain volume that was previously lost (Figure 7-1).

Immediate postextraction implant placement with simultaneous GBR allows for a reduction of the overall treatment time, because fewer surgical

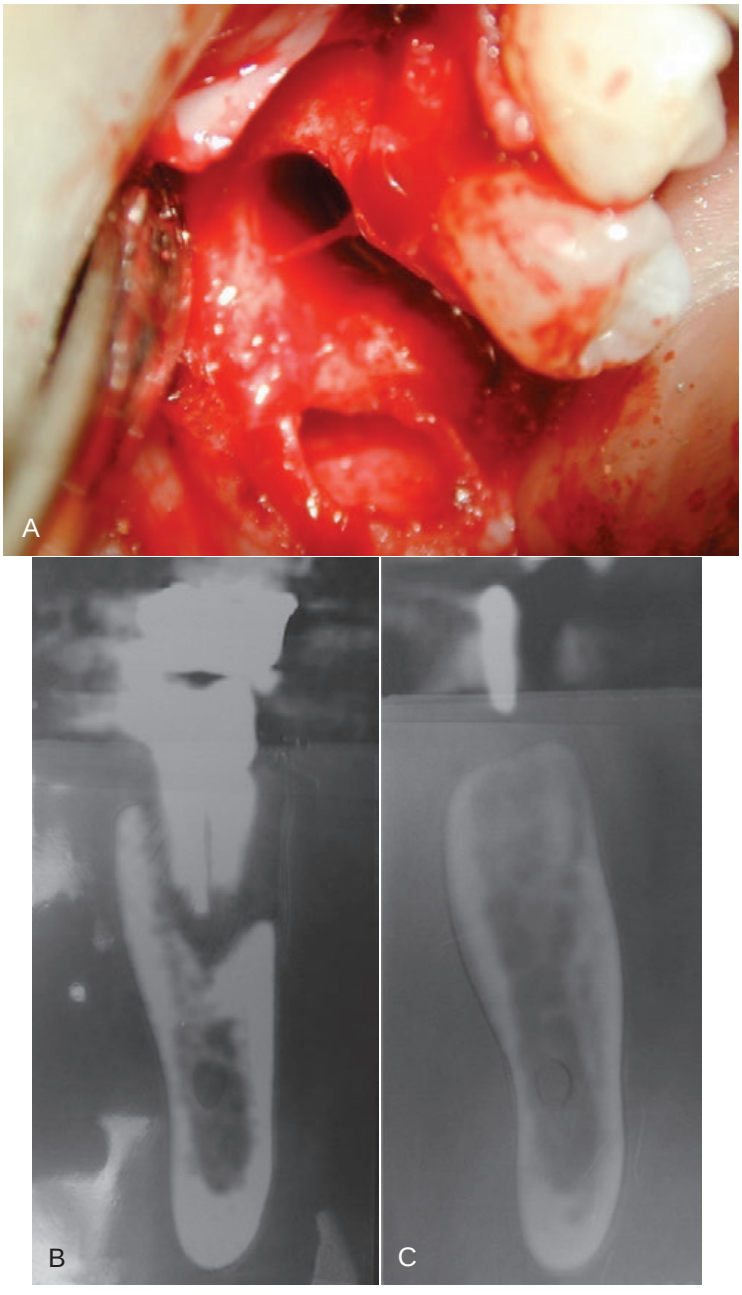

Figure 7-1 **A,** Preoperative view of an alveolar ridge in which the hard and soft tissues available are inadequate for an implant procedure. **B,** A preoperative cone beam computed tomography (CBCT) section of the mandible reveals a buccal bony deficiency. **C,** Postoperative CBCT view of the same section after augmentation.

procedures are required to attain the desired outcome. Bone and soft tissue esthetics can be preserved through the support provided by immediate replacement. This improved treatment efficiency, in combination with optimized esthetics, may also enhance patient acceptance, because cost and the duration of treatment are reduced and the esthetic outcome is maximized.

This chapter discusses the prerequisites for use of barrier membranes and bone grafts for GBR at the time of dental implant placement and the various techniques currently available.

CRITERIA FOR SIMULTANEOUS IMPLANT PLACEMENT AND GUIDED BONE REGENERATION

During the clinical examination for implant placement, the dental practitioner may encounter horizontal, vertical, and intraalveolar bone defects (Figure 7-2). These are common, and they are therapeutically important. The practitioner can choose either to perform GBR simultaneously with implant placement or to use a staged approach.

The main purpose of an implant is to establish a stable anchorage for a fixed or removable prosthesis. Considering this and other treatment objectives, the advantages of GBR with simultaneous implant placement are a reduction of treatment time, reduction of the number of surgical procedures and cost, optimal soft tissue esthetics, and enhancement of patient acceptance.

Proper diagnosis of a patient's condition allows practitioners to use clinical guidelines, along with their experience, to make better decisions on a suitable treatment plan that can be predictably executed.

To ensure osseointegration, the practitioner must place the implant in a correct three-dimensional position. Primary stability must be achieved. Another important determinant is bone morphology to attain predictable bone regeneration of the defect around the implant.

As mentioned, primary implant stability in a position to meet the high demands of esthetics and function must be achieved during implant placement to have successful osseointegration. Brånemark et al.,[4] Albrektsson et al.,[5] and Buser

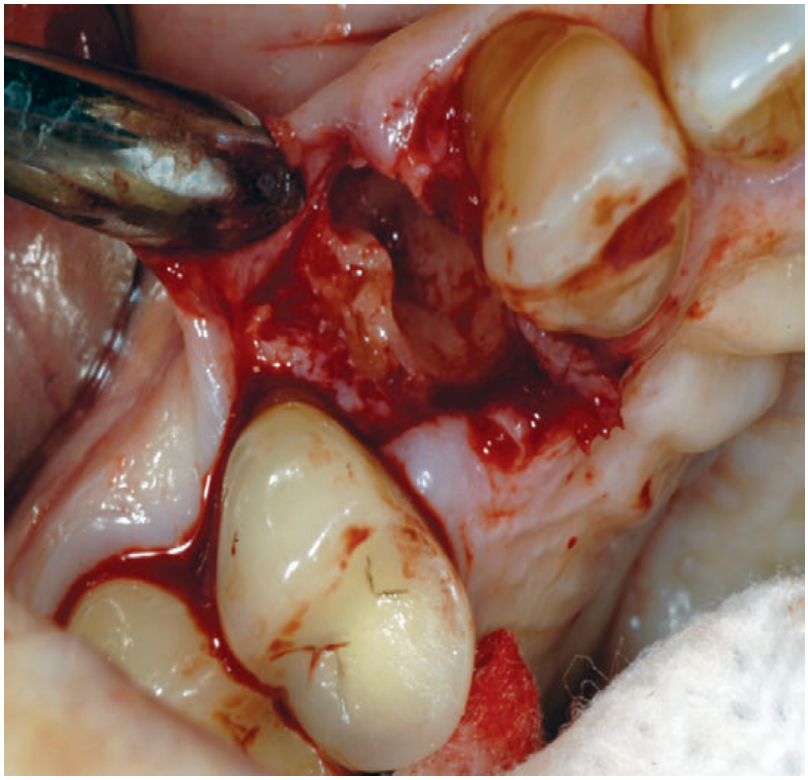

Figure 7-2 Clinical view of a bony defect.

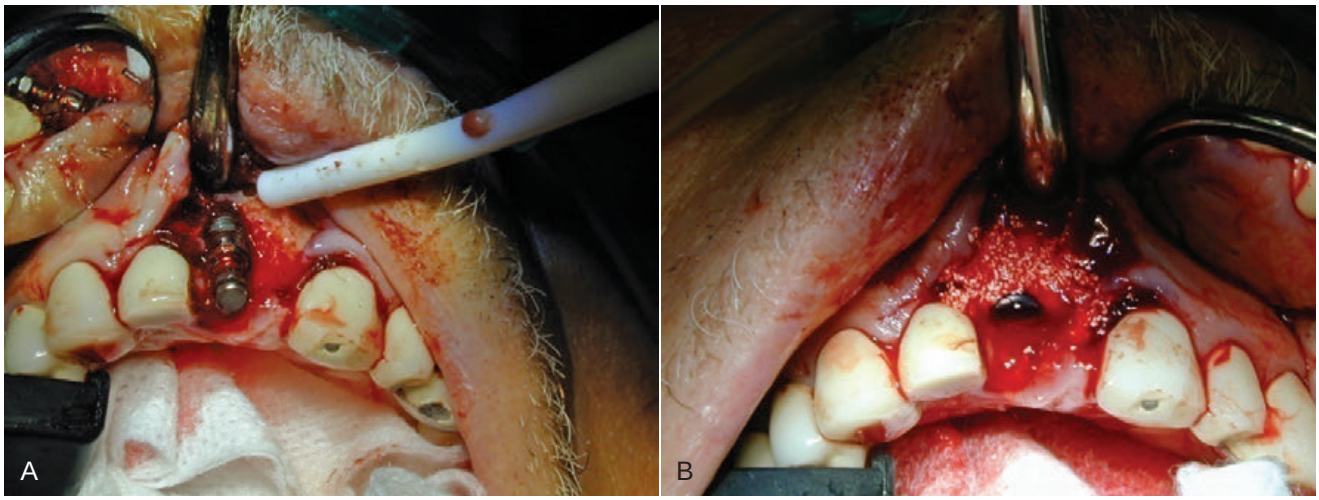

Figure 7-3 **A,** Placement of an implant in a correct three-dimensional position results in a dehiscence defect. **B,** Graft particles are packed into the implant site.

have described the importance of primary stability as a prerequisite for osseointegration during the initial healing period.

Correct three-dimensional placement, both in position and in direction (mesiodistal and buccolingual), is important to achieving esthetics and function. This principle was introduced by Garber and Belser,[6] who found that in any restoration or natural tooth, the surrounding soft tissue profile played an integral role in the final esthetics. Similarly, in implant restorations, merely attaching a prosthetic device to the underlying fixture is no longer sufficient; for optimal esthetics, it is essential to reconstitute the implant site in a three-dimensional approach. This invariably involves redevelopment or replacement of lost hard tissue and redevelopment of the correct soft tissue profile so that the implant can be placed in the desired position, as determined by the restoration, while the soft tissue profiles are generated by the actual form and contours of the prosthetic device. As a general rule, the implant should be placed along the palatal wall of the extraction socket in the maxilla and toward the buccal side in the mandible.

Bone morphology to achieve predictable bone regeneration of the defect around the implant is another important determinant for performing GBR. Bone defects may be classified as vertical, horizontal, and intraalveolar. Numerous studies have shown that treatment of this type of defect is highly predictable. Horizontal bone defects include dehiscence (Figure 7-3) and fenestration (Figure 7-4). With a facial osseous dehiscence defect, the shape and size of the defect determines the predictability of the GBR procedures.[7] A variety of graft materials, barrier membranes (both reabsorbable and nonreabsorbable), and techniques have been used for bone augmentation or grafting.[8] It has been shown that new bone formation depends mainly on the surface area of the exposed bone and its marrow cavity. The periodontal literature has shown that the most important local factor in regeneration is the ratio between the surface area of exposed bone and the defect volume. Sculean et al.[9] noted that the more bone wall available in a defect area, the better and more predictable the regeneration outcome. These authors concluded that no additional benefits of combination treatments (graft and barrier membrane) were detected in models of three-wall intrabony defects. However, in supraalveolar and two-wall intrabony (missing buccal wall) defect models of periodontal regeneration, combination of grafts and barrier membrane results in superior bone repair.

The established method adopted from periodontal regeneration[9] helps the practitioner differentiate various clinical situations according to defect morphology that can contribute to bone repair. Three-wall defects have shown a very favorable and successful regenerative outcome compared with one-wall defects. One-wall defects have a less favorable outcome because antigenic and osteogenic cells have much longer distances to

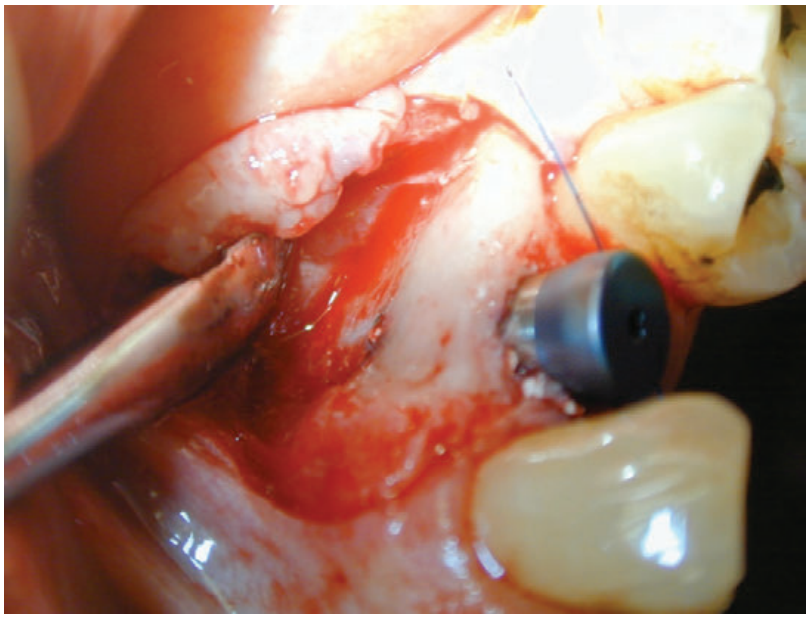

Figure 7-4 Placement of an implant in a correct three-dimensional position results in an apical fenestration defect.

bridge and repair the defect. Two-wall defects have a favorable defect morphology after extraction and immediate implant placement.

CLINICAL EVALUATION OF THE PATIENT

Correct dental implant placement requires a comprehensive pretreatment evaluation of the patient. This evaluation should include a thorough review of the patient's health history to identify any conditions that may interfere with implant therapy. The review should include cardiovascular health, history of diabetes, osteopenia or osteoporosis, anticoagulation therapy, and history of smoking. A thorough examination of the patient's oral cavity also should be performed to identify areas of disease or tooth malposition that may affect the overall success of the final implant prosthesis. The evaluation should include decayed and missing teeth and the relationship of the opposing dentition and related interdental spacing. Needless to say, it is imperative that the patient maintain good periodontal health.

RADIOGRAPHIC EXAMINATION

A thorough radiographic examination also is necessary for proper implant placement. Adjacent vital structures should be identified and avoided during the placement procedure. Neurovascular structures and adjacent tooth roots are often easily identified with standard periapical and panoramic radiography, but anatomic variation in undercuts and sinus extensions are better identified with cone beam computed tomography (CBCT). CBCT provides a more detailed, three-dimensional image of the proposed surgical site, which allows for more precise implant planning. During treatment planning, CBCT can be used for virtual implant placement, which enables the practitioner to determine the most appropriate location relative to the proposed prosthesis and the anatomy involved (Figure 7-5). Once the implant's location has been determined, the data can be exported to milling software for creation of a surgical guide to help the surgeon place the implants correctly in the predetermined location.

GUIDED BONE REGENERATION FOR IMPLANT SITE DEVELOPMENT

If adequate ridge width or height is not available at the onset of implant therapy, these often can be augmented at the time of implant placement. This procedure may involve grafting of excessive socket space after extraction with immediate implant

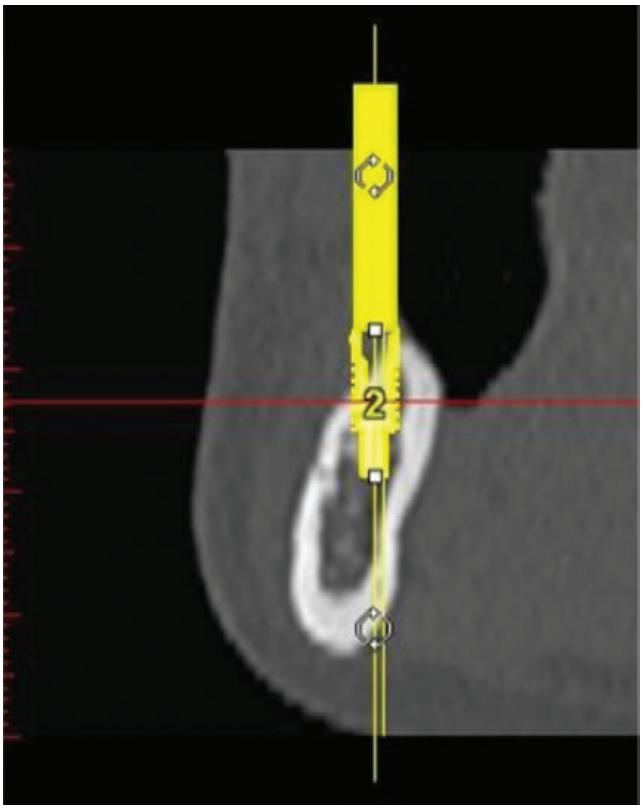

Figure 7-5 Cone beam computed tomography (CBCT) section of the mandible with virtual implant placement reveals a buccal bony deficiency with the implant in the proposed position.

insertion or more extensive augmentation of a horizontal or vertical ridge deficiency encountered at implant placement. Using the principles of GBR, a variety of methods can be used to repair these defects. For successful augmentation, a three-dimensional space must be maintained long enough for the regeneration process to take place and the final matrix to mineralize. This space can be created with a nonrigid or rigid mesh or membrane material and a particulate bone graft.

When a tooth is extracted and an implant is immediately placed in the resulting defect, a discrepancy often exists between the implant's surface and the surrounding bony housing. Augmentation may be used to establish an adequate thickness of facial bone to prevent future loss and compromise of implant esthetics.[10] This may be accomplished through placement of a graft in the socket housing or on the overlying facial bony plate immediately before implant insertion (Figure 7-6). As an alternative, the graft material can be placed after fixture placement, although instrumentation and graft placement at the apex of the defect often are more difficult with this sequence.

Once the fixture and graft are placed in the desired locations, particle containment and cellular exclusion can be performed with a resorbable or nonresorbable membranous material. If

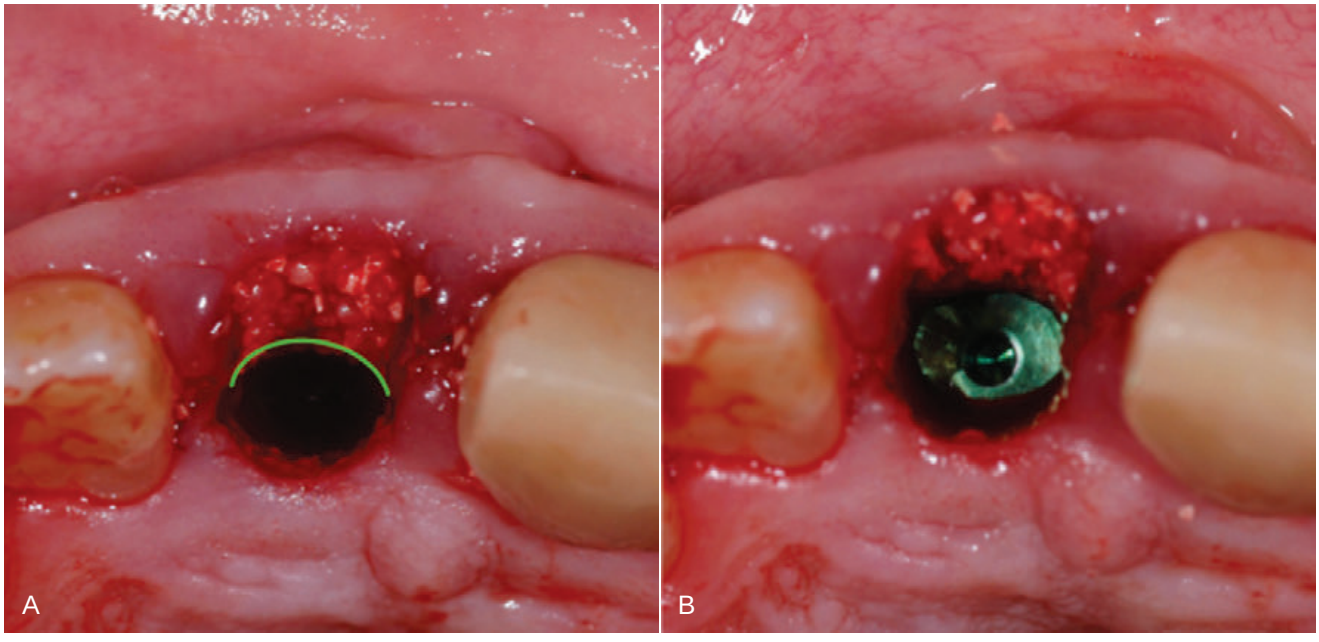

Figure 7-6 **A,** Particulate graft placement in a fresh extraction site immediately before implant insertion. **B,** Implant insertion after graft placement.

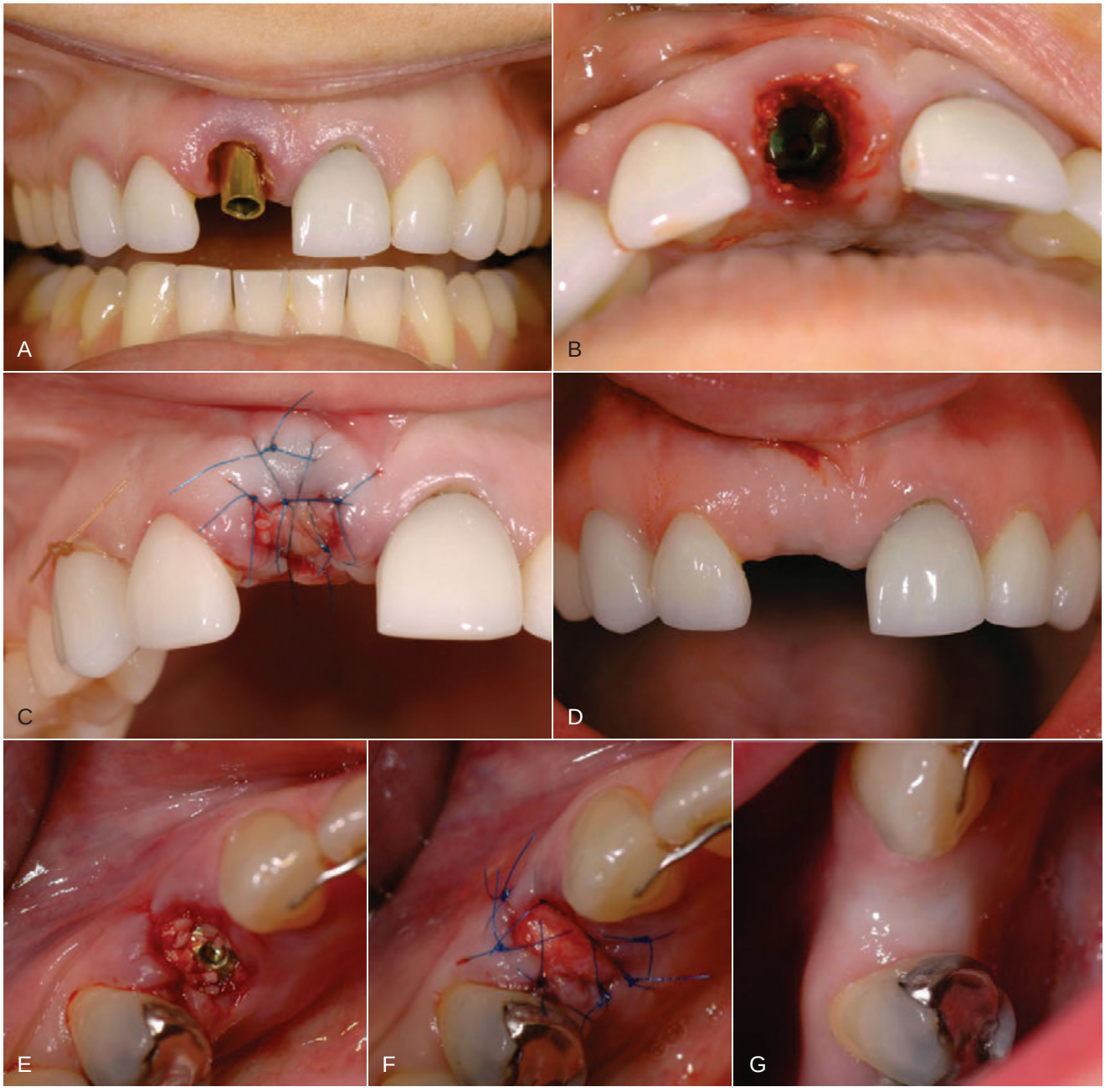

Figure 7-7 **A,** Immediate implant placement in a fresh extraction site. **B,** Particulate bone graft on the facial surface of the implant. **C,** An autogenous connective tissue graft covers the surgical site and augments the soft tissue contours. **D,** Postoperative result, showing abundant soft tissue. **E,** Immediate implant placement in a fresh extraction site with particulate bone graft on the facial surface. **F,** An acellular dermal matrix graft covers the surgical site and augments the soft tissue contours. **G,** Postoperative result, showing abundant soft tissue.

augmentation of the attached gingiva is desired, an autogenous or allogenic connective tissue graft is ideal for both functions. This not only provides adequate graft containment, but also serves as scaffolding for regeneration of the surrounding soft tissues. These materials also offer the benefit of not requiring primary closure of the wound site, thus requiring less tissue release for flap advancement (Figure 7-7).

If primary closure is not obtainable and soft tissue augmentation is not required or desired, a nonresorbable polytetrafluoroethylene (PTFE, or Teflon) membrane may be used (Figure 7-8). This material may be left exposed during healing, but

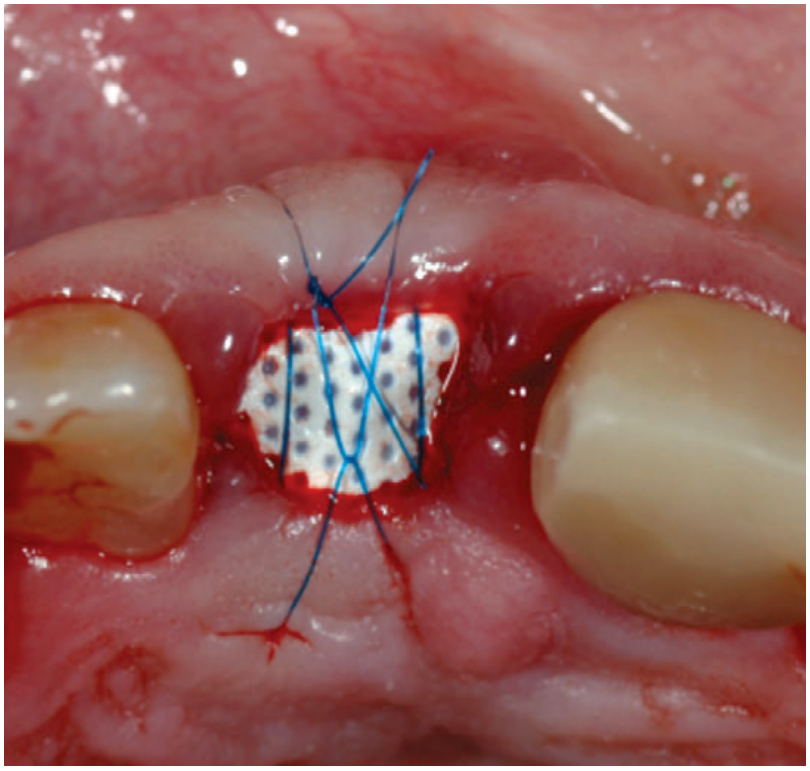

Figure 7-8 A nonresorbable polytetrafluoroethylene (PTFE, or Teflon) membrane can be used to cover the surgical site when soft tissue augmentation is not required.

it will provide insignificant enhancement of the soft tissues.[11] If adequate attached gingiva is present at the time of placement and primary closure can be obtained at the site, a resorbable collagen membrane material may be used before closure.

Often at the time of initial placement, inadequate bone is present adjacent to the implant. In such cases lateral or vertical augmentation can be performed simultaneously, providing the implant has adequate initial stability in the proposed site. To offset the compressing pressures from the overlying flap and tissues, a rigid device must be used to provide three-dimensional space maintenance while the graft is maturing. Traditionally the primary rigid mesh material used for space maintenance in GBR has been made from titanium. The advantages of this material are proven biocompatibility, ease of contouring and stabilization at the surgical site, and maintenance of rigidity under reasonable load (Figure 7-9). Although titanium mesh provides acceptable graft containment and stabilization, surgical re-entry is always required to remove it. Often removal of the mesh can be a lengthy procedure, because soft tissue can invade the latticework of the mesh, creating difficulty.

More recently, rigid, resorbable membranes have been used in GBR, eliminating the need for re-entry removal surgery. Membranes made from thermoplastic D- and L-polymers of lactic acid have been successfully used to create three-dimensional shapes for placement of particulate bone graft material in the same method in which traditional titanium mesh has been used. Rather than fixation screws or tacks that require removal, the membrane is fixed with a resorbable pin made from the same polymer, allowing for eventual resorption through hydrolysis (Figure 7-10).

This resorbable system uses an ultrasonic vibrating handpiece to create frictional heat that fixes the polymer pin into the host bone. Once the pin has been fixated, the polymer membrane is welded to the pinhead using the same sonic principle. Studies have shown that this frictional heat creates only a minimal elevation in temperature for short periods where the two hard surfaces are in contact.[12]

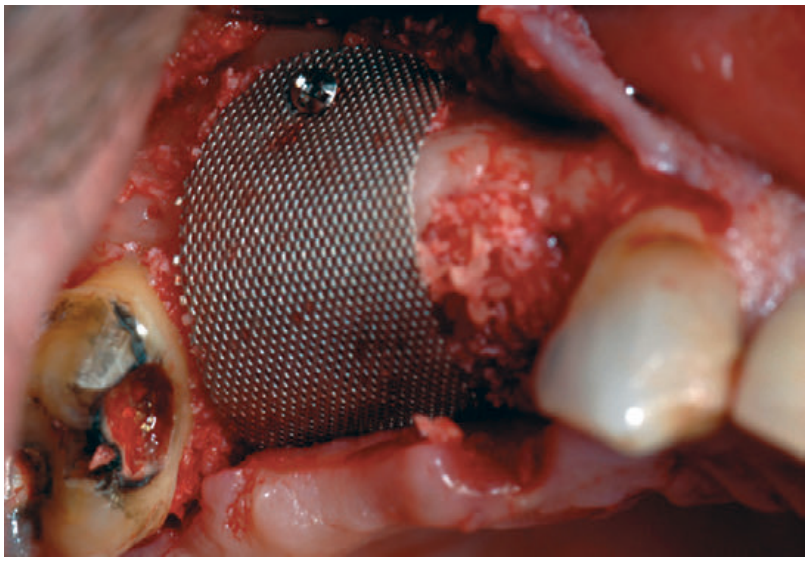

Figure 7-9 Titanium mesh used for three-dimensional hard tissue augmentation.

The introduction of rigid resorbable membranes has allowed for predictable hard tissue implant site development under a variety of circumstances, without the need for subsequent re-entry into a surgical site to retrieve fixation screws, pins, or meshes. Although these materials offer the opportunity to avoid a second surgical entry for removal, as with any regenerative technique, adequate site access must be obtained for uncompromised initial graft placement. Surgical flap management is important not only to create uncompromised access to the surgical site, but also to ensure proper closure at the completion of the procedure.

FLAP IMPLANT SURGERY

FLAP DESIGN

When surgical implant placement requires access through the oral soft tissues to the underlying alveolar bone, proper access design is important not only at the time of surgery, but also to minimize postoperative complications related to dehiscence or flap retraction. Typically, midcrestal or slightly palatal placement of the incision is appropriate for osteotomy preparation. Before this incision is made, however, the quality and quantity of the attached gingiva should be determined. When the incision is made in attached gingiva, the improved tissue density helps minimize marginal trauma during initial flap reflection. This improved density also facilitates suture placement and reduces the incidence of tearing upon completion of the procedure (see Figures 7-7 and 7-10; also Figure 7-11).

The initial incision should extend through the full thickness of the gingiva and periosteum to the underlying bony crest. This allows for a clean initial reflection of the mucoperiosteal flap in the surgical site. Failure to incise both layers carefully results in more difficulty with the initial reflection and leads to a higher incidence of tearing and trauma of the flap margin. This damage ultimately complicates the final wound closure, because the blood supply to this critical area may be compromised, resulting in poor tissue stability postoperatively. If papillary reflection is required, the papilla should be split evenly to maintain as much thickness as possible in the reflection. By maintaining the integrity of the papilla in the reflection, compromise is reduced and postoperative vitality is enhanced (see Figure 7-8; also Figure 7-12).

Once the initial full-thickness reflection is complete, the practitioner may chose to incise the periosteum, thus creating a more mobile supraperiosteal reflection.[13] If access to the buccal surface for hard tissue regeneration is required, this periosteal release must be carried out more apically to allow access to the site. If hard tissue augmentation is not required or if a ridge-splitting procedure is to be carried out, the periosteal release should

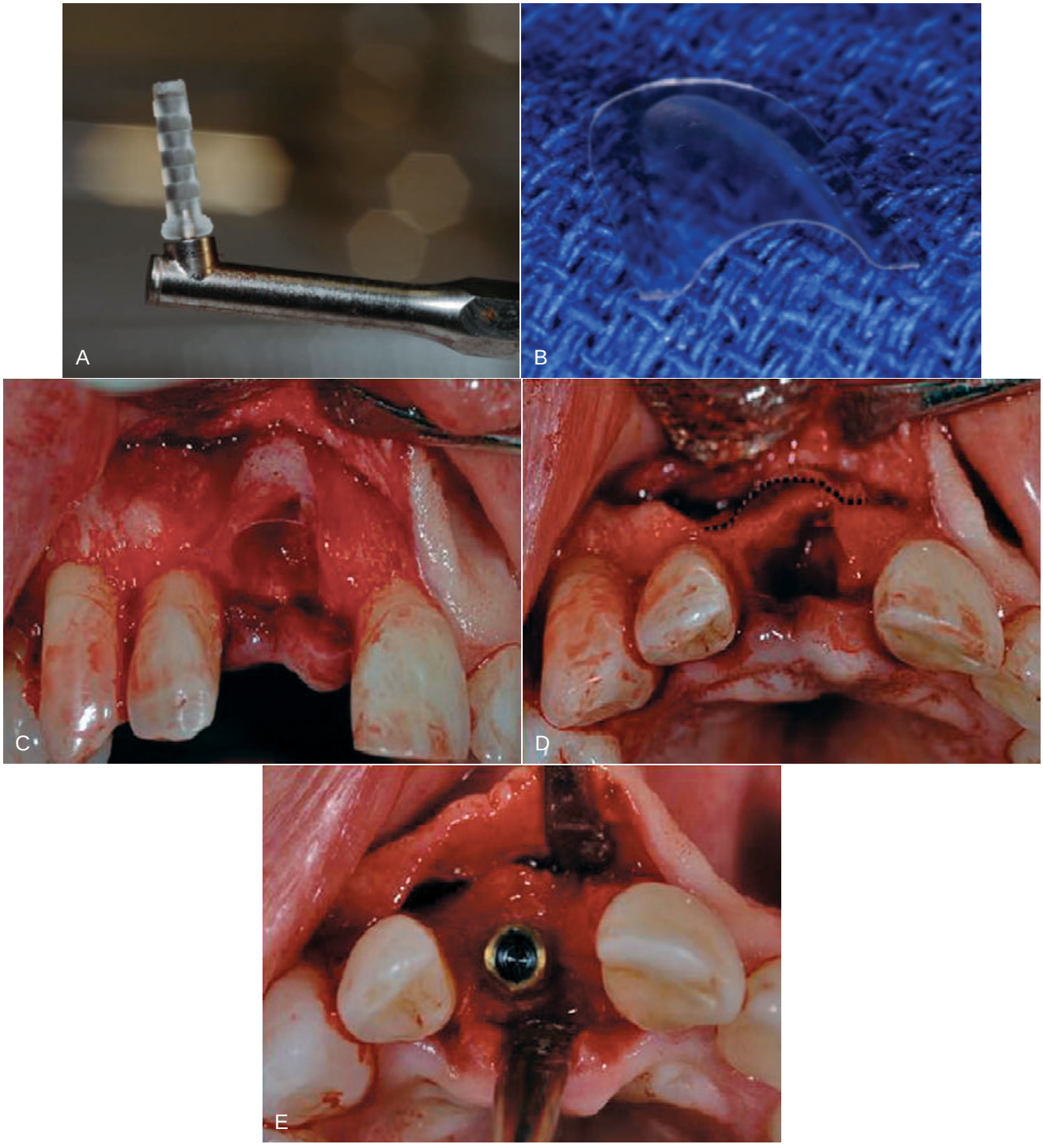

Figure 7-10 **A,** SonicWeld Rx resorbable fixation pin. **B,** SonicWeld RX resorbable rigid membrane. **C,** The resorbable rigid membrane is used for buccal hard tissue ridge augmentation. **D,** Occlusal view showing space creation with the rigid membrane. **E,** Implant placed with buccal ridge augmentation.

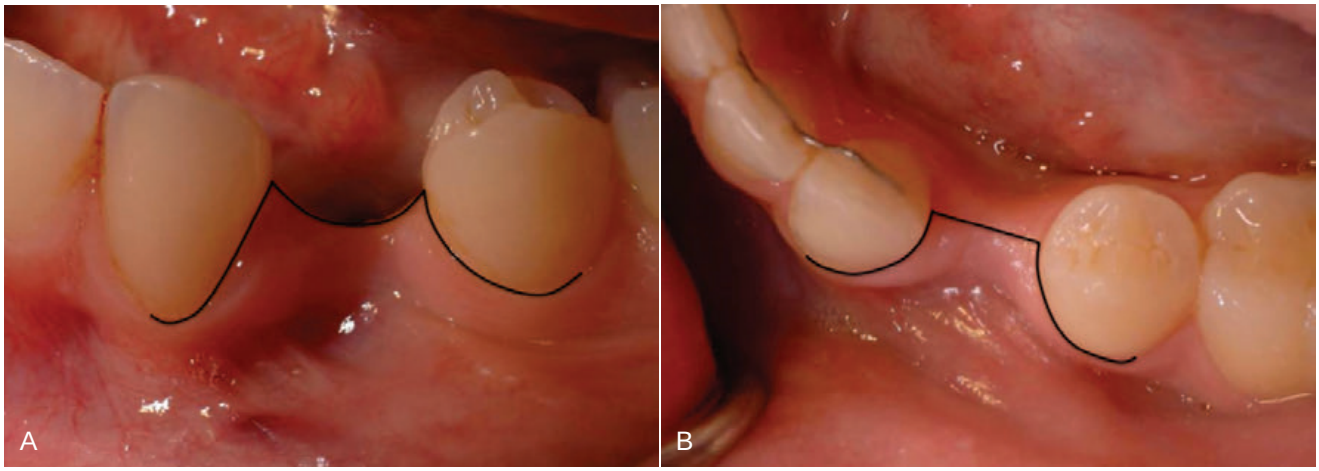

Figure 7-11 **A,** Outline of an envelope flap design to minimize vertical releasing incisions and maximize available attached gingiva on the ridge crest. **B,** Outline of an alternate envelope flap design to minimize vertical releasing incisions and maximize available attached gingiva on the ridge crest.

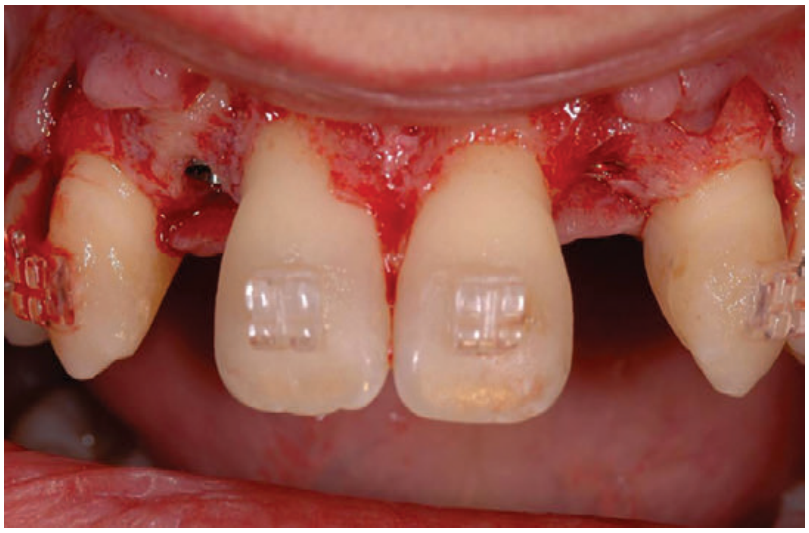

Figure 7-12 Envelope flap to minimize vertical releasing incisions.

be performed more coronally in the reflection so as to maintain the periosteal blood supply to the cortical plate and limit postoperative remodeling.[14]

In keeping with traditional surgical principles, broad-based flaps should be created to minimize compromise of the blood supply to the reflected soft tissues. Microsurgical instruments can be used to gain minimalized access through creation of a reduced incision and minimal flap reflection. In this way, vertical incisions can be reduced or eliminated, as can the associated risk of postoperative dehiscence.

WOUND CLOSURE

Once the surgical procedure is complete, passive wound closure is imperative for success. Because the periosteum provides for only a limited amount of mobility, periosteal release often is required for proper wound closure. After this release, tissue repositioning can be performed with greater ease. After positioning, the soft tissues should be carefully reapproximated at the desired locations with atraumatic suturing. For procedures that require short-term reapproximation, a resorbable or slowly resorbing material can be used (e.g., chromic gut). For procedures that require longer term wound

support, a nonresorbable material (e.g., polypropylene or PTFE) may be used and then removed at the practitioner's discretion. Adequate flap release should have been performed before closure; therefore, sutures should be able to be placed without creating tension on the flap margins.

SUMMARY

This chapter presented a rationale for addressing hard tissue deficiencies at the implant site and their subsequent augmentation at the time of dental implant placement. The importance of a thorough clinical and radiographic preoperative evaluation of a potential implant patient, including CBCT, was explained. The chapter also discussed the surgical access for dental implant placement and hard tissue augmentation, consisting of incision design, flap management, and closure.

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CHAPTER 8

Immediate Implant Placement and Provisionalization of Maxillary Anterior Single Implants

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Chapter Outline

Diagnosis and Treatment Planning
Clinical Procedure: Fabrication of Provisional Restoration
Surgical Procedure
    Immediate Provisionalization
Postoperative Instructions
Definitive Restoration

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Recognize prognostic factors that are esthetically important for anterior implants
- Accurately diagnose the conditions of the failing tooth
- Perform appropriate patient selection for immediate implant placement and provisionalization in the anterior maxillary region
- Demonstrate proficiency in the immediate implant placement and provisionalization procedures

The impending loss of a single tooth in the esthetic zone of an otherwise healthy periodontium can be a distressing experience for patients.[1,2] In such a circumstance, the right procedure can make all the difference. In 1998 Wohrle first demonstrated success with immediate implant placement and provisionalization (IIPP) of single anterior maxillary implants, and then others followed.[1,3,4-15] One of the most desirable features of IIPP is its efficacy in optimizing esthetic success by preserving the existing osseous and gingival architecture.[1,3,16,17]

The esthetic success of IIPP procedures is influenced by a number of factors that can be identified as intrinsic or extrinsic.[18] Intrinsic factors are patient dependent and include the relationship between hard and soft tissues, gingival biotype, and sagittal root position in the alveolar bone.[19,20] Extrinsic factors, on the other hand, are clinician dependent and include three-dimensional (3D) implant positioning and angulation and contouring of the abutment and provisional restoration.[16,19]

DIAGNOSIS AND TREATMENT PLANNING

Proper diagnosis of the patient's condition allows the dental practitioner to devise a suitable treatment plan that can be predictably executed. Recognizing unfavorable conditions enables the practitioner to incorporate adjunctive procedures to prevent compromised situations. The following parameters must be evaluated for an IIPP procedure.

1. *Gingival level:* The gingival level of the failing tooth should be (1) the same as (or more coronal than) that of the contralateral tooth and (2) harmonious with adjacent dentition, because some gingival recession can be expected after the procedure (Figure 8-1).[1] Therefore, when the gingival level of the failing tooth is more apical than that of the contralateral tooth, orthodontic forced eruption, if possible, should be implemented before IIPP.[21]
2. *Osseous-gingival tissue relationship:* The osseous-gingival tissue relationship can be evaluated by bone sounding, which entails probing until the bone crest is detected. The bone sounding measurement is the distance between the soft tissue crest and the bone crest. When the bone sounding measurements on the facial and proximal aspects of the tooth are about 3 and 4.5 mm, respectively, they are considered "normal crest."[19] When the bone sounding measurements are greater or less than "normal," they are classified as "low crest" or "high crest," respectively.[19] With a low crest, tissue recession tends to occur after extraction, with or without immediate implant placement.[19] Therefore, for IIPP the bone sounding measurements should

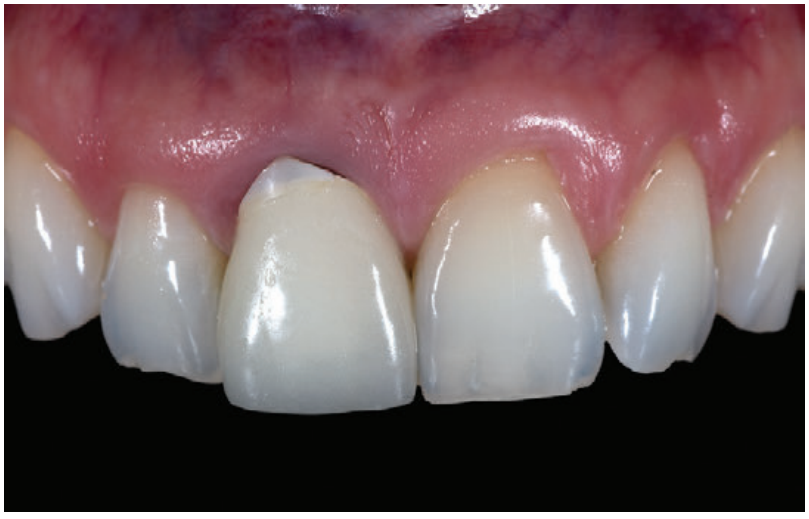

Figure 8-1 The gingival level of the failing tooth (#8) should be (1) the same as (or more coronal than) that of the contralateral tooth and (2) harmonious with adjacent dentition, because some gingival recession can be expected after the procedure.

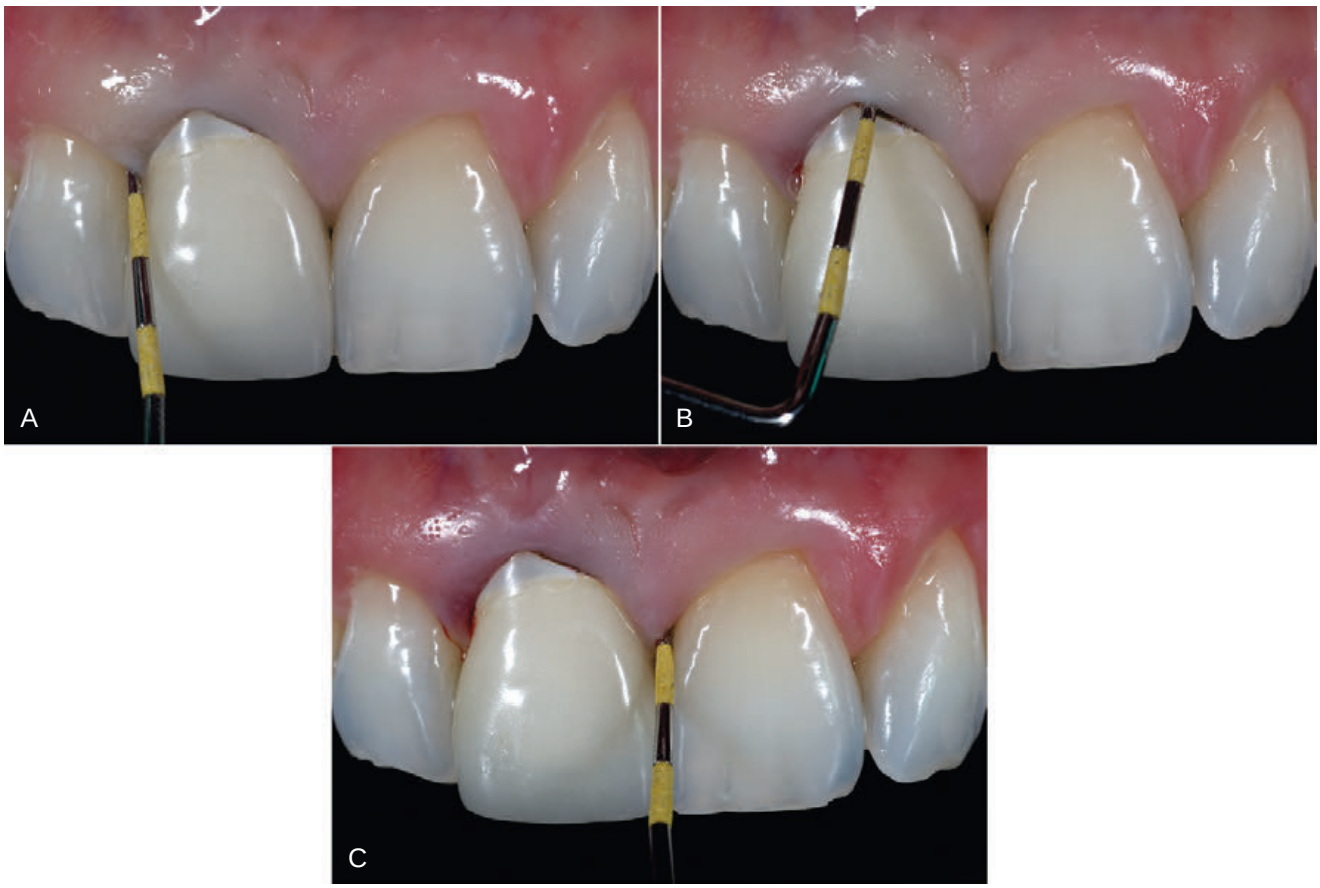

Figure 8-2 The osseous-gingival tissue relationship can be evaluated by bone sounding. It should measure 3 mm on the facial aspect of the failing tooth and 4.5 mm on the proximal aspect of adjacent teeth.

be 3 mm on the facial aspect of the failing tooth and 4.5 mm on the proximal aspect of adjacent teeth (Figure 8-2). Depending on the gingival level, a compromised osseous-gingival relationship can be improved by orthodontic or periodontal treatments, or both.

3. *Gingival biotype:* The gingival biotype can be assessed during bone sounding and categorized according to the visibility of the underlying periodontal probe (SE Probe SD12 Yellow; American Eagle Instruments, Missoula, Montana) through the gingival tissue. If the probe is visible, the patient has a thin biotype; if it is not visible, the patient has a thick biotype (see Figure 8-2).[22,23] A thin gingival biotype, which has been shown to sustain more tissue recession after surgical insults than a thick biotype, can be enhanced by using a bilaminar subepithelial connective tissue graft (SCTG) at the time of IIPP.[18]

Box 8-1 Classes of Sagittal Position

- Class I: The root is positioned against the labial cortical plate.
- Class II: The root is centered in the middle of the alveolar housing without engaging either the labial or palatal cortical plates at the apical one third of the root.
- Class III: The root is positioned against the palatal cortical plate.
- Class IV: At least two thirds of the root engages both the labial and palatal cortical plates.

4. *Sagittal root position (SRP):* The sagittal root position of the failing tooth in the alveolar bone can be identified with cone beam computed tomography (CBCT) and can be categorized as one of four different classes (Box 8-1 and Figure 8-3).[20] Because changing the SRP is impractical,

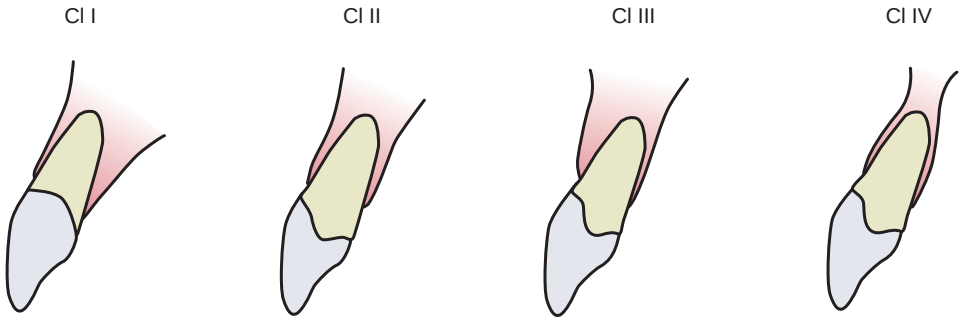

Figure 8-3 Sagittal root position classification. Class I: The root is positioned against the labial cortical plate. Class II: The root is centered in the middle of the alveolar housing without engaging either the labial or palatal cortical plates at the apical one third of the root. Class III: The root is positioned against the palatal cortical plate. Class IV: At least two thirds of the root engages both the labial and palatal cortical plates.

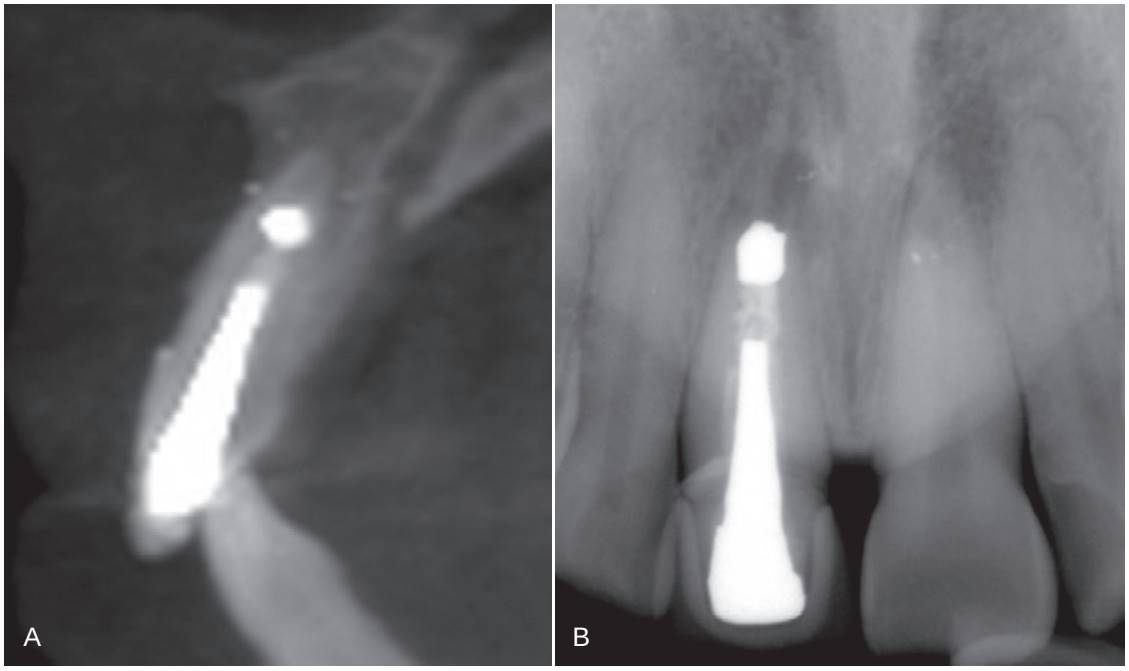

Figure 8-4 **A,** Cone beam computed tomography (CBCT). **B,** Periapical radiograph of the failing tooth.

it is important for practitioners to recognize cases that are favorable for IIPP (Class I SRP), cases that are more technique sensitive and entail additional attention (Class II and Class III SRP), and cases in which IIPP is contraindicated and hard and/or soft tissue augmentation is required before implant placement (Class IV SRP).[20]

5. *Buccolingual width and interradicular mesiodistal widths:* The buccolingual width and interradicular mesiodistal widths of the failing tooth determine the diameter of the implant to be used. These widths can be evaluated using CBCT and periapical radiographs (Figure 8-4).

CLINICAL PROCEDURE: FABRICATION OF PROVISIONAL RESTORATION

A diagnostic waxing of the failing tooth on the study cast should (1) represent, as closely as possible, the definitive restoration, (2) match the contralateral tooth, and (3) be harmonious with the adjacent and opposing dentition. Proper diagnostic waxing provides information necessary for treatment planning, especially when adjunctive procedures are required (orthodontic or periodontal intervention or both). The provisional restoration, as well as implant and soft tissue surgical

templates, can be accurately fabricated from a well-executed diagnostic waxing.

SURGICAL PROCEDURE

Immediate implant placement entails extraction of the failing tooth and then placement of an osseointegrated implant. The extraction must be minimally traumatic, with controlled expansion of the bony socket, to prevent soft and hard tissue damage. This can be accomplished by first using a periotome to make a sulcular incision with transeptal fiberectomy that extends apically beyond the marginal bone. This incision separates the tooth from the periodontal tissue, facilitating extraction with no or minimal damage to the usually thin labial bony plate (Figures 8-5 and 8-6). After the extraction, the integrity of the labial plate must be verified using a periodontal probe. Fenestrations located at least 5 mm apical to the intact facial marginal bone are generally inconsequential to the IIPP procedure, because these defects can be addressed predictably with grafting.

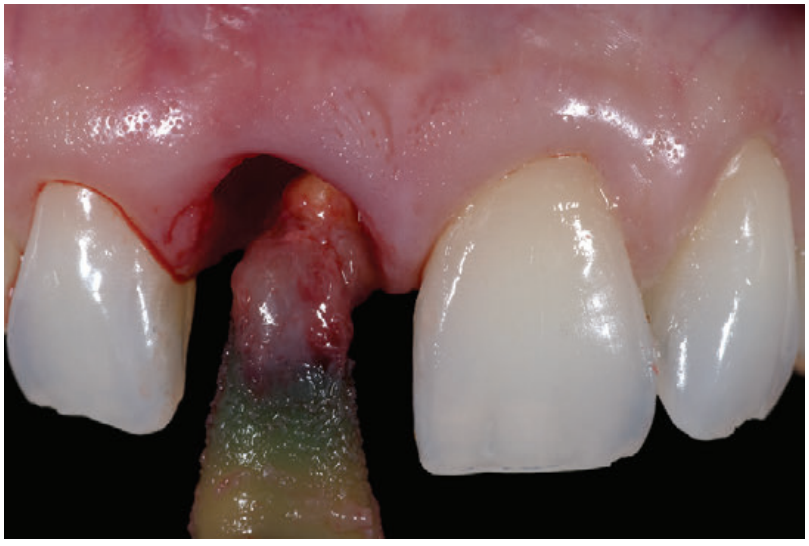

Figure 8-5 Minimally traumatic extraction of failing tooth #8.

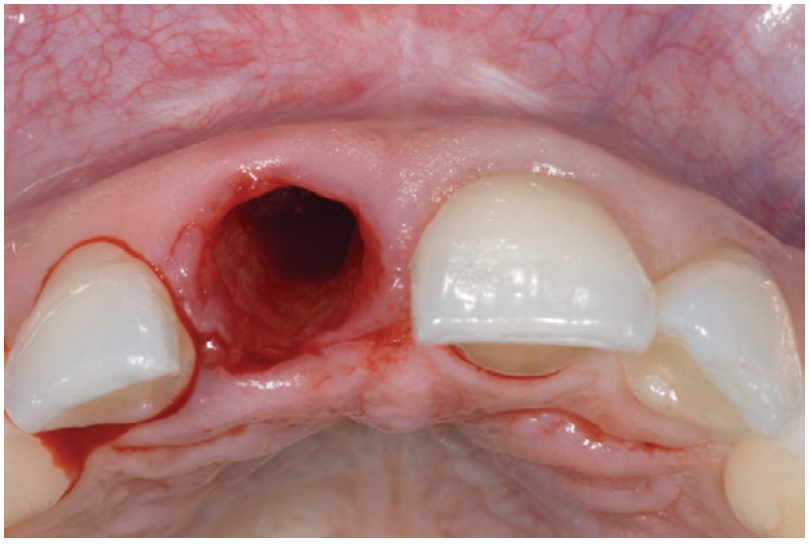

Figure 8-6 Intact extraction socket.

However, when a facial osseous dehiscence or defect is detected, the shape and size of the defect determines the predictability of the IIPP in conjunction with guided bone regeneration (GBR) procedures.[24] A V-shaped defect, which is isolated to the midfacial portion of the facial bony plate, responds favorably to IIPP with GBR (Figure 8-7). However, significant facial gingival recession after 1-year of function has been reported when IIPP with GBR was attempted on failing teeth with a U-shaped defect (extends to the mesial and/or distal aspect of the failing tooth) or a UU-shaped defect (extends to the mesial and distal aspects of the immediately adjacent teeth) (Figure 8-7).[24] Therefore, IIPP is contraindicated for a failing tooth with a U- or UU-shaped defect.

Primary implant stability is a prerequisite for IIPP and is usually achieved by engaging the palatal wall and the bone 4 to 5 mm beyond the apex of the extraction socket (Figure 8-8). Therefore, a class I SRP, with a considerable amount of bone present on the palatal aspect for implant engagement to attain primary stability, is optimal for IIPP. A class IV SRP, with a limited amount of bone for implant engagement, is a contraindication.[20] Class II and class III SRPs present compromised or challenging conditions for IIPP.[20] With a class III SRP, the stability of the implant relies on its engagement to the available bone on the labial aspect, which can potentially lead to facial fenestration or perforation.[20] With a class II SRP, because available bone on both the palatal and labial aspects is inadequate, the implant's stability relies primarily on the amount of available bone beyond the apex of the extraction socket.[20]

The final implant diameter should be within the confines of the tooth socket but should not engage the usually thin coronal portion of the labial plate; this helps prevent perforation. Furthermore, a minimal distance of 2 mm between the implant and adjacent teeth is recommended to minimize marginal bone loss resulting from encroachment.[25] The final implant position and angulation should be in accordance with the following guidelines.

- *Mesiodistally:* The implant should be placed at the center of the predetermined mesiodistal width of the final restoration with a minimal distance of 2 mm from the adjacent tooth (Figure 8-9).

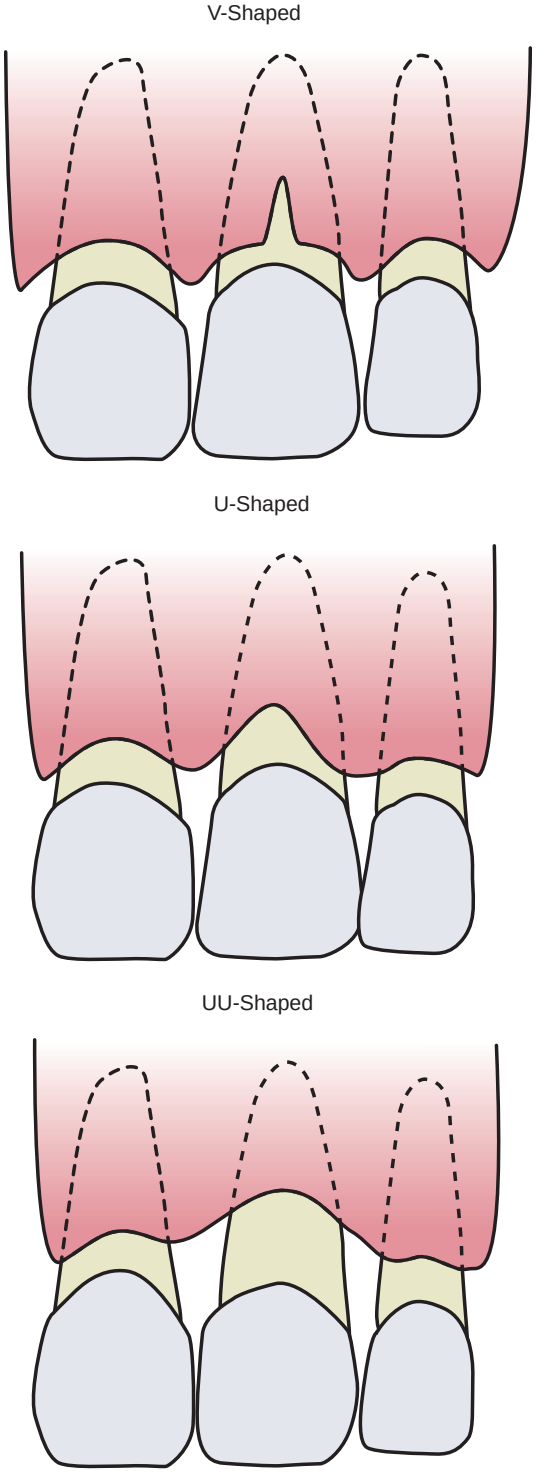

Figure 8-7 Facial bone defect classification. V-shaped defect: Isolated to the midfacial portion of the facial bony plate. U-shaped defect: Extends to the mesial and/or distal aspect of the failing tooth. UU-shaped defect: Extends to the mesial and distal aspects of the immediately adjacent teeth.

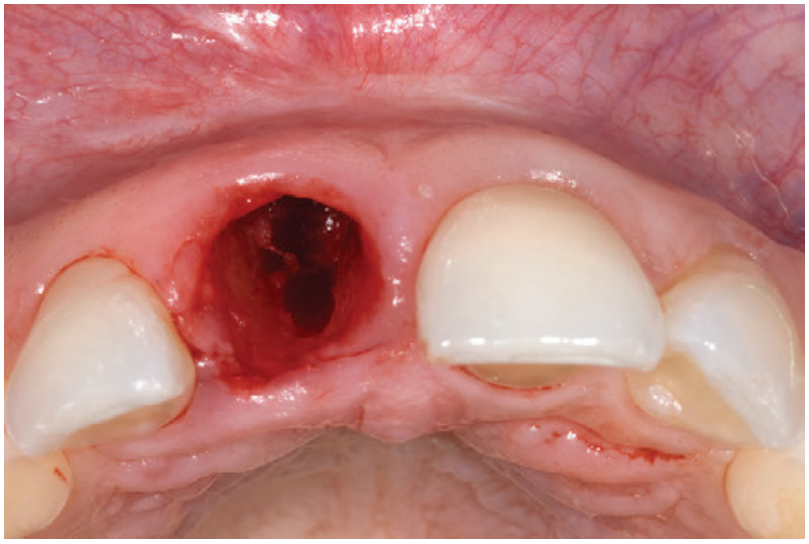

Figure 8-8 An osteotomy is made against the palatal bone for primary implant stability and to avoid potential facial bone damage.

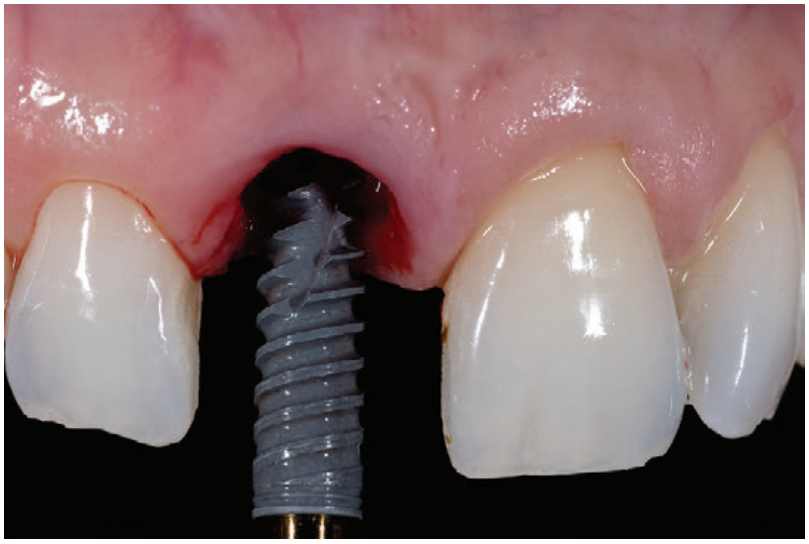

Figure 8-9 The implant should be placed at the center of the predetermined mesiodistal width of the final restoration with a minimal distance of 2 mm from the adjacent tooth.

- *Labiopalatally:* The implant should be placed along the palatal wall of the extraction socket for primary stability. At the cervical level, the implant should emerge slightly lingual to the predetermined buccolingual width of the final restoration. At the incisal level, the implant should emerge at the incisal edge of the final restoration (Figure 8-10, *A*). With this labiopalatal position and placement, a gap of at least 1.5 mm between the implant and the buccal bone is maintained and the integrity of the labial bone is ensured (Figure 8-10, *B*).
- *Apicocoronally:* The neck of the implant is placed approximately 3 mm apical to the predetermined midfacial free gingival margin of the final restoration (Figure 8-11).

IMMEDIATE PROVISIONALIZATION

For immediate provisionalization, a prefabricated zirconium abutment or metal provisional

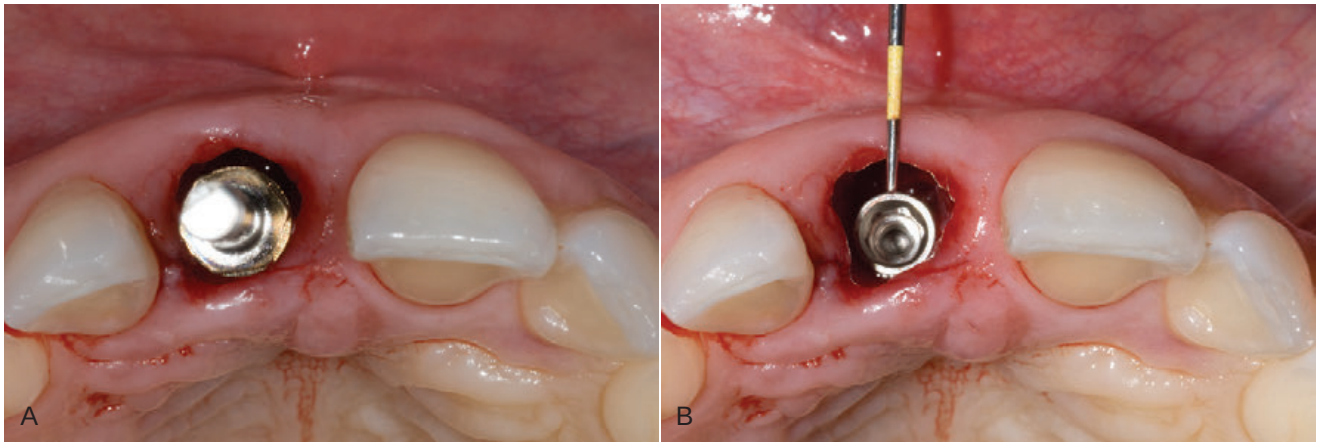

Figure 8-10 **A,** The implant emerges at the incisal edge of the final restoration. **B,** A gap of at least 1.5 mm between the implant and the buccal bone is maintained to ensure the integrity of the labial bone.

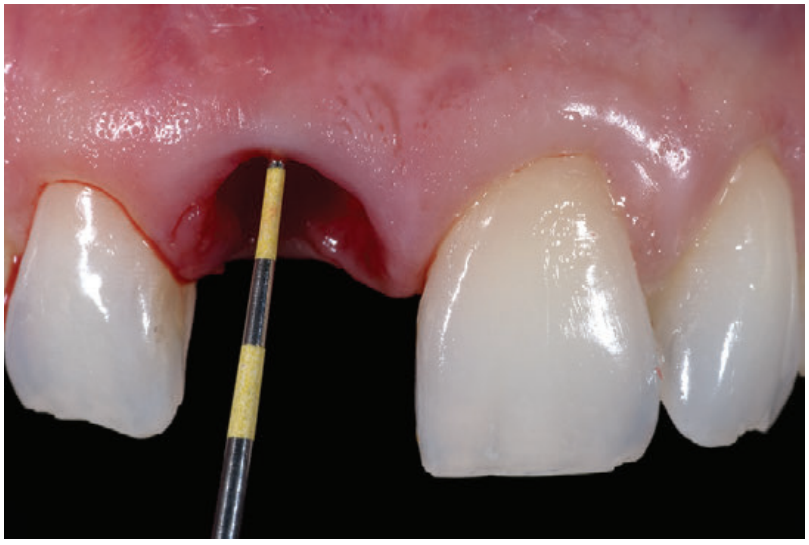

Figure 8-11 The neck of the implant is approximately 3 mm apical to the predetermined facial free gingival margin of the final restoration.

abutment is manually prepared extraorally and then hand-tightened onto the implant (Figure 8-12). The provisional shell is then relined with light polymerized acrylic resin to capture the cervical gingival emergence of the extracted tooth and adjusted to clear all centric and eccentric functional contacts.

After immediate implant placement in an anterior tooth socket, the facial bony plate undergoes remodeling, characterized by bone fill from the inside of the socket and resorption of the labial bony plate from the outside.[26] Without bone grafting, significant horizontal and vertical facial bone loss, and subsequently facial gingival tissue loss, can occur.[26-30]

To maintain the facial osseous contour, bone graft material (e.g., Bio-Oss; Osteohealth, Shirley, New York, and Puros; Zimmer Dental, Carlsbad, California) is placed in the gaps between the implant and the bony socket (Figure 8-13). If the patient has a thin gingival biotype, a subepithelial connective tissue graft can be placed subgingivally between the labial free gingival margin and the labial bone to improve the gingival condition (Figure 8-14).[18] Cementation of the provisional restoration with provisional cement (e.g.,

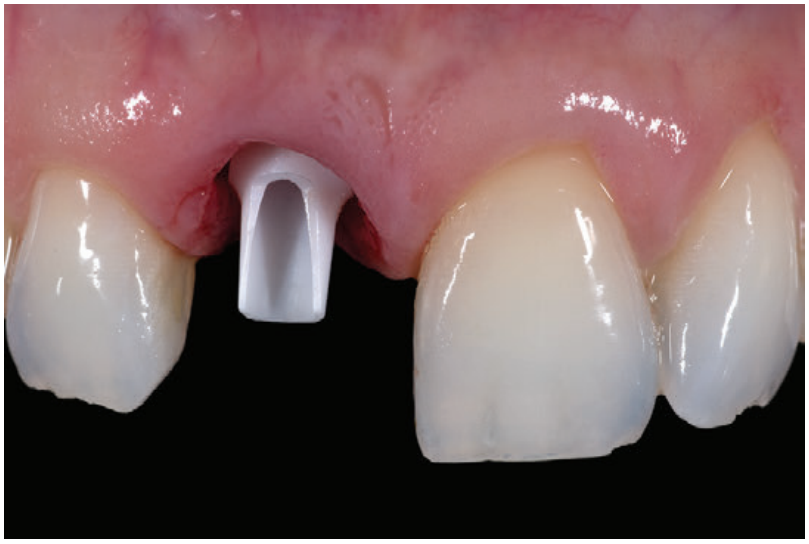

Figure 8-12 A prefabricated zirconium abutment used as a provisional abutment.

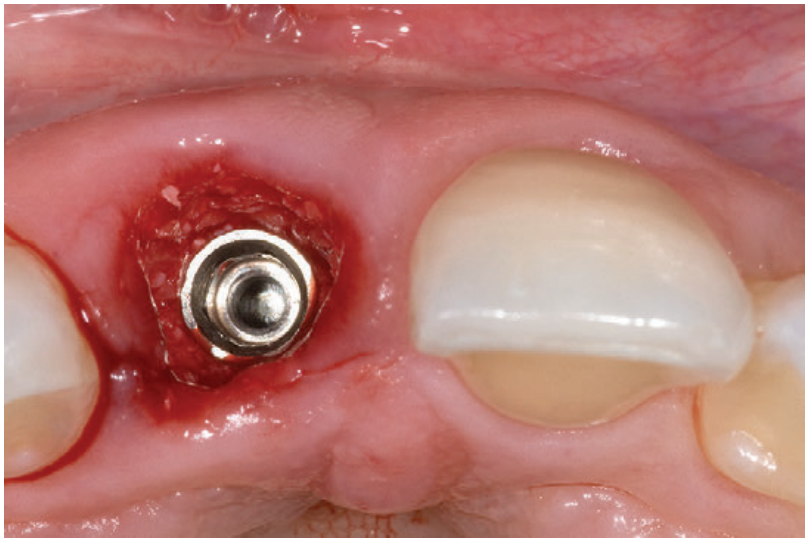

Figure 8-13 Bone graft material is placed in the gaps between the implant and the bony socket to maintain the facial osseous contour.

Temp-bond; Kerr USA, Romulus, Michigan) should be performed simultaneously with placement of the SCTG (see Figure 8-14; also Figure 8-15).

A minimal amount of cement should be used, and it should be mostly isolated at the intaglio incisal and lingual areas of the provisional for ease of later removal and also to minimize extrusion into the soft tissues cervical to the margin. Light finger pressure must be applied over the grafted site with moist gauze for 5 minutes to minimize blood clot formation between the graft and its underlying and overlying tissues. A thick blood clot may hinder the anastomosis of new capillary buds from the recipient bed, thus jeopardizing graft survival.[31] The fit of the crown can be ascertained with a periapical radiograph (see Figure 8-15).

POSTOPERATIVE INSTRUCTIONS

Appropriate antibiotics and analgesics are prescribed for use after surgery. The patient is instructed not to brush the surgical site, but instead

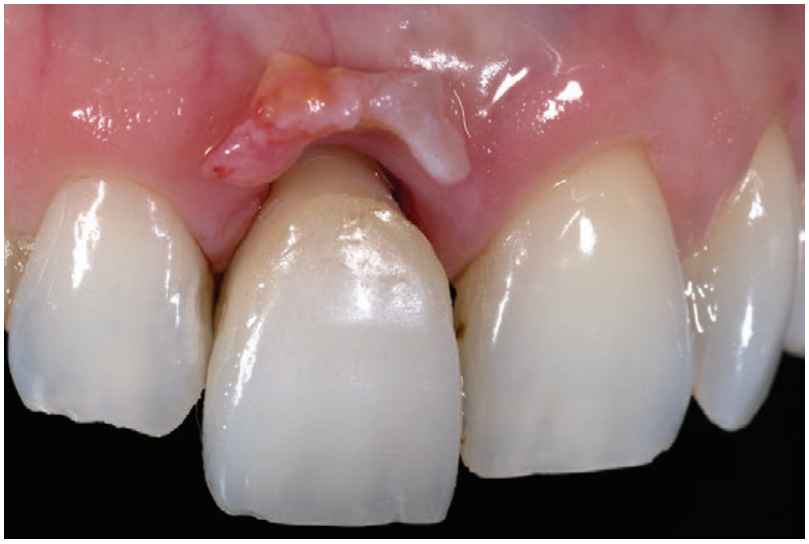

Figure 8-14 A subepithelial connective tissue graft (SCTG) can be placed simultaneously with cementation of the provisional restoration.

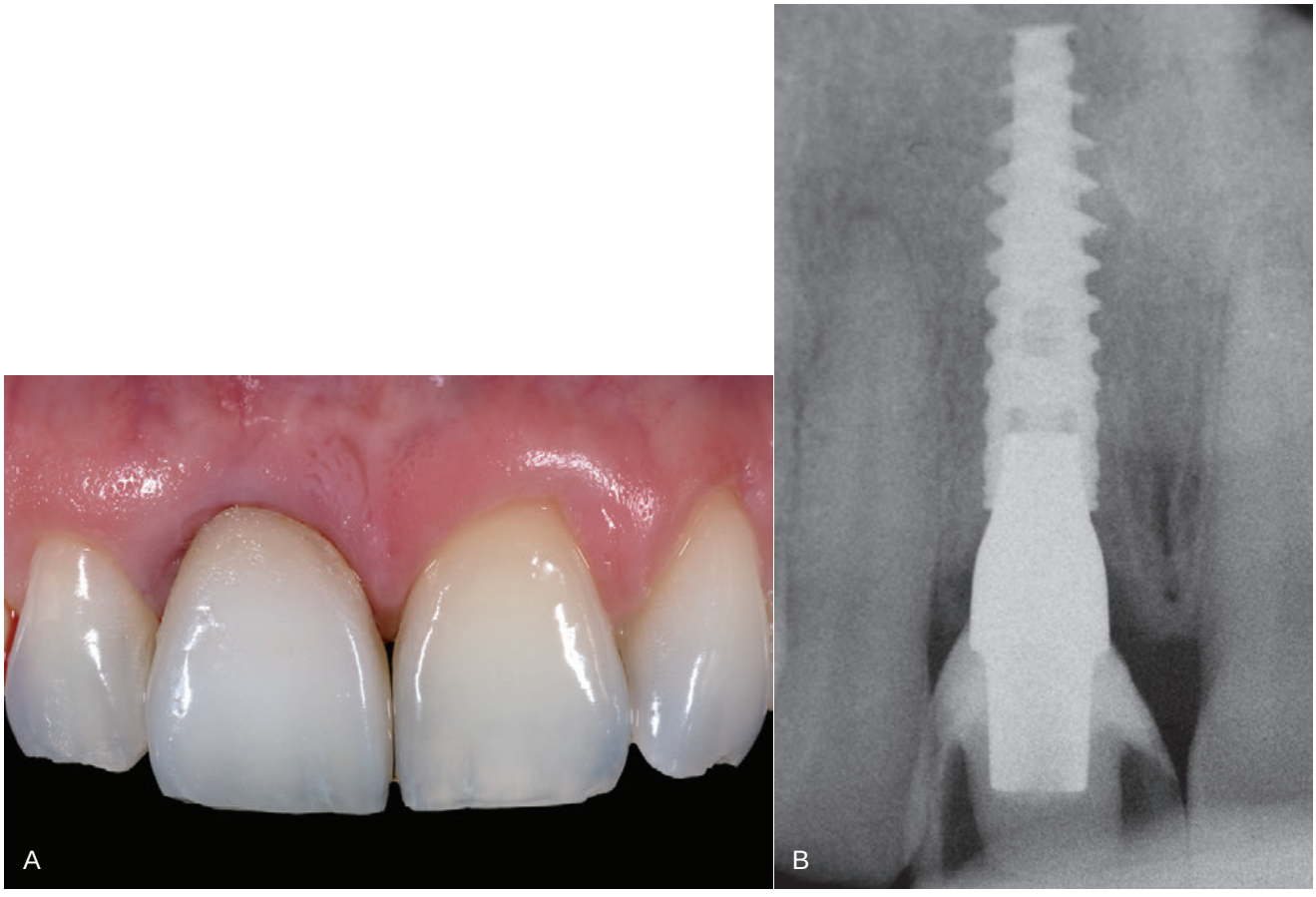

Figure 8-15 Clinical image **(A)** and radiographic image **(B)** of immediate implant placement and provisionalization of #8.

to rinse gently with 0.12% chlorhexidine gluconate (e.g., Peridex; 3M ESPE Dental Products, St. Paul, Minnesota). A liquid diet is required for 2 weeks after the operation, and a soft diet is recommended for the rest of the implant healing phase, which typically lasts 4 months. The patient is also advised against any activity that could irritate the surgical site.

DEFINITIVE RESTORATION

The final implant impression is usually made 6 months after the surgery. A customized zirconium/gold alloy abutment (Procera; Nobel Biocare Procera, Mahwah, New Jersey) is fabricated, duplicating the gingival emergence profile of the provisional restoration (Figure 8-16). The abutment should be tightened onto the implant with the manufacturer's recommended amount of torque, and the fit should be verified with a periapical radiograph. Subsequently, the definitive restoration is cemented (Figure 8-17 and 8-18). Follow-up appointments with the patient should be made for 1 month, 3 months, 6 months, 12 months, and annually thereafter to ascertain the functional and esthetic outcome (see Figure 8-18).

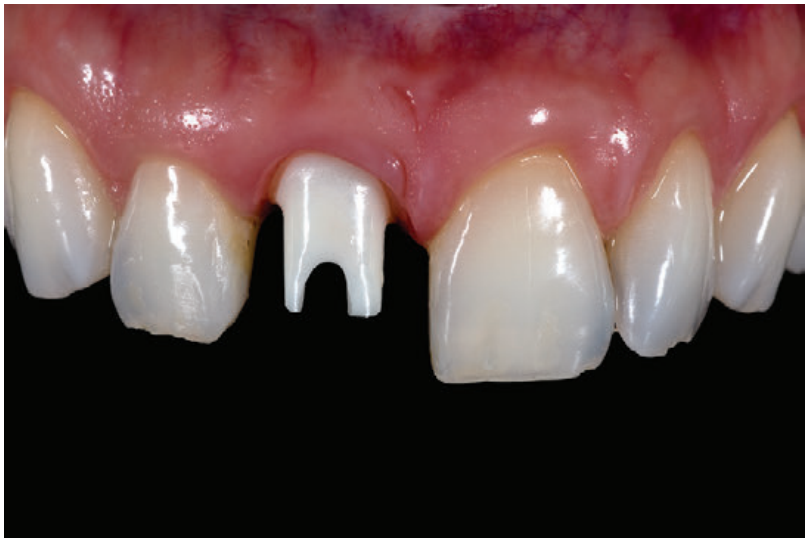

Figure 8-16 Customized zirconium abutment.

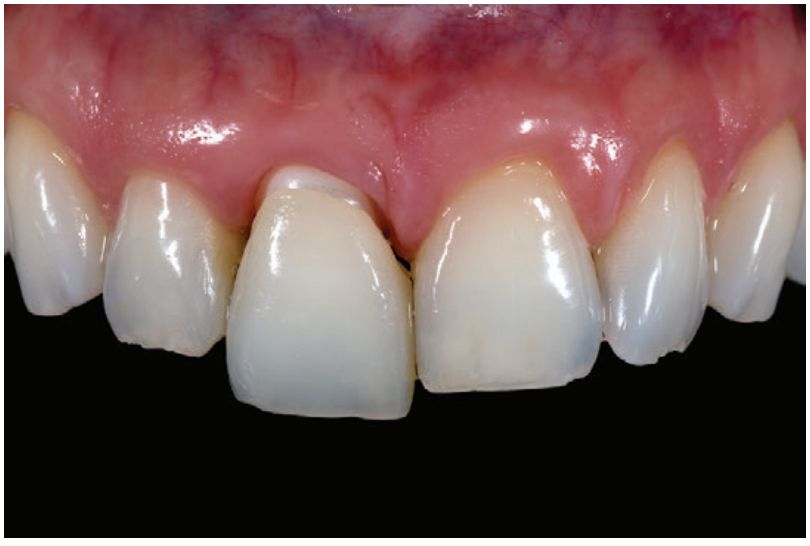

Figure 8-17 Cementation of an all-ceramic definitive restoration.

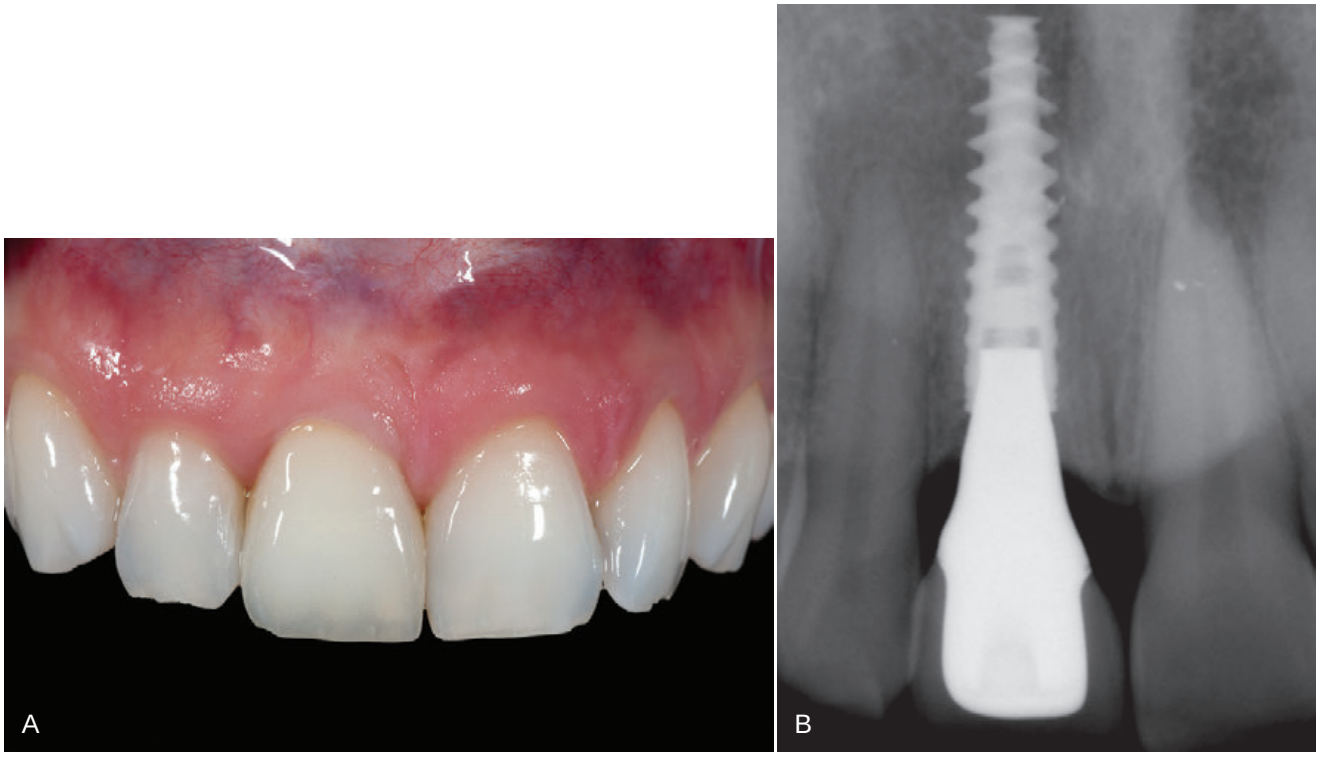

Figure 8-18 Clinical image **(A)** and radiographic image **(B)** of the definitive restoration 12 months after the surgery.

SUMMARY

Although a well-executed immediate implant placement and provisionalization of anterior maxillary single implants has been shown to be a predictable treatment modality, its success depends primarily on careful patient selection, accurate diagnosis, proper planning, and careful adherence to the recommended surgical protocol.

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CHAPTER 9

Restoration of the Single Implant

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Chapter Outline

Implant Survival and Complications Data
Design Principles
- Biomechanics
- Implant Location and Alignment
- Methods of Compensating for Potential Overload
- Occlusion

Retaining the Soft Tissue and Interdental Papillae
Immediate Implant Placement and Loading
- Systematic Reviews, Critical Reviews, and Consensus Statements
- Implant Loss from Immediate Loading
- Other Complications with Immediately Placed Implants

Clinical and Laboratory Procedures
- Examination, Diagnosis, and Treatment Planning
- Radiographic Template
- Ridge Augmentation
- Single Crown Prosthodontic Protocol for Immediate Provisionalization
- Definitive Impression for Crown, Cast, and Crown Fabrication
- Crown Cementation

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the rationale for selecting an implant-supported single crown as a treatment option with awareness of the complications that can occur.
- Explain the design principles involved in the fabrication of an implant-supported single crown with consideration of the biomechanical factors involved.
- Describe challenges in retaining the soft tissue and interdental papillae and the guidelines suggested to minimize complications associated with the soft tissue around the dental implant.
- Explain the concept of immediate implant placement and loading, different impression techniques, clinical considerations, and laboratory procedures involved in the fabrication of an implant-supported crown.

Osseointegrated implants have been successfully used to replace single teeth, both anteriorly and posteriorly, and considerable information has emerged regarding design, clinical procedures, survival, failure, and complications. Before discussing the restoration of single implants, however, it is important to consider the clinical data on success and failure.

IMPLANT SURVIVAL AND COMPLICATIONS DATA

In 2008 a systematic review determined the 5-year survival of single implants to be 96.8% and that of single crowns to be 94.5%.[1] Despite these high survival rates, both biologic and mechanical complications have been reported.[1] In fact, another systematic review concluded that crown complications are common.[2]

A literature review of clinical complications provided the following data on mechanical complications with single crowns attached to single implants: 20% of abutment screws loosened with early screw designs; 7% loosened with newer screw designs and the use of torque devices; and 2% of abutment screws fractured.[3] The same literature review reported that 1% of implants fractured, but the data were related to all types of implant prostheses and were not specific to single crowns. However, multiple reports of implant fractures associated with single posterior implants have been published.

A third systematic review presented data from both short-term studies (6 months to 5 years) and long-term studies (5 to 10 years) of single crowns and fixed partial dentures.[4] The long-term data on single crowns showed that abutment screw loosening ranged from 1% to 10% in the nine studies that provided data on abutment screw loosening with single crowns. Abutment screw loosening occurred with both external and internal abutment connections.

These data clearly show that mechanical complications occur and that design and material changes have reduced but not eliminated the incidence of complications. Therefore, the use of appropriate design principles is important to minimize the chances of problems developing.

DESIGN PRINCIPLES

Information on design principles is limited, but some articles can serve as useful guides for designing crowns so as to minimize undesirable forces on the implant system.

Rangert et al.[5] evaluated the forces and moments that occur on Brånemark implants. Based on theoretical considerations and clinical experience with Brånemark implants, these authors presented guidelines for controlling the forces applied to implants. They recommended that the restoration not extend lateral to the implant more than approximately one implant diameter in the molar region and no more than two implant diameters in the incisor region.

In another article, Rangert et al.[6] discussed the probable causes of 39 implant fractures. All nine fractures of implants supporting single crowns occurred in the mandibular molar area (eight first molars and one second molar) (Figures 9-1 to 9-5). Several factors that result in adverse loads on implants were discussed, including:

- Excessive height of the occlusal surface above the implant
- Deviation of the long axis of the implant from a perpendicular relationship to the occlusal plane
- Substantial differences between the dimension of the occlusal surface and the diameter of the implant
- Bruxism or heavy occlusal forces

Implant fractures are not common, and statistical differences in fracture rates based on location in the mouth have not been shown. However, Eckert et al.[7] analyzed the incidence of fracture among 4,937 implants. They determined that the only implant fractures associated with single crowns occurred in molar areas. Based on the observation that single implant fractures were associated only with molar crowns, the authors stated, “Despite the lack of statistical significance, this clinical observation makes it appear prudent to consider the single implant–supported molar to be at a higher risk of fracture.”

Rangert et al.[8] identified risk factors that increase the load applied to implants. The following factors

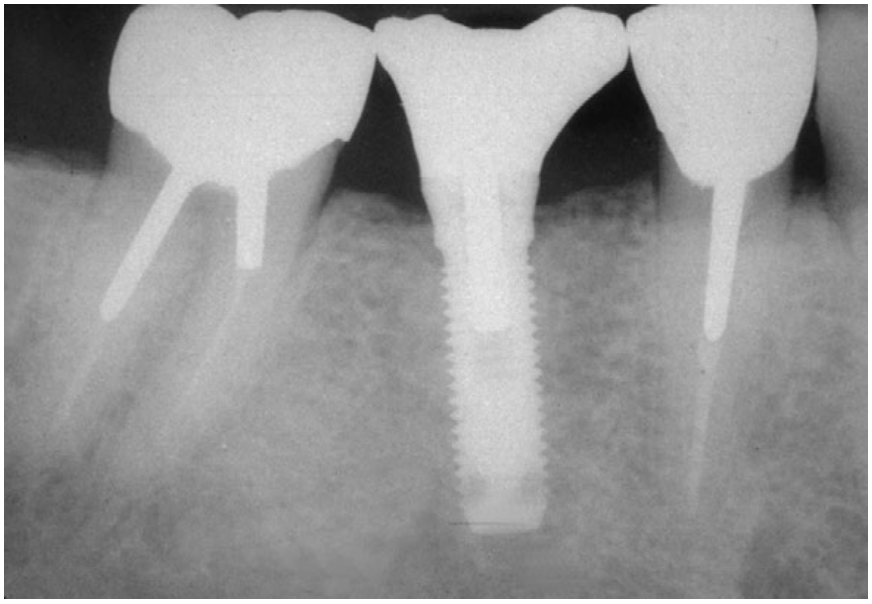

Figure 9-1 Radiographic image of a mandibular implant-supported crown. Note the mesial cantilever. The patient had a history of bruxing.

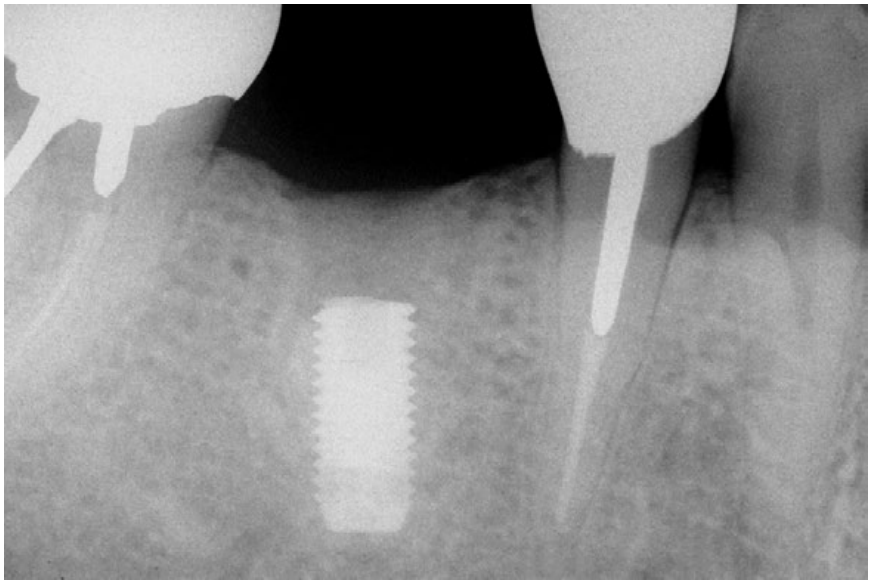

Figure 9-2 Radiographic image showing the fractured implant due to biomechanical overload.

related to implant single crowns: (1) extension of the occluding surface lateral to the implant; (2) increasing the distance between the occlusal surface and the implant; (3) use of one implant to support the replacement of a multi-rooted tooth; and (4) bruxism or the presence of heavy occlusal forces as evidenced by tooth wear/tooth structure fractures. When a molar is replaced using a single implant, the authors emphasized the importance of controlling occlusion so as to avoid heavy centric occlusal contact. They suggested light centric occlusal contact as a means of avoiding heavy contact.

BIOMECHANICS

Anterior Biomechanics

In light of the guidelines set by Rangert et al.,[5] a reasonable conclusion is that anterior implant single crowns can extend laterally a moderate

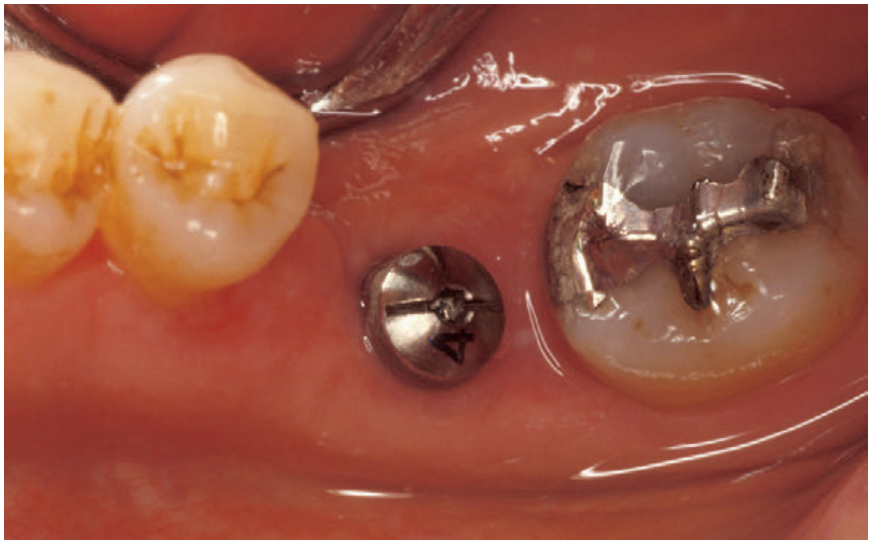

Figure 9-3 Implant placed to replace mandibular first molar is more lingually positioned when compared to the location of adjacent natural teeth.

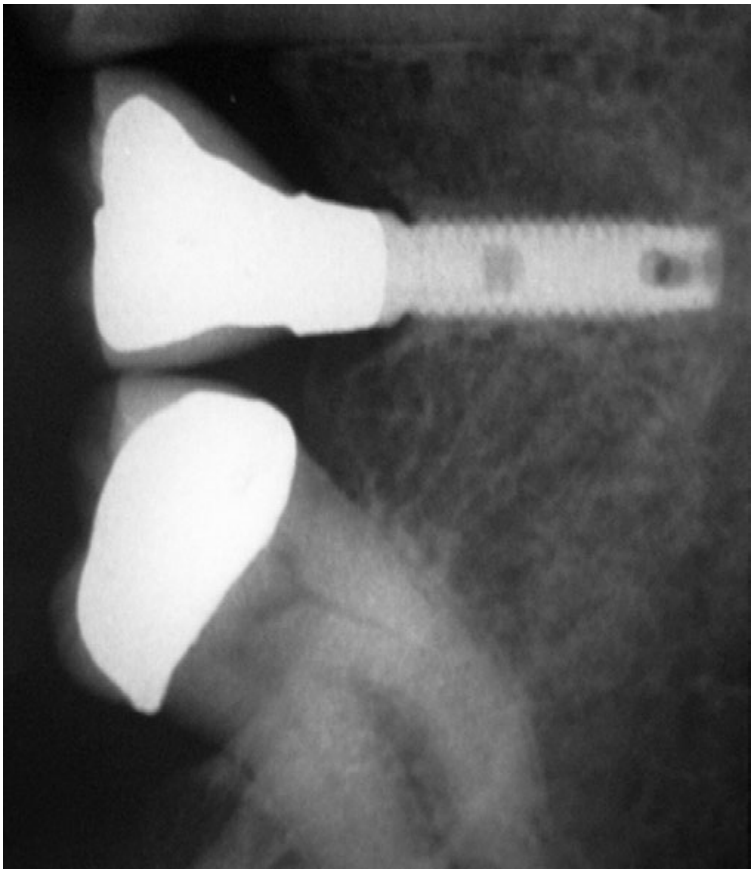

Figure 9-4 Radiographic image of the implant-supported crown made for the implant shown in Figure 9-3 that shows the mesial cantilever.

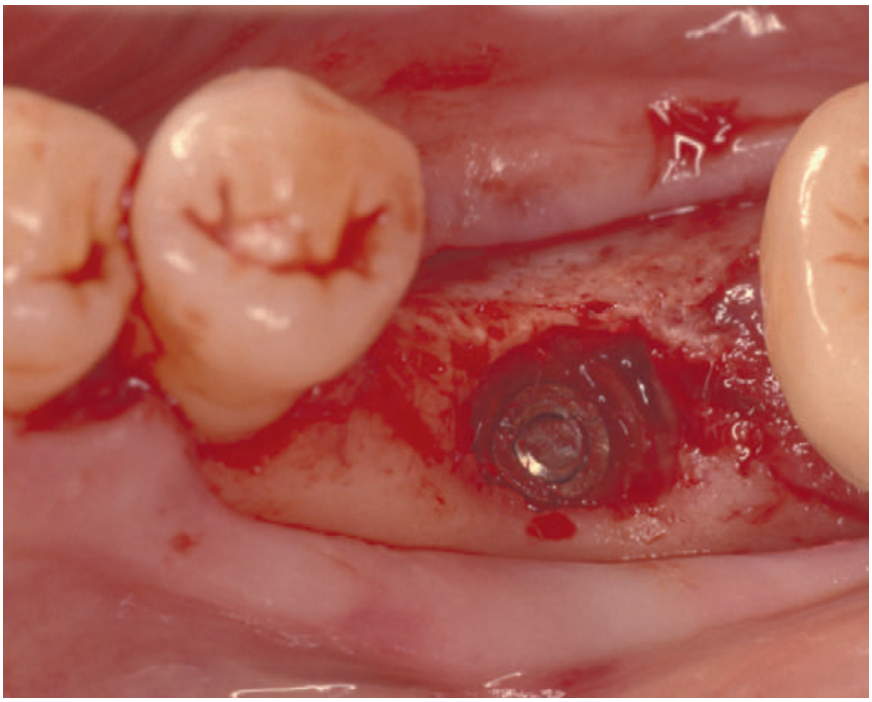

Figure 9-5 Implant fracture at the level of the crestal bone attributed to biomechanical overload resulting from the buccal and mesial cantilevers created by the position of the implant.

distance beyond the periphery of the implant. This is possible because the maximum occlusal load in the anterior region of the oral cavity is less than the maximum load in the posterior region. Depending on the material used for fabrication of the implant, abutment, and retaining screw and the clamping force achieved when the retaining screw is tightened, an implant-supported crown can resist a specific load before the retaining screw deforms. The practitioner must understand the anticipated load that will be placed on the implant and limit the dimensions of the crown to prevent occlusal overload.

The average dimensions of anterior teeth are 5 to 8.5 mm mesiodistally and 6 to 8.3 mm faciolingually; therefore, adverse leverage is unlikely to be created by the mesiodistal or faciolingual dimensions of the crown. Biomechanical overload of an anterior crown is more likely to occur in an incisocervical dimension, because the distance from the top of the implant to the location of occlusal contact can be substantial, especially if the implant is placed deep below the soft tissue for esthetic reasons (Figure 9-6) or if a significant alveolar defect exists before implant placement.

If risk factors create the potential for implant overload, alterations in the incisal guidance and implant angulation in the bone may help reduce that risk.[9]

Posterior Biomechanics

If the previous recommendations about forces and moments[5] are applied to posterior single crowns placed on implants, the conclusion is that the crown should not extend lateral to the implant more than one implant diameter. Therefore, for an implant 4 mm in diameter, the maximum lateral cantilever should be about 4 mm; this means that the crown should extend mesially, distally, facially, or lingually only 4 mm lateral to the implant.

The preceding recommendation places limits on the total mesiodistal or faciolingual dimensions of the crown and is designed to provide a conservative, safe guideline that minimizes mechanical overload. The dimensions of a typical premolar do not exceed this guideline, nor do average-sized molars. However, biomechanical overload can occur with molars as a result of excessive occlusal forces or larger than normal mesiodistal or faciolingual dimensions.

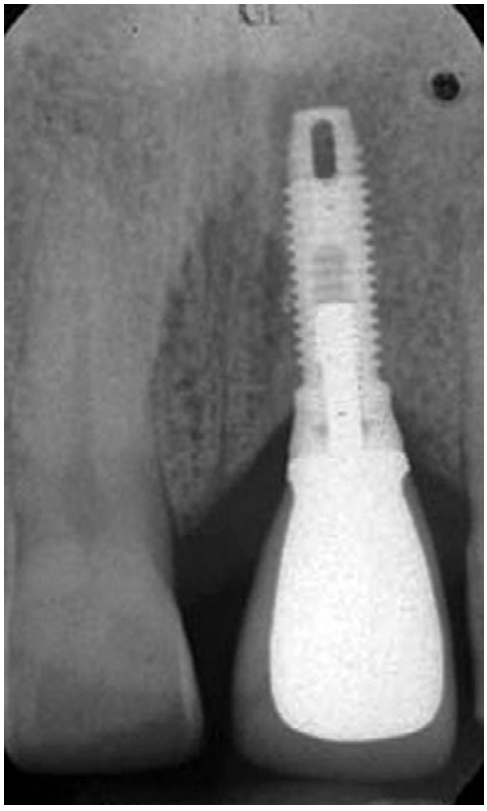

Figure 9-6 Biomechanical overloading of an anterior crown is more likely to occur in an incisocervical dimension, because the distance from the top of the implant to the location of occlusal contact can be substantial. This problem is especially likely if the implant is placed deep below the soft tissue for esthetic reasons or if a substantial alveolar defect exists before implant placement.

Figure 9-7 documents the relative number of fractures found by Rangert et al.[6] for implants located in different sites. Biomechanical overload is more likely if a single molar implant is not centered under the crown. In addition, the possibility of overload increases as the distance from the occlusal surface to the implant increases. The combination of a tall crown and an implant that is not centered beneath it compounds the potential for overload.

Weinberg and Kruger[10] mathematically compared four clinical variables that can affect torque production and implant loading: (1) cuspal inclination, (2) implant inclination, (3) horizontal implant offset, and (4) apical implant offset. A knowledge of these factors can help the practitioner design crowns that transfer more favorable forces to the implant system. Cuspal inclination and horizontal implant offset have the greatest effect on torque, and implant inclination and apical implant offset have a lesser impact. The effects are as follows:

- For every 10-degree increase in cuspal inclination (steepness), torque increases approximately 30%
- For every 1 mm of horizontal offset (i.e., the implant is not centered beneath the occlusal surface of the crown), torque increases approximately 15%
- For every 10-degree increase in implant inclination relative to the angle of applied occlusal force, torque increases approximately 5%
- For every 1 mm increase in the vertical implant offset (i.e., the distance from the occluding surface to the implant, also known as the *crown-to-implant ratio*), torque increases approximately 5%

Guidelines for reducing torque are presented in Box 9-1.

IMPLANT LOCATION AND ALIGNMENT

The location of the implant in the bone is an important aspect of biomechanical success and crown esthetics with implant single crowns. The implant should be centered mesiodistally in the edentulous space for esthetic and biomechanical reasons. This position equalizes the lever arm developed by the mesial and distal portions of the crown, which project laterally to the implant. When the implant is displaced to the mesial or distal of center and occlusal forces are applied, greater leverage is exerted on the implant and other components than if the implant were centered.

Centering the implant mesiodistally also facilitates the development of a normal emergence profile and permits better morphologic replication of the contralateral tooth than when the implant is displaced to the mesial or distal. If an implant cannot be centered, the practitioner should consider the anatomy of the tooth being replaced to establish the most favorable implant position. For example, in the maxillary incisor region, the mesial surface of an incisor generally has a straighter emergence than the distal surface, which has a more curvilinear emergence from the natural

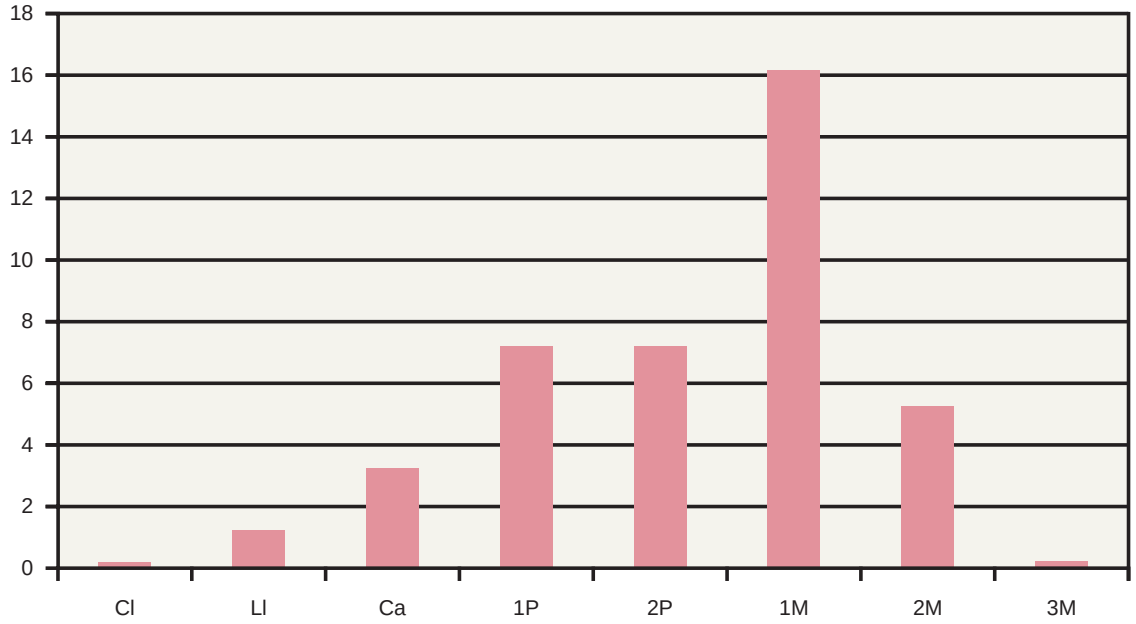

Figure 9-7 The relative number of fractures that occur with implants located in different sites. (Data from Rangert B, Krogh PHJ, Langer B, Van Roekel N: Bending overload and implant fracture: a retrospective clinical analysis, *Int J Oral Maxillofac Implants* 10:326-334. 1995.)

Box 9-1 Summary of Torque Reduction Guidelines

1. The implant should be centered beneath the crown; this emphasizes the importance of determining the crown position before placing the implant and of using the crown's position to determine where the implant should ideally be located.
2. The crown should not be extended lateral to the perimeter of the implant any more than necessary, particularly with molar crowns.
3. With heavy occlusal forces, it is important to minimize as much as possible all factors that increase torque. This can be done by decreasing cuspal steepness, centering the implant beneath the crown, minimizing the inclination of the implant relative to the application of occlusal force, and avoiding implants that are placed deep in the bone relative to the occlusal surface (creating a large crown-to-implant ratio).

tooth root. When an implant is located off the mesial-distal center of the edentulous space, a design priority should be given to the surface with the straighter or flatter proximal morphology so it matches the contralateral tooth as it emerges from the mucosa.

When locating the implant in bone, the practitioner must take care to avoid approximating adjacent teeth, which can lead to a need for endodontic treatment, damage to the roots, or loss of the implant, or all of these.

The faciolingual positioning of the implant is also important to biomechanical success. Centering an implant beneath a posterior crown helps reduce the potential for biomechanical overload, a factor particularly important for molars or premolars when heavy occlusal forces are present.

In esthetically critical locations, a faciolingually centered position is preferred when existing bone dimensions permit. Lingual positioning of the implant produces a crown with deficient facial cervical contour or one in which porcelain must overlap the facial soft tissue to create the desired cervical crown morphology. The overlapping makes oral hygiene more difficult and will not be esthetically pleasing if the soft tissue recedes apically. Conversely, if the implant is

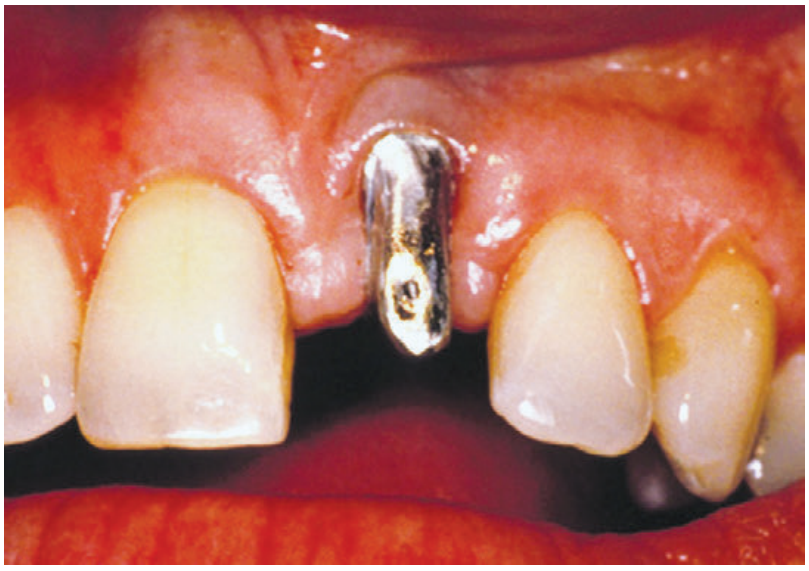

Figure 9-8 An implant placed too far facially creates esthetic challenges.

placed too far facially, the facial bone becomes thin and subsequent remodeling may result in soft tissue recession and/or gray discoloration of the overlying soft tissue. Placing an implant too far facially can create such a substantial esthetic challenge that the implant may have to be removed, bone grafting performed, and another implant subsequently placed in a more favorable position (Figure 9-8).

Aligning the implant so it is perpendicular to the occlusal surface reduces the leverage applied to the various metal components.

The incisocervical/occlusocervical location of the implant is largely determined by the location of existing bone (Figure 9-9) and the esthetic need to transition from a smaller diameter round form to a larger diameter form with a different geometric perimeter. Typically, implants have been placed apical to the cementoenamel junction of adjacent teeth to permit the required changes in morphology to occur somewhat gradually. While an early textbook[11] recommended that implants in the esthetic zone be placed 4 mm or more apical to the cementoenamel junctions of adjacent teeth, it is currently felt that implants should not be positioned this deep but should be located so the implant platform is approximately 3 mm apical to the predetermined midfacial margin of the mucosa.

METHODS OF COMPENSATING FOR POTENTIAL OVERLOAD

In some cases, because of the position or dimensions (or both) of the residual bone in the edentulous area, implants cannot be placed in an ideal location. In such cases bone grafting should be used to enhance the location of the implant. If grafting is used and a positional deficit remains, or if grafting is not possible because of the patient's choice or the added expense, compensatory designs should be used to reduce the overload potential. These design modifications are particularly important with molar implants because of the higher overload potential as a result of heavier occlusal forces and larger crown dimensions. Methods of overload compensation with molar implants include narrowing of the occlusal table, use of wider diameter implants (5 or 6 mm) (Figure 9-9), or use of two implants to support one molar crown (Figure 9-10 *A, B*).[12]

OCCLUSION

The centric occlusal contact between a crown and the opposing dentition should be light when the patient taps the teeth or holds the teeth together without clenching. With this type of contact, shim

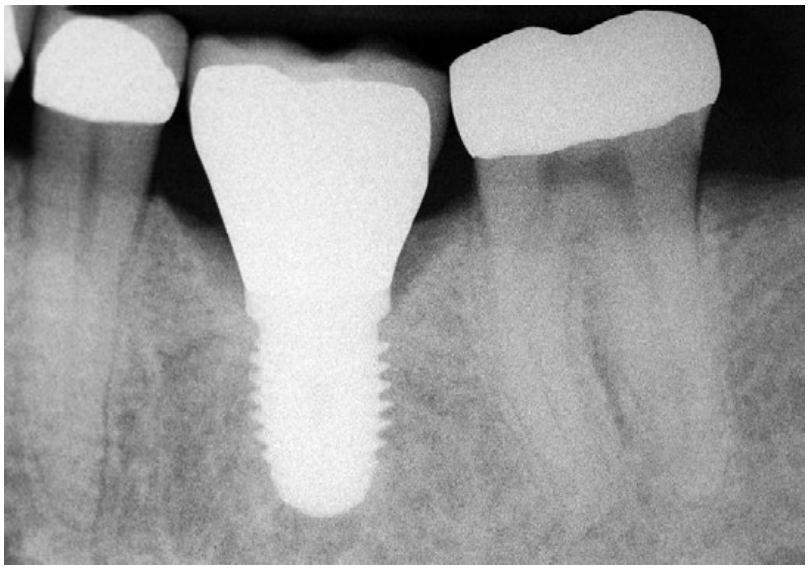

Figure 9-9 A wider diameter implant is used to reduce overload.

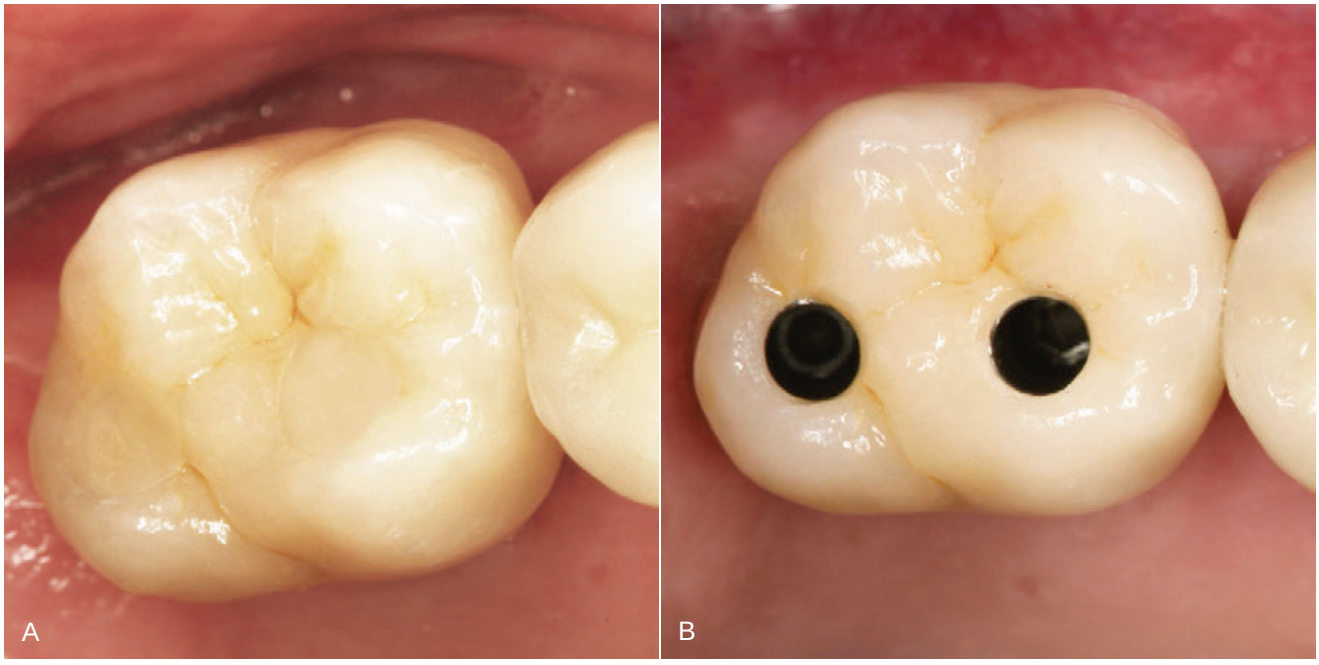

Figure 9-10 **A** and **B,** Two implants are used to support one molar crown.

stock should not be firmly grasped and should just slide from between the crown and opposing tooth or teeth.

When the patient fully activates the masticatory muscles (as in clenching), the shim stock should be grasped with the same intensity that it is grasped between opposing natural teeth. This protocol helps prevent the implant crown from being in heavy occlusal contact when the patient clenches or bruxes the teeth.

Eccentric occlusal contacts should be avoided on posterior single crowns. Whenever possible on anterior teeth, eccentric contact should be shared between the implant crown and adjacent natural teeth during protrusive, lateroprotrusive, and working side movements.

Box 9-2 Synopsis of Design Guidelines

- Center the implant mesiodistally in the edentulous space.
- If the faciolingual dimensions of the bone permit, center the implant faciolingually so that a normal emergence profile can be developed.
- If the implant is to be positioned substantially to the lingual because of lack of facial bone, consider some type of bone augmentation procedure so that the implant can be placed in a more facial location.
- Place the implant as perpendicular to the occlusal surface as possible.
- With posterior implant single crowns, avoid extending the occlusal surface lateral to the implant by a distance greater than the diameter of the implant.
- Use wider diameter implants when access, bone dimensions, and esthetics permit.
- Maintain light centric occlusal contact (shim stock just slides through) between the implant single crown and the opposing tooth during normal tapping occlusal contact.
- When the patient fully engages the musculature, the shim stock should only then be grasped by the crown with the same intensity as opposing natural teeth.
- Avoid eccentric occlusal contact on the implant single crown or develop group function if contact cannot be avoided.
- Bruxism increases the magnitude of the force applied and its frequency. Therefore, minimizing all factors that increase torque on the crown is important (e.g., cusp steepness, horizontal implant offset, implant inclination, and apical implant offset). Having the patient wear an occlusal device (night guard) also is prudent.

Because occlusal habits such as bruxism increase the forces placed on implant single crowns, an acrylic resin occlusal device should be fabricated that the patient can wear during the times bruxism occurs.

A synopsis of implant design guidelines is presented in Box 9-2.

RETAINING THE SOFT TISSUE AND INTERDENTAL PAPILLAE

Single crowns on implants can produce exceptional esthetic results, but challenges can arise when implants are placed in highly visible maxillary anterior edentulous areas.

Interdental dark spaces may be present (Figure 9-11); the marginal tissue may be thicker than the gingival margin around adjacent teeth; the apical location of the soft tissue margin may not be at the same height as adjacent or contralateral natural teeth; interdental papillae may not have the most desirable form or height; and recession of the soft tissue may lead to crown length variations or exposed metal, or both (Figure 9-12). Although some deficits may not be noticeable to patients,[13] others can be significant. Because of the esthetically critical nature of some deficits, the form of the soft tissue around implant single crowns has been clinically evaluated and compared with that of contralateral natural teeth[14] to better understand the characteristics that produce normal and abnormal soft tissue forms around implant single crowns.

The stability of soft tissues and the associated esthetic outcome of implant treatment are determined by several factors, including surgical technique, implant position, prosthetic protocol, biotype of the soft tissues, tooth shape, bone condition, and the position of the osseous crest.

If the bone is the proper height interproximally, the soft tissue usually fills the cervical embrasure spaces.[15] In a study of 27 single implants placed in the anterior maxilla of 26 patients, a papilla was present 100% of the time when the distance from the proximal contact point to the crest of the interproximal bone adjacent to the natural tooth was 5 mm or less.[15] The papilla was present only 50% of the time when the distance from the contact point to the bone was 6 mm or greater. This study indicates that the distance from the soft tissue crest to the bone is important in maintaining the presence of papillae between natural teeth and implants.

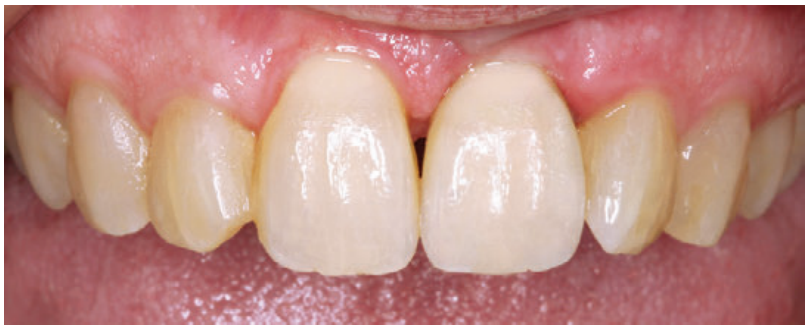

Figure 9-11 Dark interdental spaces are one of the complications of anterior implant placement.

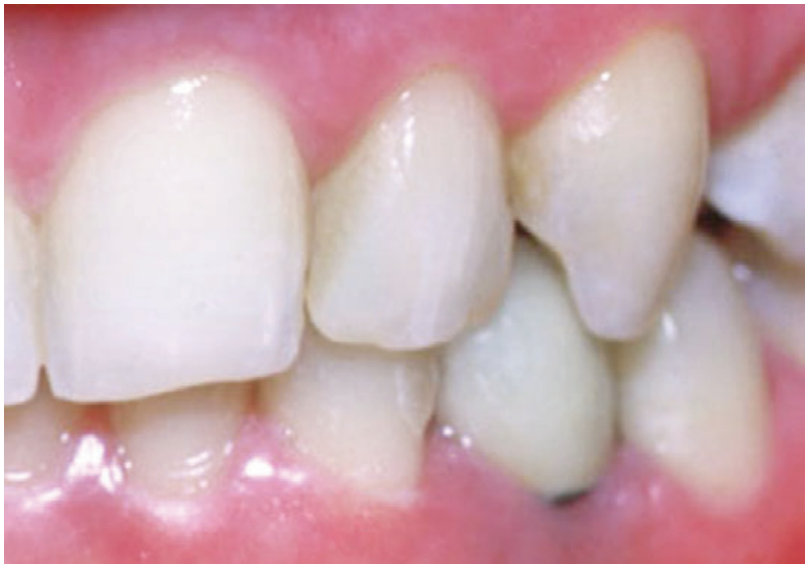

Figure 9-12 Gray discoloration is visible at the cervical aspect of the implant restoration as a result of soft tissue recession.

Kan et al.[16] studied the effect of the periodontal biotype (thick versus thin soft tissue) on the peri-implant mucosa dimension around 45 maxillary anterior single implants. The measurements for individuals with a thick biotype were significantly greater than those for patients with a thin biotype. These authors suggested that the height of the soft tissue incisal to the bone "can seldom be recreated beyond 4 mm" when patients with a thin gingiva are treated.

When two implants are placed next to each other, the potential esthetic challenge is even greater. A study by Tarnow et al.[17] of 33 patients provides valuable clinical guidelines for this esthetically difficult situation. In this study, the average height of the interimplant soft tissue was 3.4 mm (range, 1 to 7 mm). However, in most cases only 2, 3, or 4 mm of soft tissue was present. Based on these authors' findings, a reasonable conclusion is that only about 3 mm of soft tissue will be present incisal to the interproximal bone between two adjacent implants.

The longer an area has been edentulous, the more likely it is that a soft and hard tissue discrepancy will exist as a result of bone resorption and concomitant changes in the soft tissue contour. When a substantial esthetic deficiency is noted clinically or from a diagnostic wax pattern formed on a cast, bone or soft tissue grafting (or both) may be necessary. However, some esthetic deficiencies are not totally correctable through grafting procedures; in such cases emphasis should be placed on retaining soft tissue form rather than restoring lost tissue. Methods of retaining soft tissue form and location include immediate implant placement and immediate

placement of a provisional restoration when these procedures are indicated (see Chapter 8).

IMMEDIATE IMPLANT PLACEMENT AND LOADING

Immediate implant placement and provisionalization after extraction of a tooth have been performed successfully in the maxillary esthetic zone, preserving the papillae.[18] The results are most predictable when certain characteristics are noted in the prospective implant site before tooth extraction. The dentogingival complex dimensions (i.e., the distance from the free gingival crest to the osseous crest) ideally should be 3 mm on the facial surface of the tooth to be extracted and 4.5 mm on the interproximal surfaces of the adjacent teeth. Deviations from these dimensions are likely to result in less pleasing soft tissue esthetics.[19]

SYSTEMATIC REVIEWS, CRITICAL REVIEWS, AND CONSENSUS STATEMENTS

A systematic review by Esposito et al.[20] compared the success rates of immediately or early loaded implants with those of conventional delayed-loaded implants. Seven randomized controlled trials were identified, and five of the trials (involving a total of 124 patients) were judged suitable for inclusion. The implants were immediately loaded after placement (2 to 3 days), loaded early (6 weeks), or loaded after 3- to 8-month periods in edentulous mandibles with appropriate bone quality and morphology.

In the trials studied, 376 implants were placed in 124 edentulous mandibles. Of these, 116 were immediately loaded, 72 were loaded early, and 188 were loaded after a delayed period. During the review's 1-year follow-up period, 11 implants failed (1 immediately loaded implant, 7 early loaded implants, and 3 delayed-loaded implants).[20] However, the results were not specific to single implants.

No significant differences were noted between the loading protocols for prosthesis failures, implant failures, or marginal bone loss on intraoral radiographs. However, the authors indicated in their discussion that the number of trials and the number of patients were too limited to allow reliable conclusions to be drawn.[20]

In 2002 the Sociedad Espanola de Implantes World Congress consensus meeting stated that multiple independent investigations indicated that immediate or early loading is possible in many clinical situations, but additional documentation is needed.[21]

In 2009 Atieh et al.[22] published a systematic review of single implant crowns in the anterior esthetic region. They determined that immediate loading carries a significantly higher risk of implant failure than does loading after the bone has healed around the implant. The authors suggested that nonoccluding provisional crowns (absence of occlusal contact in the intercuspal position and during eccentric mandibular movements) are actually loaded during mastication. The authors also stated that the meta-analysis should be interpreted with caution, because only five randomized clinical trials were included in the review and the overall sample size was only 248 implants.

IMPLANT LOSS FROM IMMEDIATE LOADING

Although not specific to single implants, a large number of studies provide data on the loss rate of immediately loaded implants.[23-68] In these studies, a total of 6,474 implants were placed, and 281 were lost (an implant loss rate of 4%). In several of the studies, no implants were lost*; in several others, the loss rates were between 1% and 3%.† The highest implant loss rates were 17%,[44] 15%,[23] 14%,[25] and 14%.[33]

OTHER COMPLICATIONS WITH IMMEDIATELY PLACED IMPLANTS

Studies have reported other complications with immediately loaded implants, including loose provisional crowns (2 of 53 single crowns,[35] 1 of 14 single crowns,[33] and 3 of 35 single crowns[49]); loose definitive crowns (1 of 53 single crowns[35] and 3 of 8 single crowns[41]); fractured definitive crowns (4 of 53 single crowns[35]); loose provisional abutments

*References 28, 30, 38, 39, 41, 43, 47, 49, 52, 53, 56, 57, 61, 64, 65, and 67.
†References 24, 26, 29, 32, 36, 40, 48, 50, 51, 58, 62, and 68.

(2 of 35 abutments[49] and 1 of 102 abutments[62]); improperly seated abutments (2 of 91 abutments[59]); peri-implant infection (1 of 53 single implants[35]); postoperative swelling (4 of 10 patients[43]); mucositis (2 of 8 single provisional crowns[41]); calculus on the provisional crown (1 of 8 single crowns[41]); fistulas (1 of 8 single provisional crowns[41] and 4 of 35 provisional single crowns[49]); and the need to change the abutments for esthetic reasons (18 of 94 units, either single crowns or fixed partial dentures[45]).

CLINICAL AND LABORATORY PROCEDURES

EXAMINATION, DIAGNOSIS, AND TREATMENT PLANNING

A clinical examination, medical and dental history, periapical and bitewing radiographs, and diagnostic casts are required to plan treatment. In some areas of the mouth the implant may need to be placed in proximity to vital structures and therefore it may be prudent to use cone beam computed tomography (CBCT) so a 3-dimensional analysis can be performed. Systemic factors that can compromise implant success also should be evaluated. The clinical examination and radiographs should be used to detect any caries and to evaluate bone health and quality, incisocervical/occlusocervical bone dimensions, the distance between adjacent roots, the pulpal and periodontal health of adjacent teeth, and the quality and integrity of existing restorations in adjacent teeth. Any diseases in teeth approximating the edentulous area should be treated. Untreated diseases can cause implant loss.

When practitioners examine patients with single missing teeth who may benefit from implant-supported/retained single crowns, it is important for them to determine whether the morphologic form of a crown would be esthetically appropriate when developed on the existing edentulous ridge with the implant contained in available bone. This decision requires the development of a diagnostic pattern, a procedure that can identify any esthetic deficiencies in crown dimensions or cervical contour caused by bone resorption of the alveolar ridge.

RADIOGRAPHIC TEMPLATE

The available bone dimensions in the alveolar ridge can be determined through bone sounding, or use of cone beam computed tomography. Using a radiographic template, the practitioner can relate the diagnostic form and location of the crown to available bone to determine whether an implant can be positioned within the available bone. The template also aids the development of a crown with the appropriate form and dimensions. These data, in addition to the clinical examination findings, diagnostic casts, and diagnostic pattern of the most desirable crown form, identify patients in whom bone augmentation is necessary to achieve the best possible esthetic result. They also allow patients to make decisions on their treatment.

RIDGE AUGMENTATION

When ridge augmentation is needed, the ideal ridge form can be developed in wax on the diagnostic cast while a denture tooth is simultaneously adapted to the wax ridge. This process is continued until the desired crown form is established. A provisional removable partial denture can then be fabricated over the form of the ideal ridge developed in wax.

The provisional prosthesis validates the desired esthetic crown form and also can be used as a template during the ridge augmentation procedure. The flap is reflected; bone graft material is packed against the ridge; the provisional prosthesis is placed in the mouth to evaluate whether the ridge has been sufficiently enhanced in size; and a barrier membrane is placed over the graft material. The flap is then closed and sutured. After healing, the practitioner can assess whether the desired ridge form has been achieved.

SINGLE CROWN PROSTHODONTIC PROTOCOL FOR IMMMEDIATE PROVISIONALIZATION

In esthetic zones, placement of a provisional crown at the time of implant placement allows soft tissue healing to occur around the shape of the provisional crown; this can produce more esthetic soft tissue contours than does tissue healing in contact with a circular healing abutment (Figure 9-13).

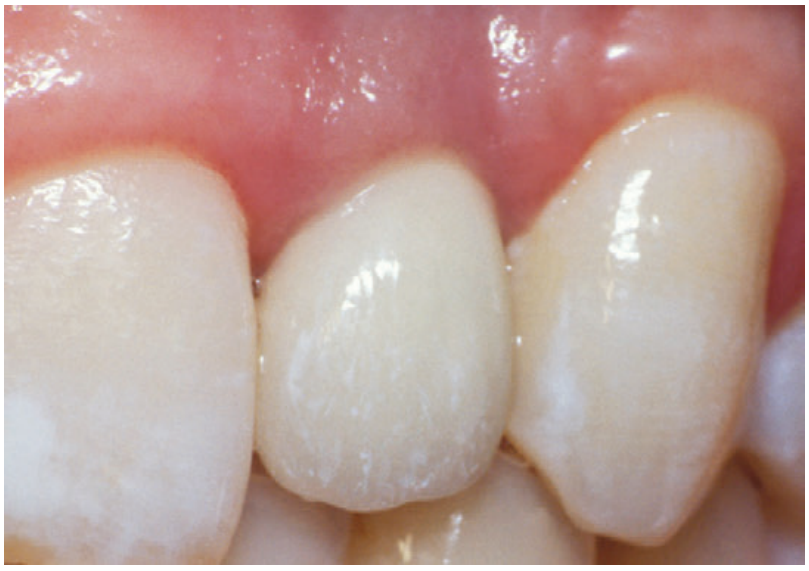

Figure 9-13 Placement of a provisional crown as shown on the maxillary lateral incisor implant at the time of implant placement creates more esthetic soft tissue contours.

After implant placement, a provisional abutment is selected and resin is applied to the cervical aspect of the abutment. The resin is contoured so that it has the proper emergence profile for that tooth.

The abutment is then prepared (out of the mouth) so that it has the correct angulation, and a finish line is established on the cervical resin. After the resin is polished, the provisional abutment is attached to the implant and a resin provisional crown is fabricated and cemented over the abutment.

An advantageous procedure is to prepare a provisional abutment in advance with the desired height and faciolingual inclination; these factors can be determined using a diagnostic cast. A thin resin coping can then be fabricated that fits over the prepared abutment and has excellent marginal adaptation. Additionally, the outer form of the provisional crown can be established by fabricating a shell before surgery, along with an incisal/occlusal index that orients the provisional shell to adjacent teeth. After implant placement and attachment of the provisional abutment, the coping can be seated and resin can be placed inside the shell and over the incisal aspect of the coping. The shell is then seated over the coping, and the incisal index is used to align the provisional shell properly. Excess cervical resin is removed before polymerization of the resin. The provisional crown can then be removed and the transitional contour finalized between the outer shell and the inner coping.

If a tooth that was restored with an all-ceramic or metal-ceramic crown requires extraction, in some cases the crown can be removed from the extracted tooth, thoroughly cleaned and disinfected, and then relined over the provisional abutment.

If a natural tooth requires extraction and the crown is intact, the natural tooth crown can be used as the outer form of the provisional restoration for a single implant.

After implant placement and provisionalization, the patient is given dietary guidelines. The patient must follow a liquid diet for 2 weeks and thereafter a soft diet for 2 months. This allows sufficient time (about 2 months) for the lower density woven bone that forms around the implant shortly after implant placement to be replaced with some stronger lamellar bone.

After an appropriate implant healing period (3 to 6 months, depending on the bone density and implant stability), the provisional crown and abutment are removed and an implant-level impression is made for fabrication of a definitive custom abutment and crown (Figure 9-14, 9-15).

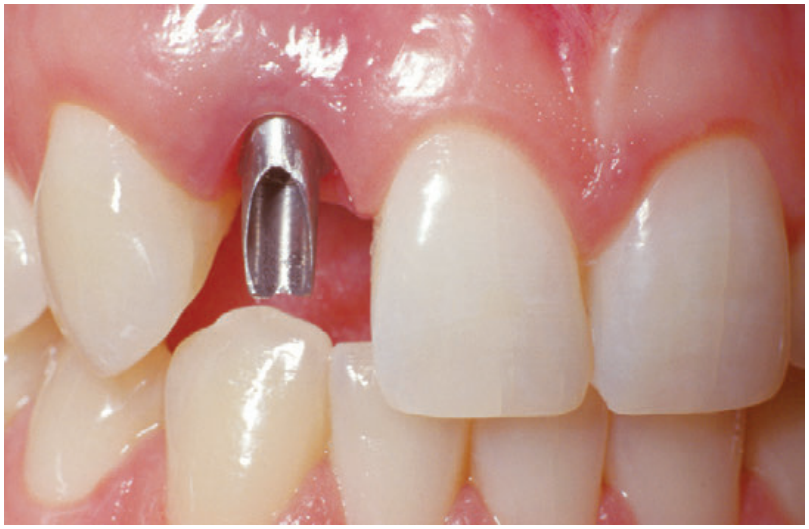

Figure 9-14 Custom abutment in place.

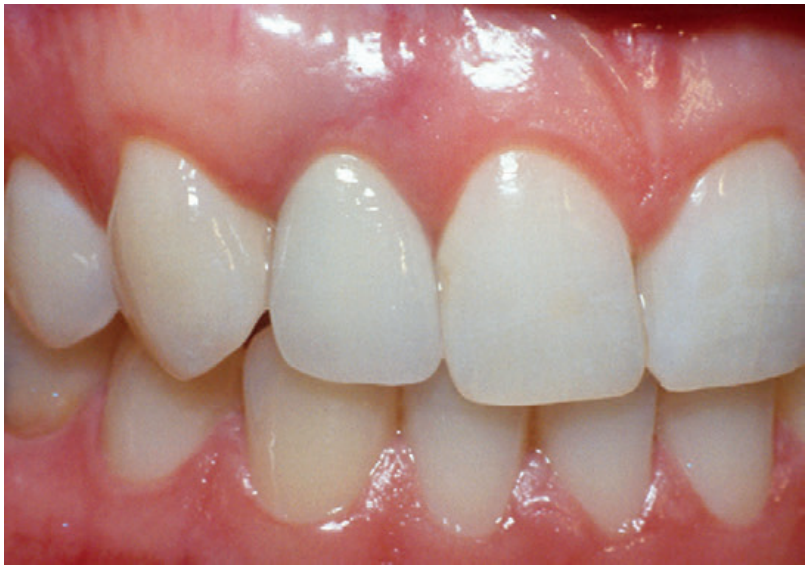

Figure 9-15 Implant crown placed over the custom abutment restoring tooth #7.

DEFINITIVE IMPRESSION FOR CROWN, CAST, AND CROWN FABRICATION

Two methods are used to attach a definitive single crown to an implant: (1) the crown is attached directly to the implant with a screw; or (2) an intermediate abutment is attached to the implant with a screw, and the crown is cemented over the abutment or attached to it with a screw.

A crown can be attached directly to an implant if the long axes of the implant and the crown closely approximate each other; this allows the screw access hole (the hole in the crown that provides access for screw tightening) to pass through nonvisible lingual areas of anterior crowns or occlusal surfaces of posterior crowns. If the long axes of the implant and the crown are not aligned with each other, an intermediary abutment is required to create a transition between the angulation of the implant and the angulation of the crown.

Abutments can be prefabricated (supplied by a manufacturer) or custom made by CAD/CAM milling of zirconia (Figure 9-16) or by casting metal (Figure 9-17). Impressions for prefabricated abutments record the form and position of the abutment after it is attached to the implant,

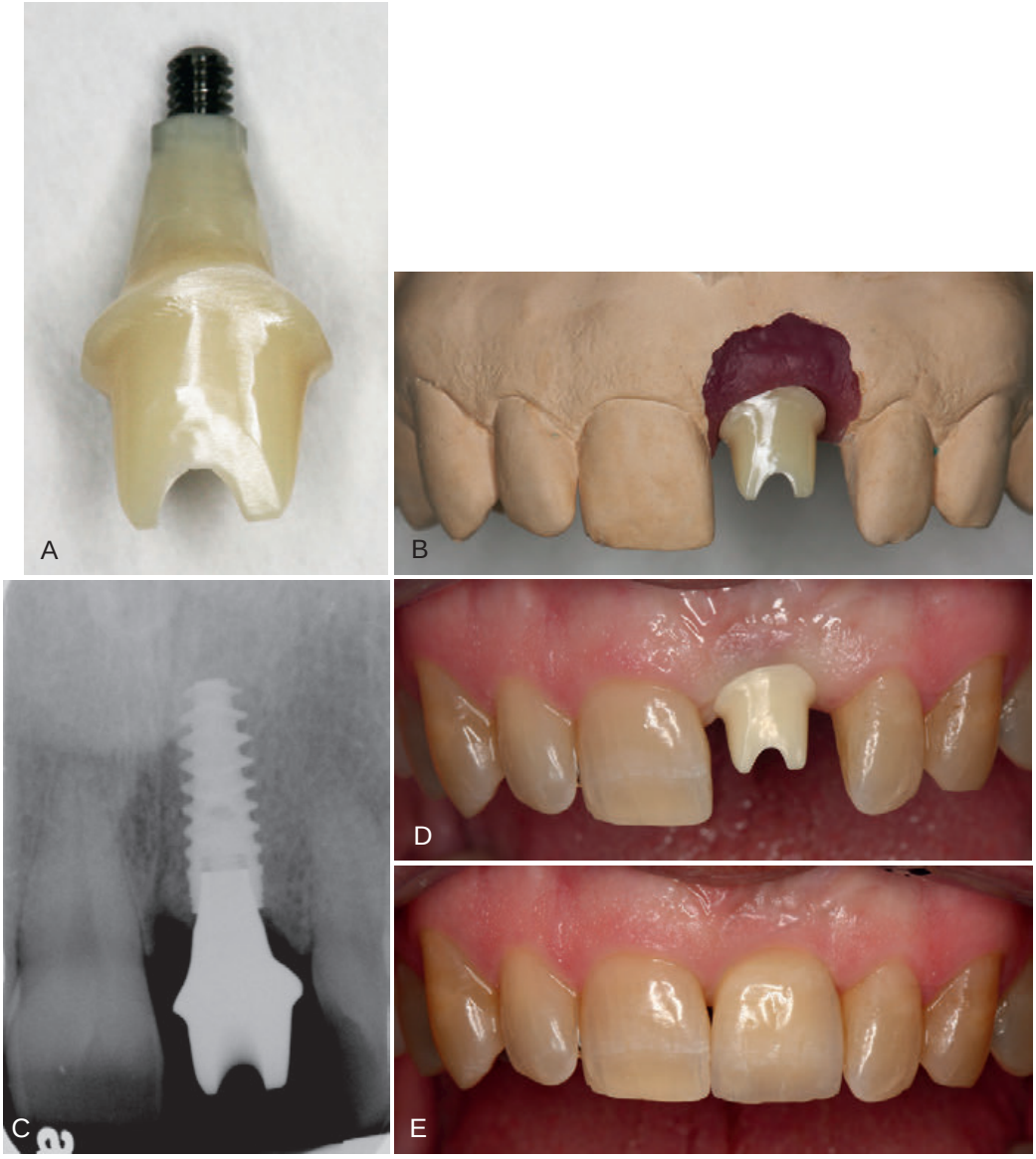

Figure 9-16 **A,** Custom CAD/CAM zirconia abutment. **B,** Zirconia abutment seen on definitive cast. **C,** Radiographic image of zirconia abutment torqued to the implant. **D,** Frontal view of zirconia abutment. **E,** Photograph showing all-ceramic crown after cementation to the zirconia abutment .

whereas impressions for custom abutments record the position of the implant.

With prefabricated abutment impressions, a metal replica of the abutment is placed in the impression and a cast is poured for laboratory fabrication of the definitive crown. As an alternative, the practitioner can place a prefabricated abutment, prepare the abutment in the same manner that a tooth would be prepared, place gingival retraction cord, make a conventional impression that records the finish line and shape of the prepared abutment, and then pour a gypsum die and cast (Figures 9-18 and 9-19).

When a custom abutment is used, an implant-level impression is made using an impression coping that attaches to the implant. Two types of impression copings can be attached to the implant and record its position: a tapered coping (Figure 9-20, *A*), which allows the impression to be removed from the mouth while the impression coping remains attached to the implant, and a geometrically shaped coping

Figure 9-17 **A,** Tooth #9 has been prepared for a collarless metal ceramic crown on the labial margin for optimum esthetic result. Tooth #10 area shows the edentulous site after implant placement. The soft tissue has been nicely conformed with a provisional restoration. **B,** Facial view of metal ceramic crowns. **C,** Photograph showing the intaglio surfaces of the metal ceramic crowns. Note the labial collarless ceramic margin on the crown for tooth #9. **D,** Occlusal view showing the implant and the surrounding healthy soft tissue. **E,** Photograph of custom abutment for #10 implant, cast with high noble metal alloy. **F,** Photograph showing metal ceramic crown on tooth #9 and implant-supported cemented crown on #10 area.

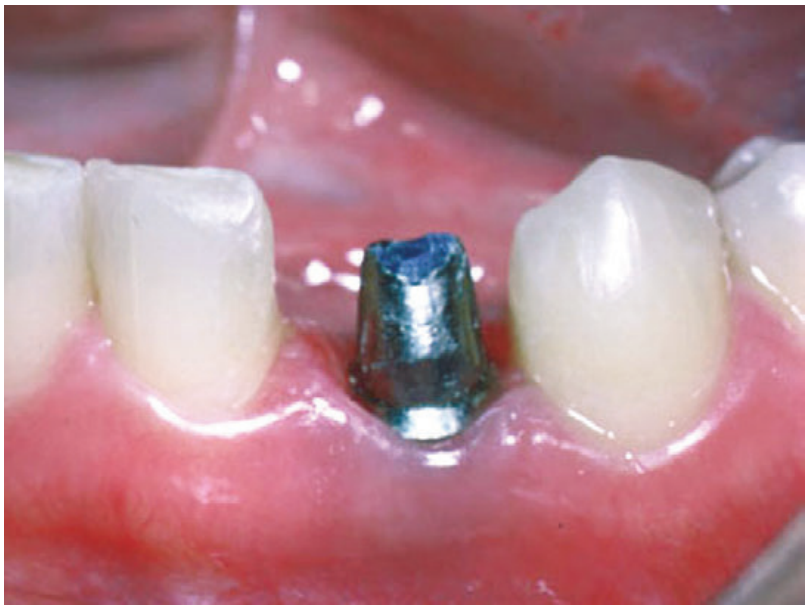

Figure 9-18 Prepared abutment ready for impression.

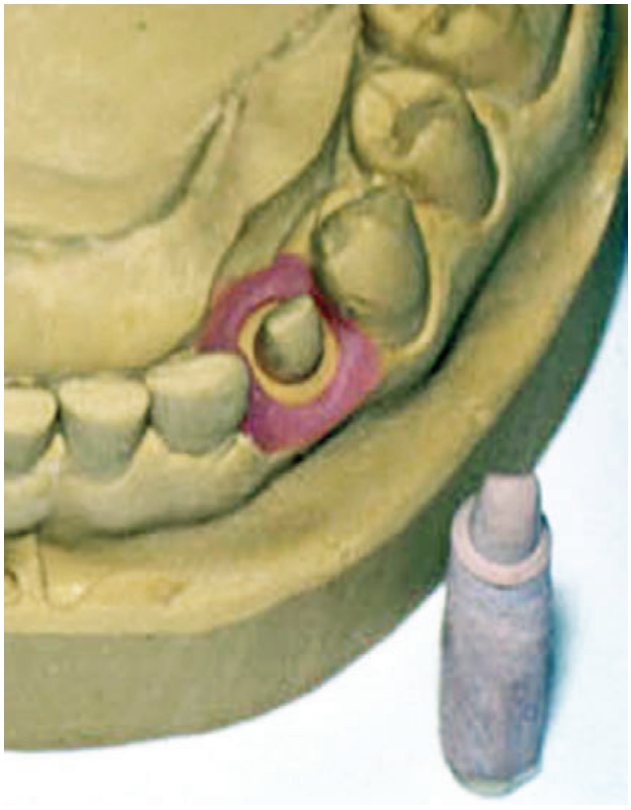

Figure 9-19 Gypsum die of the abutment and cast poured from the impression on which the crown will be fabricated.

with undercuts (Figure 9-20, *B*), with which the impression cannot be removed from the mouth until the coping is unscrewed from the implant.

Tapered impression copings are used when the long axis of the implant (and therefore the long axis of the coping) is sufficiently parallel to the remaining natural teeth that the impression can be removed from the mouth after the impression material polymerizes. This type of impression has been called a "closed-tray" impression, because a conventional impression tray can be used (the impression tray does not require a hole in its surface to provide access to the impression coping after the impression material polymerizes).

When the long axis of the implant is different from those of the remaining teeth (Figure 9-21, *A*, *B*), impression material locks around a tapered impression coping (because its angulation is different from the teeth) and prevents removal of the polymerized impression from the patient's mouth. Under these circumstances, a geometrically shaped coping is used. The geometric form, which has undercuts, allows the coping to be grasped by the impression material and therefore is retained in the impression material. A screw, in the form of a metal rod, is used to attach this form of coping to the implant. The metal rod (screw) is long enough to pass through the impression tray (Figure 9-21, *C*). The screw can be loosened after the impression

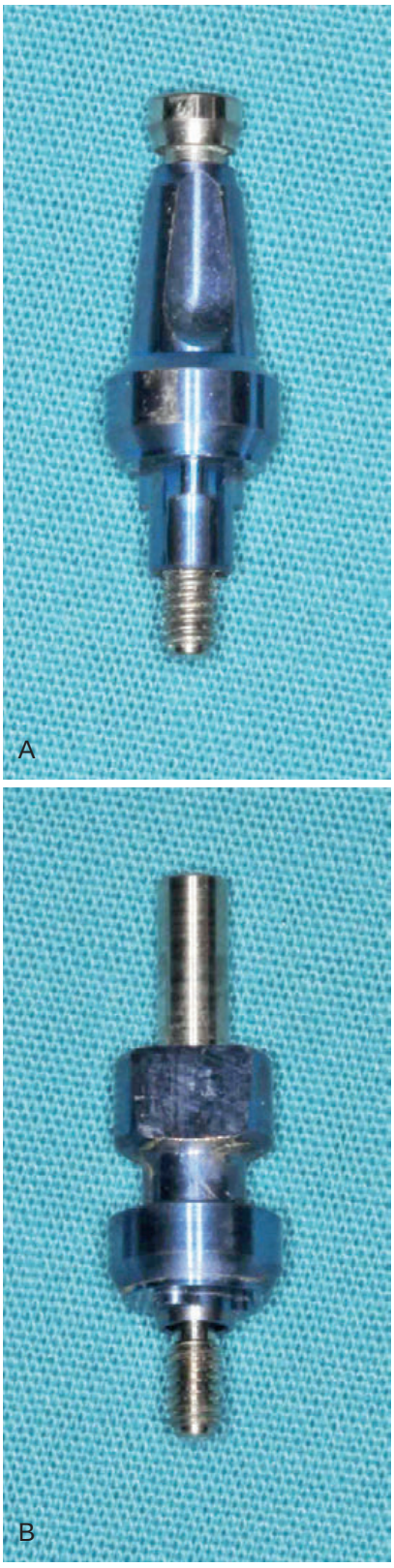

Figure 9-20 **A,** Tapered impression coping used for closed-tray impressions. **B,** Geometrically shaped impression coping used for open-tray impressions.

material polymerizes, allowing the impression to be removed while the coping is retained in the impression material (Figure 9-21, *D*). This type of impression has been called an "open-tray" impression, because the impression tray must have a hole through which the screw can project, allowing it to be loosened after the impression material hardens.

An implant analog (machined replica of the implant) is attached to the coping using the same screw that attached the coping to the implant (Figure 9-21, *E*), and a cast is poured (Figure 9-21, *F, G*). The resulting cast can be used to fabricate a custom abutment using routine casting techniques or computer-assisted design methods. When the implant is aligned with the long axis of the overlying crown, the crown can be fabricated so that it is attached directly to the implant with an abutment screw without an intervening abutment. This process reduces the complexity of the treatment and eliminates the cost of a custom abutment.

The definitive crown is fabricated on the working cast such that it can be cemented over a prefabricated or custom abutment that is retained by a screw into a prefabricated abutment, retained by a screw that attaches the crown directly to the implant without an intervening abutment, or retained by a lingual screw that attaches the crown to a custom abutment.

CROWN CEMENTATION

When crowns are cemented to abutments, removing all cement expressed from beneath the crown is very important. A patient treatment report in 1999 highlighted the problems associated with excess cement[69]; these included bleeding, soreness, acute swelling, purulent exudates from the peri-implant tissue, and radiographic evidence of bone loss. A study by Agar et al.[70] demonstrated the difficulty of removing glass ionomer and resin cements and showed that zinc phosphate cement was the easiest definitive cement to remove. The authors noted that deep subgingival margins make removing excess cement difficult. They also emphasized the importance of postplacement appointments after cementation and suggested that patients should be scheduled no later than 1 week after cementation and regularly after that (1 month, 3 months, and 6 months).

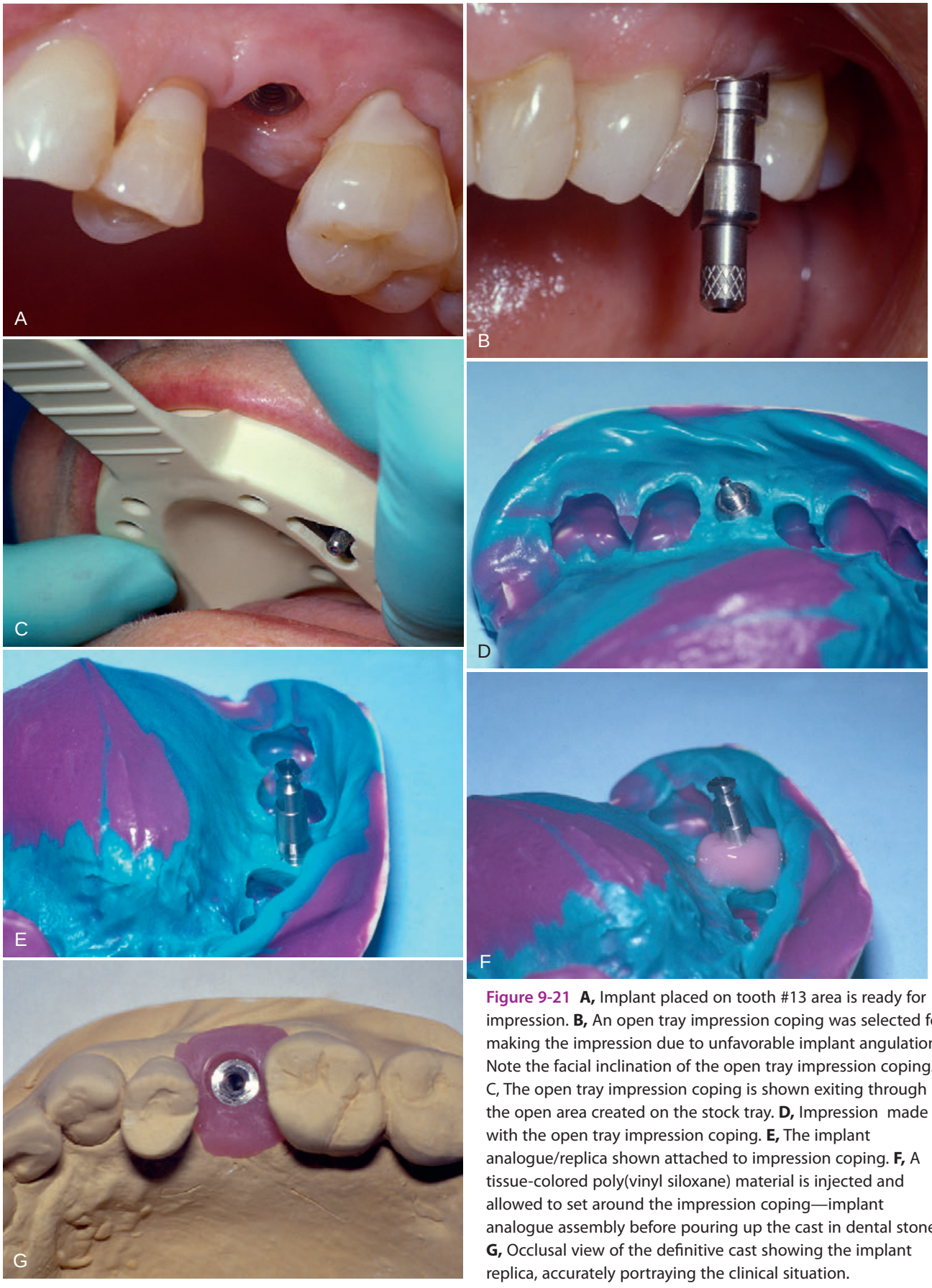

Figure 9-21 **A,** Implant placed on tooth #13 area is ready for impression. **B,** An open tray impression coping was selected for making the impression due to unfavorable implant angulation. Note the facial inclination of the open tray impression coping. C, The open tray impression coping is shown exiting through the open area created on the stock tray. **D,** Impression made with the open tray impression coping. **E,** The implant analogue/replica shown attached to impression coping. **F,** A tissue-colored poly(vinyl siloxane) material is injected and allowed to set around the impression coping—implant analogue assembly before pouring up the cast in dental stone. **G,** Occlusal view of the definitive cast showing the implant replica, accurately portraying the clinical situation.

A study by Wadhwani and Pineyro[71] evaluated the radiopacity of eight cements to determine how easily excess amounts around dental implants could be detected. Cements containing zinc (zinc oxide, zinc phosphate) were detectable at a thickness of 1 mm, whereas other cements (glass ionomer, resin, and implant-specific cements, such as Improv and Premier Implant Cement) were not detected even at this significant thickness. The authors concluded that some types of cement commonly used for implant-supported crowns have poor radiodensity and may not be detectable during a radiographic examination. In light of these data, every effort should be made to minimize cement extrusion into the peri-implant mucosa, and only zinc-containing cements should be used.

Zinc oxide eugenol cement should be used when the form and height of the abutment afford good retention. When the abutment has a limited occlusocervical dimension or a large total occlusal convergence (greater than 20 degrees) or when retention is compromised by the location and size of the abutment screw access channel, zinc phosphate cement should be used.

Zinc phosphate is the preferred definitive type of cement, because it has the least tendency to adhere to textured metal surfaces; it is brittle, and hardened excess is easier to remove; and it has a higher intraoral solubility, which is important if very small amounts are not removed. Resin, resin-modified glass ionomer, and glass ionomer cements are not recommended.

Techniques have been proposed to prevent the extrusion of cement into the soft tissues around an implant. In one technique, a strip of Teflon tape (also known as plumber's tape) is placed inside the crown, and the crown and tape are seated clinically over the abutment.[72] The practitioner then removes the crown from the mouth and uses a syringe to apply polyvinyl siloxane impression material inside the crown; the material also is built up to form a handle. After the material polymerizes, it is removed from the crown, producing a polyvinyl siloxane die. The cement is mixed and placed inside the crown, and the crown is seated on the rubber die to express excess cement, which is cleaned away from the margins. The crown is removed from the polyvinyl siloxane die and seated on the abutment in the mouth. Because the excess cement was expressed by seating the crown on the rubber die, little, if any, marginal cement is expressed clinically.

In another technique, the laboratory makes a polyvinyl siloxane putty abutment that duplicates the shape of the definitive abutment.[73] The process of applying cement inside the crown, seating the crown on the putty abutment, removing the excess cement, and cementing the crown clinically is the same as described previously.

SUMMARY

This chapter presented clinical data, design principles, soft tissue considerations, immediate loading guidelines, and clinical and laboratory procedures associated with the restoration of a single implant. Sound diagnosis and treatment planning, along with knowledge of potential complications, helps the dental practitioner achieve a successful outcome for this treatment modality.

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CHAPTER 10

Dental Implant Maintenance

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Chapter Outline

Periodontitis Versus Peri-implantitis
Characteristics of Healthy, Stable Dental Implants
Dental Implant Maintenance Program
Frequency of Maintenance Appointments
Indications for Surgical Intervention
Patient Implant Hygiene Procedures

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Describe the peri-implant attachment apparatus and compare it with the periodontium of natural teeth.
- Describe the clinical and radiographic characteristics of healthy dental implants.
- List procedures commonly performed at dental implant recall appointments.
- Describe the instrumentation used for dental implant débridement.
- Discuss the use of adjunctive antimicrobial therapy in implant maintenance.
- List indications for surgical treatment of peri-implantitis.
- Determine the appropriate recall interval for dental implant patients.

During the past three decades, replacement of missing teeth with implant-supported restorations has become increasingly common. Dental implant placement is a viable option for both complete and partially edentulous cases and is often the treatment of choice. Although implant-supported restorations are not subject to the risk of dental caries, as are natural teeth, they are susceptible to peri-implant mucositis and peri-implantitis, just as the natural dentition is subject to gingivitis and periodontitis. It has been well established that periodic periodontal maintenance can optimize the long-term prognosis of the natural dentition. Likewise, successful dental implant therapy must include an appropriate recall program.

This chapter reviews the similarities of and differences between the hard and soft supporting tissues of natural teeth and dental implants, discusses the etiology and pathogenesis of peri-implant mucositis and peri-implantitis, and presents a protocol for a comprehensive implant maintenance program.

PERIODONTITIS VERSUS PERI-IMPLANTITIS

The dentogingival complex associated with natural teeth consists of the gingival sulcus, the junctional epithelium, and the connective tissue attachment. The connective tissue fibers are oriented perpendicular to the long axis of the tooth and insert into the root surface cementum.[1-3] Although a sulcus and a junctional epithelium are associated with dental implants, the connective tissue fibers are oriented parallel to the long axis of the implant and the attachment is an adhesion.[4,5] Whether the difference in the nature of connective tissue attachment results in greater risk of attachment loss for implants is not known. For natural teeth, animal studies have shown no difference in the risk of breakdown between connective tissue and junctional epithelial attachments.[6]

The composition of the associated microbial flora is similar for natural teeth and implants.[7,8] Periodontal pathogens are reduced but not eliminated in completely edentulous patients, leaving these patients at some risk for colonization of implant surfaces.[9,10] A major etiologic factor in periodontitis is the formation of a biofilm harboring pathogenic bacteria, and this is also true for peri-implantitis. Bacterial colonization of implant abutments is similar for zirconia and titanium abutments.[11]

Peri-implantitis is an inflammatory process that affects the tissues around an osseointegrated implant in function, resulting in loss of supporting bone. Peri-implant mucositis is a condition of reversible inflammatory changes of the peri-implant soft tissues in the absence of bone loss.[12,13] The prevalence of peri-implantitis has been reported to be as low as approximately 10% to as high as 47%; the prevalence of peri-implant mucositis is generally greater, ranging from 32% to 80%.[14-17]

Periodontal and peri-implant bone turnover is a balanced dynamic process that involves resorption and formation, controlled and influenced by the local production of cytokines, with a wide range of inflammatory, hemopoietic, metabolic, and immunomodulatory properties.[18,19] Peri-implant microbial contamination or infection (bacteria and viruses) elicits an immune response regulated by key cytokines (i.e., tumor necrosis factor alpha [TNF-alpha], interleukin 1 beta [IL-1 beta], transforming growth factor [TGF-beta], IL-10) that control the progression or suppression (or both) of the inflammatory response. Overproduction of proinflammatory cytokines, released by monocytes/macrophages and T cells in response to a microbial challenge, can lead to the breakdown of the periodontal or peri-implant tissues.[20] Studies have shown that the subgingival microbiota around implants affected by pocketing and bone loss had high levels of periodontal pathogens, and periodontally involved teeth in partially edentulous patients may serve as microbial reservoirs.[21,22] In addition, surgical trauma is partly responsible for an early hyperinflammatory response, which is characterized by the release of both TNF-alpha and IL-1 beta.[23] On the other hand, ions released from dental implants can stimulate peripheral blood mononuclear cells (PBMCs) to produce IL-1 beta and TNF-alpha in vitro.[24] Commercially pure titanium and titanium alloys have been associated with the production of other cytokines such as IL-6 and IL-18.[25]

IL-1 beta and TNF-alpha appear to play major roles in mediating the inflammatory response in the pathogenesis of many chronic inflammatory diseases, such as rheumatoid arthritis.[26,27] Elevated

levels of IL-1 beta are present in the gingival crevicular fluid (GCF) in the course of periodontitis and peri-implant inflammation.[28,29] IL-1 beta is produced primarily by monocytes but may be produced by other nucleated cells in response to injury.[24] TNF-alpha, a cytokine with some functions similar to those of IL-1 beta, has been detected in sites affected by periodontitis.[30] Moreover, TNF-alpha and IL-1 beta act synergistically to initiate the cascade of inflammatory mediators.[31] IL-6 has proinflammatory effects and is responsible for collagen resorption of gingival tissues,[32] whereas IL-10 is an inhibitor of inflammation.[33] Other cytokines, such as IL-12, appear to induce the secretion of interferon gamma [IFN-gamma] from activated T cells and natural killer (NK) cells,[34] and IL-8 acts as a potent chemoattractant for neutrophils in gingival tissues.[35]

The continuous balance that exists between the host immune response and potential subgingival pathogens (bacteria and viruses) determines the clinical condition, not only around teeth, but also around osseointegrated dental implants. Nowzari et al.[36] analyzed the production of cytokines around clinically healthy teeth and dental implants and examined their relationship to putative periodontal pathogens. Although no specific microbiologic profile was observed, teeth allowed for more colonization by *Porphyromonas gingivalis, Tannerella forsythia,* and *Fusobacterium* spp. Microscopic structural differences between dental and implant surfaces could account for this finding.

No information is available on the detection of human cytomegalovirus (HCMV) around healthy dental implants. In contrast to implants, HCMV is less often detected around periodontally healthy teeth. Nowzari et al.[36] did not detect HCMV around healthy dental implants using nested polymerase chain reaction (PCR). The absence of prominent inflammation could help explain this result. Studies addressing a potential pathologic role of HCMV around implants are needed.

A tendency toward more cytokine production was observed around implants in contrast to teeth, but a specific explanation for this finding is not available.[37] An implant may act as a foreign object and result in cytokine secretion. This raises the issue of an immune response against the chemical components of the implant. Perala et al.[38] indicated that dental implant surfaces may lead to an activation of human peripheral blood mononuclear cells for the secretion of IL-1 beta and TNF-alpha.

Titanium particles in vitro have been shown to influence the release of IL-2, TNF-alpha, and IL-6.[39] In an in vitro controlled experiment, Sedarat et al.[40] exposed titanium implants to an environment similar to in vivo conditions and measured 16 (± 5) ng/cm^2/day dissolution of titanium and titanium alloy over 96 days. The dissolution of titanium and titanium alloy and the ions released by the atomic process of biodegradation can explain, at least in part, the presence of cytokines where no microbial pathogens could be detected. The other contents of commercially pure titanium implants (e.g., carbon, iron, nitrogen, oxygen, and hydrogen) require further evaluations.

Patients who had positive results for at least one of the 11 microorganisms tested by culture had higher levels of IL-1 beta, TNF-alpha, IL-10, and IL-8 at teeth and implant sites. Virulence factors from periodontopathic bacteria (e.g., *P. gingivalis*) are potent stimulants for the secretion of proinflammatory cytokines (IL-1 beta, TNF-alpha) and the subsequent activation of matrix metalloproteinases (e.g., MMP-2) and other collagenases from gingival fibroblasts.[41] Because active IL-1 beta and TNF-alpha mediate a variety of biologic functions, including osteoclast activation,[42] leukocyte recruitment, and excessive production of MMPs,[43] the overproduction of these cytokines at some point could lead to bone resorption and collagen degradation. In addition, the production of IL-8 in gingival tissues is an important recruitment mechanism for polymorphonuclear neutrophils (PMNs) and constitutes a first line of immune defense. PMNs produce IL-1 beta in response to bacterial challenge and act in a paracrine function, preventing apoptosis and increasing the phagocytic activity of other PMNs.[44] Low PMN counts in clinically healthy gingival tissues are a common finding in histological analysis of teeth and implant sites.[45] The balance between this innate response and the bacterial challenge is partly responsible for maintaining the health of gingival tissues. Nevertheless, although previous studies have reported that cytokine activity seems to be relevant for alveolar bone resorption and destruction of collagen,[46,47] periodontal research to date has not yet established any particular cytokine profile that could help predict disease progression. Moreover, no known cytokine level threshold can differentiate between

a stable site and the initiation of a pathologic process in periodontal and peri-implant tissues.

CHARACTERISTICS OF HEALTHY, STABLE DENTAL IMPLANTS

Clinical findings for healthy dental implants include firm, pink peri-implant mucosa, shallow probing depths (3 mm or less); absence of bleeding on gentle probing, absence of purulence or suppuration, and lack of response to percussion.[48] Implant-supported restorations should provide comfortable function and appropriate esthetics. Radiographic bone levels are generally located at the first thread of the implant.[49] However, the practitioner must keep in mind that standard dental radiographs are two dimensional and do not generally provide information about buccal, lingual, or palatal bone levels. Buccal, lingual, and palatal attachment levels are assessed by gentle probing (Figures 10-1 to 10-5).

DENTAL IMPLANT MAINTENANCE PROGRAM

Many principles and features of maintenance therapy apply to both the natural dentition and to dental implants. In patients who are partially edentulous with implant-supported restorations, maintenance visits combine traditional periodontal maintenance for the remaining natural teeth and dental implant maintenance. In fully edentulous patients with implant-supported restorations, the focus is on prevention or treatment of peri-implant mucositis or peri-implantitis, because dental caries and endodontic pathologic conditions are not possible.

Data collection includes measurement of probing depths, bleeding upon probing, suppuration, recession, mobility, response to percussion, and clinical appearance of peri-implant mucosa. Probing should be done with very gentle force (not to exceed 0.15 N), because excessive force may disrupt the soft tissue attachment and has been shown to overestimate probing depths and the incidence of bleeding upon probing.[50,51] As with natural teeth, inflammation of peri-implant soft tissue results in greater apical penetration of the periodontal probe.[52] Hence, gentle probing has been shown to be an effective means to evaluate the stability of the peri-implant attachment and to detect peri-implantitis (Figure 10-6).

Follow-up periapical radiographs are generally taken 1 year after loading; thereafter the frequency of radiographic evaluation is determined by the clinical findings.[53] Care should be taken to orient the film or digital sensor parallel to the long axis of the implant; this can require special attention when an angled abutment has been used for the restoration. In general, any pain, edema, or

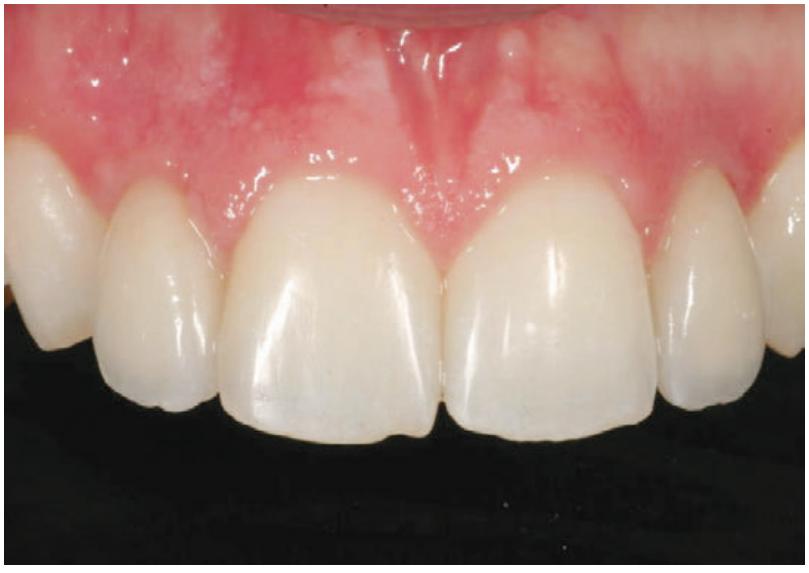

Figure 10-1 Healthy implants #7 and #10 after 6 years.

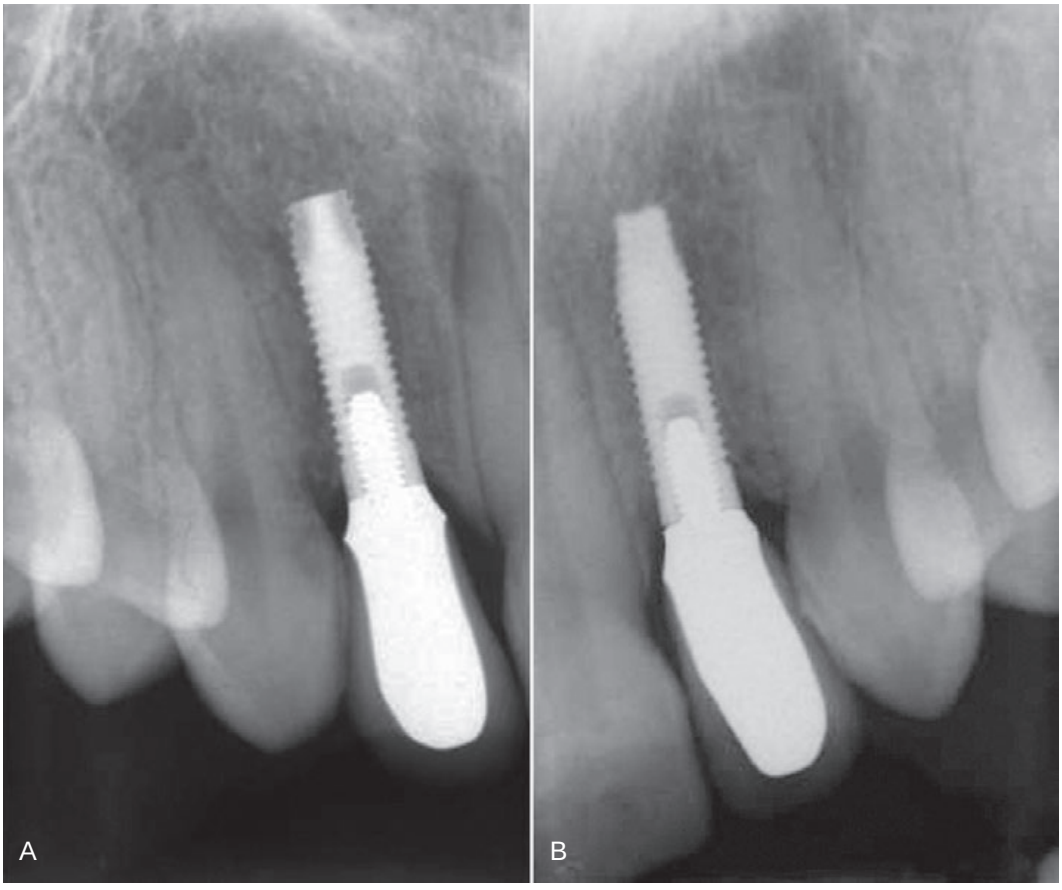

Figure 10-2 Healthy implants #7 and #10 after 6 years.

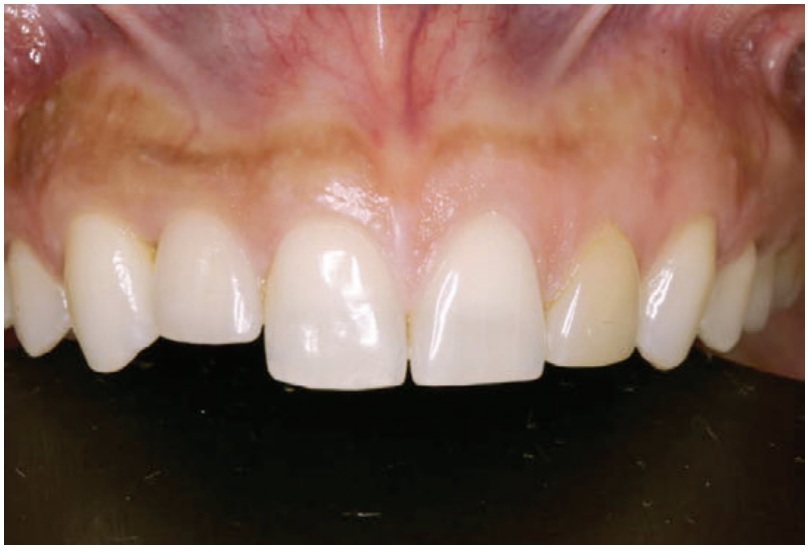

Figure 10-3 Healthy implant #7 after 10 years.

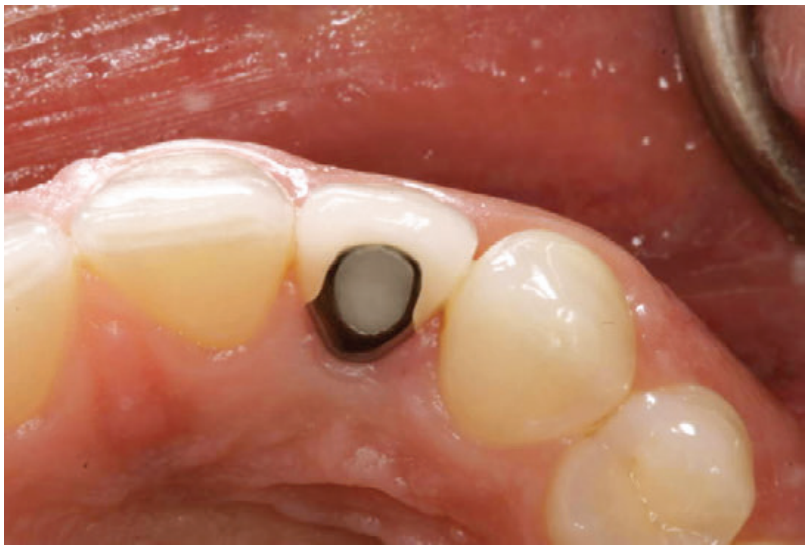

Figure 10-4 Healthy implant #7 after 10 years.

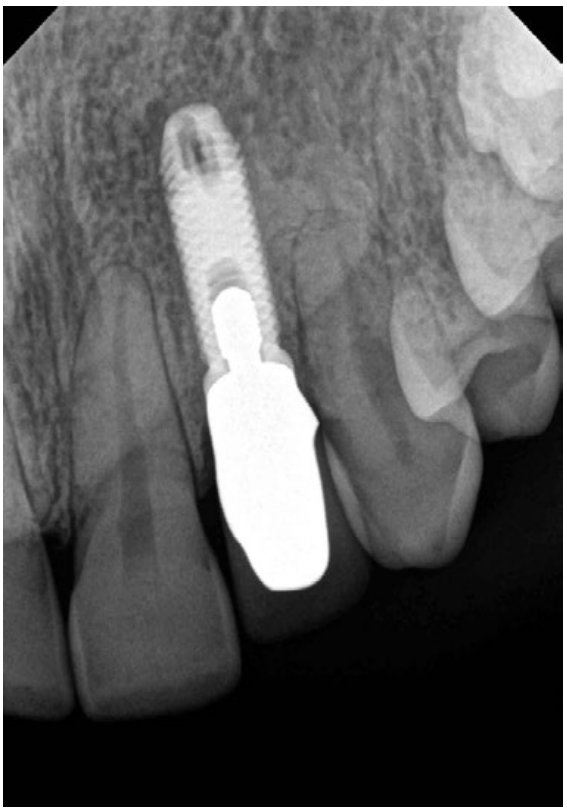

Figure 10-5 Healthy implant #7 after 10 years.

suppuration indicates the need for radiographic evaluation; otherwise, routine radiographs may be indicated only every few years.

After examination and data collection, peri-implant conditions are documented. Instrumentation then is performed to reduce or eliminate bacterial plaque and calcified deposits. Standard metal scalers and curettes are not recommended for implant débridement because of the risk of scratching the titanium surface. Although plastic scalers are available, their effectiveness in removing hard deposits is limited; gold, titanium, or vitreous carbon–tipped instruments are generally more effective. Ultrasonic and piezoelectric scalers with plastic or carbon tips have also proved effective and do not damage the implants' surfaces (Figure 10-7).[54-56]

Air polishing devices and rotary rubber cups can be used to remove plaque and smooth implant collars.[57] Biofilm disruption in the peri-implant sulcus can be accomplished with air polishing devices using either sodium bicarbonate or amino acid glycine salt powders.[58]

In addition to mechanical débridement with scalers and polishing devices, adjunctive local antimicrobial therapy can be administered, although limited and often equivocal evidence of enhanced clinical outcomes has been published.[59-64] The peri-implant sulcus can be irrigated with the antiseptic 10% povidone iodine (Figure 10-8).

FREQUENCY OF MAINTENANCE APPOINTMENTS

Periodic maintenance therapy is essential for long-term success of dental implants; however, the

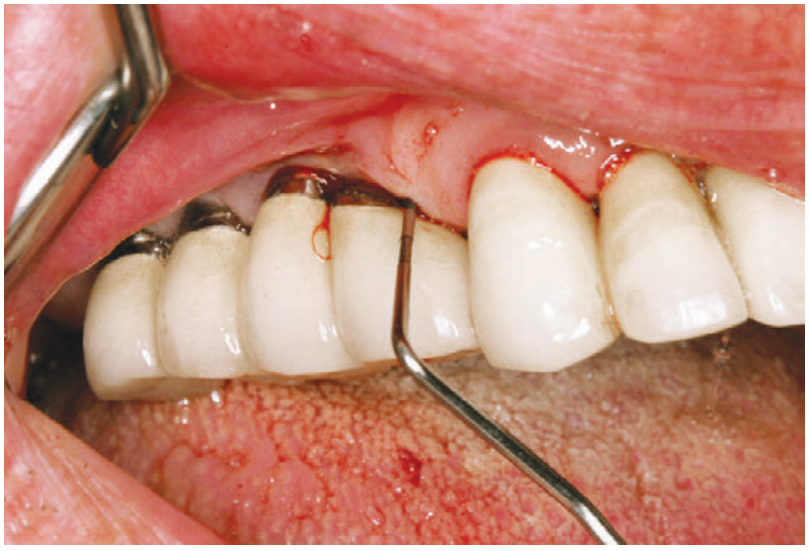

Figure 10-6 Gentle probing of the peri-implant sulcus.

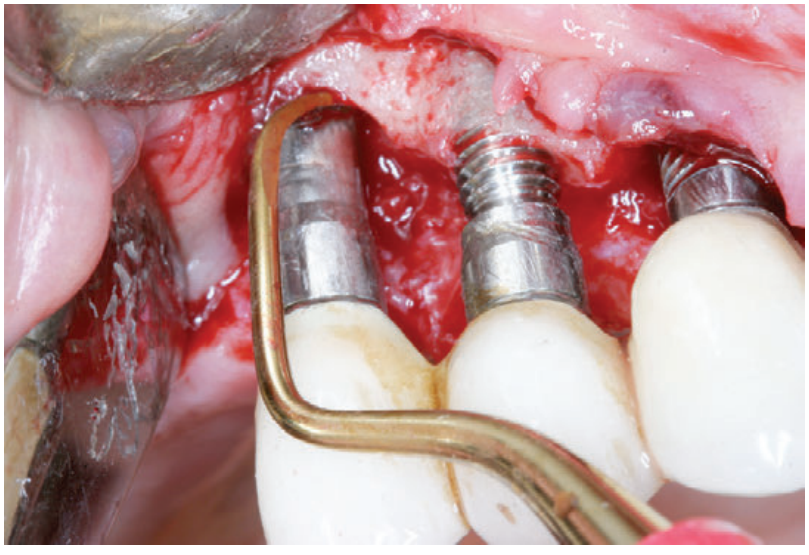

Figure 10-7 Gold-tipped curette for implant debridement.

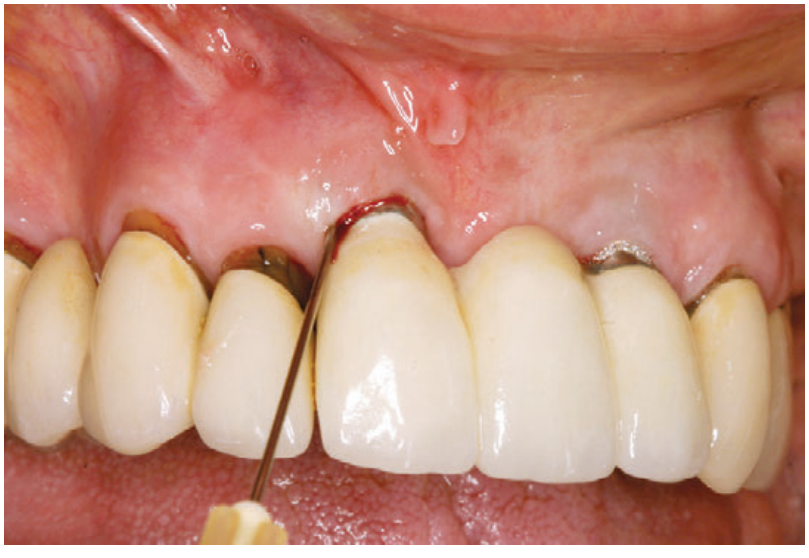

Figure 10-8 Irrigation of the peri-implant sulcus with 10% povidone iodine.

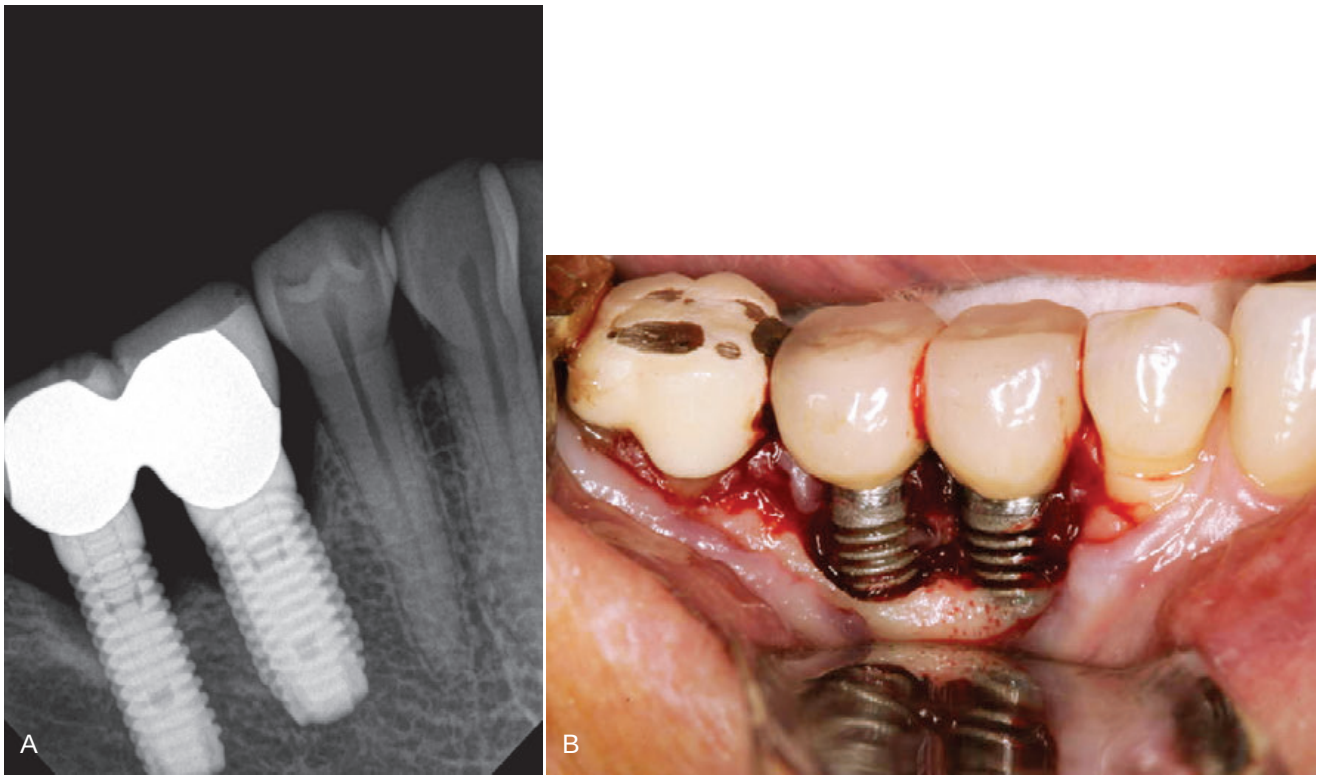

Figure 10-9 Flap reflection to facilitate débridement.

optimum frequency of recall visits is largely intuitive.[49,51] Recall intervals should be individually determined for each patient, generally every 3 to 6 months. Factors to be considered in determining the frequency of maintenance visits include a history of periodontitis or peri-implantitis, the effectiveness of daily plaque control, tobacco use, the rate of calculus formation, the peri-implant probing depths, peri-implant bleeding upon probing, and suppuration.[65-72]

INDICATIONS FOR SURGICAL INTERVENTION

Incipient peri-implantitis can often be managed successfully with nonsurgical débridement, but more advanced attachment loss with deeper probing depths may require surgical therapy. Indications for surgical intervention include suppuration or persistent bleeding upon probing after nonsurgical therapy, radiographic evidence of progressive bone loss, or persistent symptoms.[73,74] Flap reflection can facilitate granulation tissue removal and débridement of the implant surface. Plastic-, carbon-, gold-, and titanium-tipped curettes and erbium/yttrium aluminum garnet (Er:YAG) lasers all have been used successfully for mechanical débridement, and no one method has shown a clear superiority. Air polishing has also been advocated for débridement during peri-implant surgery, although the possibility of an air embolus should be considered. Regenerative therapy has been advocated to restore lost osseous support; however, predictable positive outcomes have not been well documented (Figure 10-9).[8-79]

PATIENT IMPLANT HYGIENE PROCEDURES

Bacterial plaque forms on implant-supported restorations and, depending on soft tissue recession and the depth of the peri-implant sulcus, may also accumulate on abutments and implant surfaces. Plaque formation tends to be greater on rougher surfaces and in patients who smoke, although smoking may not adversely affect the long-term

survival of dental implants.[69,80-83] Just as treatment of gingivitis reduces the risk of periodontitis, early intervention when peri-implant mucositis is detected reduces the risk of subsequent peri-implantitis.[84-86] Even though dental implants may accumulate less bacterial plaque than natural teeth, effective daily plaque control is essential to maintain the health and stability of both hard and soft implant-supporting tissues.[48,87]

Home care for dental implant–supported restorations is similar to traditional oral hygiene procedures, with some minor modifications. Plaque control for single implants can be accomplished with a toothbrush and dental floss; numerous studies have suggested that powered tooth brushes may be more effective than manual brushes.[88-90] For implant-supported fixed partial or complete dentures, floss threaders or interdental brushes are effective in controlling interproximal plaque accumulation.[91-93] Interdental brushes with a Teflon-coated wire are preferred to minimize the risk of scratching. As with natural teeth, brushing and flossing are effective in disrupting supragingival plaque but have limited benefit in subgingival areas. Oral irrigation devices, particularly those with tips designed to penetrate the sulcus, have been shown to reduce bacterial levels in periodontal pockets and have been advocated as part of patients' armamentarium for home care of dental implants. Irrigants such as plain water, saline, sea salt solution, chlorhexidine gluconate, and dilute (0.1%) sodium hypochlorite have been suggested by various authors. Based on the evidence from periodontitis reports, dilute sodium hypochlorite may be the most effective antimicrobial irrigant for home use, although some patients may object to the odor or taste.[94-97] For patients with remaining natural teeth, a dentifrice that contains fluoride is strongly recommended.

SUMMARY

As replacement of missing teeth with implant-supported restorations has become more common, increasing numbers of patients require dental implant maintenance as part of their preventive or periodontal maintenance care. Although dental implants are immune to dental caries, peri-implant mucositis and peri-implantitis can occur, just as gingivitis and periodontitis are seen with the natural dentition. Many similarities exist between natural teeth and implant-supported restorations with regard to disease etiology and pathogenesis, diagnosis, maintenance therapy, and the need for surgical intervention; however, some modifications in instrumentation and home care are required for patients with implant-supported restorations. When the option of dental implant treatment is first discussed with patients, it is important that they understand that although implants have many advantages, they do not absolve the patient of the responsibility of daily oral hygiene practices or regular recall appointments.

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CHAPTER 11

The Relevance of Scientific Evidence in the Decision-Making Process: Treatment Outcomes in Single Implant Therapy

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Chapter Outline

Clinical Outcomes
- Delayed Implant Placement
- Immediate Implant Placement

Complications
- Implant Loss
- Other Complications

Psychosocial Outcomes

Economic Outcomes

Esthetic Outcomes

Learning Objectives

At the conclusion of this chapter, the reader will be able to:

- Understand the clinical performance of single implant therapy based on current scientific evidence.
- Analyze and compare single implant restoration to other alternatives from both a patient perception and psychosocial point of view.
- Learn the incidence of the most prevalent complications associated with single implant therapy as they have been reported in scientific literature.
- To understand the expected esthetic outcomes of a single tooth replacement by means of a dental implant.

Over the past 30 years, the insertion of dental implants to restore function and esthetics in patients who are completely or partially edentulous has become a well-documented surgical and prosthetic procedure.[1-5] Single missing or failing teeth are commonly replaced with dental implants, both anteriorly and posteriorly, and the process has been studied extensively. Experimental studies and clinical trials have provided ample information on design, clinical procedures, survival and failure rates, and complications.

Because of the speed with which advances are made in implant dentistry, developing current evaluation criteria that practitioners can use is a difficult task. However, in the past decade, significant advances in the concepts of evidence-based care have provided tools for assessing most clinical therapeutic interventions.

The term *evidence based* means the deliberate use of current evidence as a guide in treatment, recognizing that no study is perfectly designed in every aspect or applicable to every patient.[6]

Implant therapy is not just the design and application of an implantable prosthetic device; more important, it also is a process of analyzing the patient's particular dental needs and providing customized care. This process begins with diagnostic assessment of the patient and determination of the prognosis of the remaining dentition, followed by an assessment of the cost/benefit ratio of maintaining the failing dentition or perhaps removing and replacing it with alternative treatments. This process can lead to the development of a patient-customized treatment plan that minimizes future complications and improves the patient's satisfaction, because the treatments provided are based on the common published experiences that have been studied and analyzed by experts in the field of implant dentistry.

The use of older studies, which may have involved techniques and materials that differ significantly from current practice, must be considered with great caution. Today's restorative dentist has a greater number of options for tooth preparation techniques[7,8] and a greater selection of restorative materials.[9-11] The field of implant therapy has evolved at least as quickly as that of restorative dentistry in general. A wider variety of implant diameters, lengths, and morphologies is available, and implant surface technology[12,14,15] and improvements in macrodesign[12-15] have dramatically altered many of the basic principles of dental implantology. The time necessary to obtain osseointegration has been significantly reduced,[12] and the initial osteointegrated interface has been strengthened.[12,14,15]

CLINICAL OUTCOMES

Based on the high success rates achieved with implants placed as described by Brånemark et al. for the restoration of edentulous and partially edentulous arches,[16] some thought that single tooth replacement by a dental implant could overcome the limitations observed in classic prosthodontic therapies.[17-19] Outcomes of this technique have been evaluated using various survival and success criteria,[20-24] but the criteria elaborated by Albrektsson et al.[20] are probably the most commonly used in dental implant literature. These researchers defined a successful implant as one that:

- Remains immobile when tested individually
- Does not demonstrate any evidence of peri-implant radiolucency under radiographic examination
- Shows a vertical bone loss of less than 0.2 mm annually after the implant's first year of service
- Does not have persistent or irreversible signs and symptoms (e.g., pain, infection, or neuropathies)
- In the context of the above, results in a success rate of 85% at the end of a 5-year observation period and 80% at the end of 10 years

The Albrektsson criteria were developed at a time when determining the biologic outcomes of titanium implants was important to prove their higher reliability over alternatives made of other materials. Initially, restorative and patient-based parameters received less attention. Mechanical and esthetic parameters were later evaluated,[25-27] as practitioners' demands for greater predictability and natural-looking restorations increased. However, criteria that analyze a wider number of parameters are far from being established as performance indicators in dental implant literature.

Two main approaches have been used for the replacement of a failing tooth, based on the timing of implant placement in relation to tooth extraction. In general, if the implant is placed during the same surgical procedure as the extraction, the approach is referred to as immediate implant placement. If the implant is placed during a separate surgical procedure after the extraction has been performed, the approach is referred to as delayed implant placement. Studies have evaluated the outcomes of both of these approaches.

DELAYED IMPLANT PLACEMENT

Traditionally dental implants were placed according to a two-stage protocol.[16] Implants were submerged beneath the soft tissues and allowed to heal undisturbed. Research findings indicated that primary implant stability and lack of micromovement were necessary to achieve predictable levels of osseointegration.[28,29]

Some thought that if movement occurred, the healing process would be altered and the implant would be encapsulated by soft tissues[30] instead of anchored in bone. With a two-stage approach, the risk of transmitting undesirable loads to the healing bone at the implant interface was reduced.

Subsequently a one-stage protocol was developed.[31] With this approach, flaps were repositioned and sutured around the supraosseous neck of the implant (single-stage implant) or around a healing abutment (two-stage implants placed in a one-stage protocol), which eliminated the need for a second surgical intervention to expose the implant connection. Success and/or survival rates for this modality ranged from 95.4% to 99.1%.[32-34]

In a recent report in the *Cochrane Database Systematic Review,* Esposito et al.[35] found no statistically significant differences between the two protocols. However, the data suggested that fewer implant failures occurred with the two-stage approach, especially in completely edentulous patients. These authors hypothesized that a one-stage approach might be preferable in partially edentulous patients, because it eliminates one surgical intervention and shortens the treatment time. A two-stage approach was proposed in certain specific situations, such as when (1) an implant has not obtained optimal primary stability; (2) barriers are used for guided tissue regeneration; and (3) removable provisional prostheses might transmit excessive forces to the exposed abutments, especially in fully edentulous patients.

A systematic review by Den Hartog et al.[36] in 2008 found an overall implant survival rate of 92.8% when data were pooled from 11 studies following 248 implants during an average follow-up period of 2.8 years. The review combined data from implants placed in one-stage and two-stage protocols.

IMMEDIATE IMPLANT PLACEMENT

Clinical studies report data on the number of implants placed and lost over a specified time. In the combined data extracted from several studies[37-45] with a minimum follow-up time of 2 years, published on single immediate implants up to 2009, 604 implants were placed and were observed for 2 to 10 years. Twenty-six implants were lost (mean implant loss rate of 4.3%). For illustrative purposes, the studies were categorized into three groups (Table 11-1). In the first group[37-41] (follow-up period of 2 to 4 years), an overall survival rate of 97.08% was observed. In the second group[42-44] (follow-up period of 4 to 6 years), a survival rate of 93.98% was observed. Surprisingly, in the third group[45] (minimum sample follow-up of 6 years), a slightly higher survival rate was observed; the survival rate was 100% after the study period.

The results of these studies indicate a high predictability of survival for implants placed in fresh extraction sockets.

COMPLICATIONS

The information on success, failure, and complications presented in the following sections was developed by combining the raw data from clinical studies that evaluated implant single crowns. A mean was calculated for each type of complication by combining the data from each study. The purpose of the information is to suggest clinical trends rather than provide statistically valid incidence data. Table 11-2 identifies the types of complications that have been encountered in the clinical studies and provides a mean based on the number of studies that provided raw data related to that complication.

Table 11-1 Implant Failure Studies Categorized by Average Follow-Up

AUTHORS	YEAR OF PUBLICATION	AVERAGE FOLLOW-UP (YEARS)	IMPLANTS PLACED/ IMPLANTS FAILED	SURVIVAL RATE
Becker et al.	2005	2-4	73/71	97.26%
Schropp et al.	2005	2-4	46/43	93.48%
Crespi et al.	2008	2-4	40/40	100%
Canullo et al.	2009	2-4	22/22	100%
Mijiritsky et al.	2009	2-4	24/23	95.83%
Ferrara et al.	2006	4-6	33/31	93.94%
Avvanzo et al.	2009	4-6	259/241	93.05%
Kahnberg et al.	2009	4-6	40/40	100%
Degidi et al.	2006	6+	67/67	100%

Table 11-2 Implant Single Crown Complications

COMPLICATION	NUMBER OF STUDIES PROVIDING DATA	TOTAL NUMBER OF PATIENTS OR COMPONENTS AFFECTED
Abutment screw loosening (1991-1996)	7	151 of 613 screws
Prosthesis screw loosening	3	43 of 214 screws
Fistula at implant-abutment level	6	38 of 451 implants
Abutment screw loosening (1998-2000)	6	42 of 623 screws
Esthetic problems	6	34 of 483 crowns
Implant dehiscence before stage two	4	11 of 270 implants
Neurosensory disturbance (after surgery)	2	5 of 141 patients
Implant loss	29	54 of 1,979 implants
Abutment screw fractures	3	7 of 274 screws

IMPLANT LOSS

In the combined data from single implant studies,[46-66] 1,979 implants were placed and were observed for 1 to 10 years; 54 implants were l ost (mean implant loss rate of 3%). This failure rate, shared with implants that support mandibular fixed complete dentures, is the lowest failure rate encountered in implant prosthodontics. Three studies[60,70,72] provided data that permit a comparison of maxillary and mandibular implant loss. Six studies* provided data on the time when the implants were lost; 47% of the implants were lost preprosthetically, and 53% were lost postprosthetically.

*References 46, 51, 53, 54, 60, and 72.

OTHER COMPLICATIONS

Other single implant complications identified in the studies included abutment screw loosening with early screw designs reported from 1991 to 1996 (25%)†; prosthesis screw loosening (20%)[56,65,74]; fistulas at the implant abutment level (8%)‡; abutment screw loosening with newer screw designs reported from 1998 to 2000 (7%)[61,62,66,67-69]; esthetic problems (7%)§; implant dehiscence before stage two (4%)[46,53,58,59]; neurosensory disturbances after surgery (4%)[46,58]; and abutment screw fracture (2%).[58,66]

†References 46, 49, 51, 52, 54, 55, and 57.
‡References 46, 49, 51, 53, 54, and 58.
§References 46, 51, 55, 61, 66, and 75.

PSYCHOSOCIAL OUTCOMES

The psychosocial effects of single implant treatment have been described in scientific studies. Patient satisfaction and pain perception have been studied in the dental implant literature. However, studies focusing on those two parameters in relation to single implant replacement therapies are scarce. Interestingly, fewer than 2% of publications on dental implants deal with patient-centered issues.[76]

Patient satisfaction is one of the most important goals in oral rehabilitation with dental implants and could be used as a success evaluator for such therapies.

Few studies have evaluated patient satisfaction in single implant restorations. In a recent study by Vermylen et al.,[77] a sample of 48 patients (52 implants) was studied after treatment with single implant restoration. The patients in this study were mailed a post-treatment questionnaire requesting information on their satisfaction with the treatment provided. The study observed that the patient opinion on the treatment was positive. Although all the patients were positive in recommending the treatment to others, almost a quarter of them responded negatively when asked whether they would be willing to undergo a similar treatment again. The authors of this study hypothesized that this result was probably related to the time elapsed between implant placement and cementing of the restoration, describing this issue as the major disadvantage perceived by patients. Other studies have shown that a one-stage surgical procedure may reduce healing time and enhance patient acceptance.[78]

Similar results were observed in a later study by Bacarat et al.[79] In this study, patient expectations before treatment and satisfaction after treatment were rated on a visual analog scale and correlated; the satisfaction value was about 40% higher than the expectations value. The results of this study confirm that single tooth replacement is a very satisfactory procedure that may surpass patients' expectations.

Pain may be defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage.[80] Given the surgical nature of the dental implant procedure, different degrees of pain in relation to the extent of the procedure can be expected. Limited published data are available on the pain associated with the surgical placement of dental implants[80,81] or on factors associated with such pain.[82] These authors know of no study that has evaluated pain perception in single implant therapy. However, some studies have reported a significant association between the number of implants placed and pain during the surgery.[74] In a study by Al-Khabbaz et al.,[83] patients with multiple implants were found to be 1.3 times more likely to experience pain during surgery than those who received a single implant. In the same study, the mean postoperative pain scores were highest 24 hours after surgery and decreased gradually after 1 week. With regard to the intensity of the reported pain, most patients reported mild pain (69.7% after 24 hours, 56.5% after 1 week, and 5.1% after 6 weeks), and a few patients reported moderate or severe pain (10.6% after 24 hours, 3.8% after 1 week, and none after 6 weeks). In general, studies have shown that maximum pain levels appear 6 to 24 hours after implant placement, and most patients rate pain as mild.[80,81] Factors associated with pain perception are listed in Table 11-3.

ECONOMIC OUTCOMES

Cost appears to be a deciding factor in determining the treatment for replacing a missing or failing tooth. A study by Al-Quran et al.[84] compared different treatment options for tooth replacement (i.e., three-unit fixed partial denture, removable partial denture, implant-supported crown, and extraction without replacement). The authors found that cost was a factor for 27.5% of the patients in the study in their decision making. Only 2% of the patients receiving implants were influenced by the price of this therapy. However, the percentage increased to 16% for patients receiving fixed partial dentures and to 34% for those treated with removable partial dentures (Table 11-4).

Cost-effectiveness is an important consideration for both the practitioner and the patient in assessing the efficiency of oral implant therapy. The growing evidence of the efficacy and effectiveness of dental implants has led researchers to study the economic impact and efficiency of this technology

Table 11-3 Pain Distribution Over Time After Dental Implant Surgery*

PAIN SCORE	DURING SURGERY N (%)	24 HOURS N (%)	1 WEEK N (%)	6 WEEKS N (%)	12 WEEKS N (%)
0	197 (84.2)	46 (19.7)	93 (39.7)	222 (94.9)	234 (100)
1-3 (mild)	30 (12.8)	163 (69.7)	132 (56.5)	12 (5.1)	0
4-6 (moderate)	6 (2.6)	21 (8.9)	8 (3.4)	0	0
7-10 (severe)	1 (0.4)	4 (1.7)	1 (0.4)	0	0
Total reporting pain	37 (15.8)	188 (80.3)	141 (60.3)	12 (5.1)	0
Mean pain score (± SE)	0.39 (0.07)	2.01 (0.11)	1.08 (0.08)	0.06 (0.02)	0

From Al-Khabbaz AK, Griffin TJ, Al-Shammari KF: Assessment of pain associated with the surgical placement of dental implants, *J Periodontol* 78:239-246, 2007.
*$N = 234$ patients. *SE*, Standard error.

Table 11-4 Factors Affecting Treatment Options with Regard to Prosthesis Type

	FIXED N (%)	REMOVABLE N (%)	IMPLANT N (%)	CONTROL N (%)	TOTAL N (%)
Cost	8	17	2	28	55 (27.5)
Pain and discomfort	18	17	20	22	77 (38.5)
Surgery	4	9	7	16	36
Duration	25	33	12	7	77 (38.5)
Neighboring teeth	17	18	28	17	80
Phobia	14	11	13	26	64

for different indications. For a true economic evaluation, the cost and benefit of different therapies are usually compared. In a recent study by Bragger et al.,[85] single tooth implants and, arguably, the most prescribed treatment alternative, a three-unit fixed partial denture (FPD), were compared. The authors found that implant treatment required more visits than FPDs (8.1 versus 2.3). However, the total treatment time was similar, averaging 4.8 hours for the implant treatment and 5.1 hours for the FPD. Laboratory costs were about 263% higher for fabrication of the FPD. The costs for treatment of technical and biologic complications were similar. The overall cost was 22% higher for the FPD therapy. The authors emphasized that especially in situations involving either unrestored or minimally restored teeth with sufficient bone, implant reconstruction should be recommended from an economical point of view (Figure 11-1).

In a study by Tepper et al.,[86] a population sample of 1,000 patients was provided with a questionnaire to determine the patients' perception of the cost of dental implants. Generally, the patients in this study thought that single implant treatment was too expensive. In a subgroup of this population comprising patients who had already had implants, 79% thought implant treatment was too expensive. With regard to subjectively perceived prices, it should be noted that implant recipients can at best give limited estimates of real implant costs. Both the complex nature of the product and the service needed make putting a price on the expected benefits extremely difficult for these patients.[86] Other authors have found that approximately 90% of the patients studied thought that the cost of implant treatment was justified or that the cost/benefit tradeoff was positive.[76,77]

ESTHETIC OUTCOMES

The esthetic expectations of both the practitioner and the patient can present a significant challenge, because various local risk factors can compromise the final outcome.[87-90] In the anterior

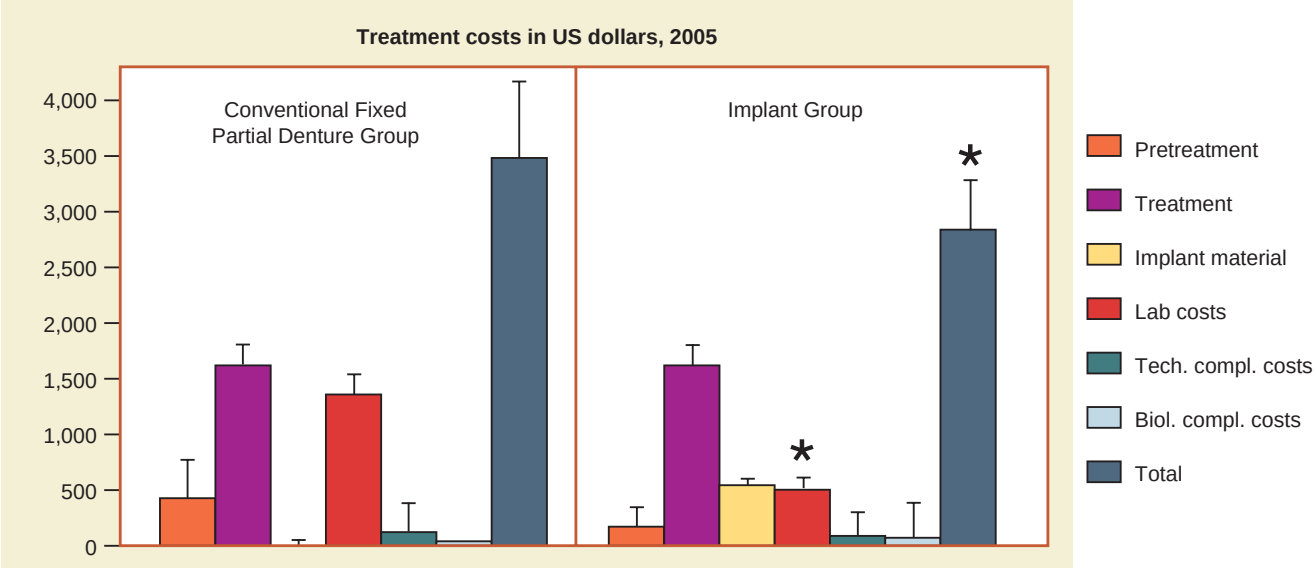


Figure 11-1 Means and standard deviations for treatment costs for single tooth replacement with conventional three-unit fixed dental prosthesis (FPD) *(T)* or single implant therapy *(I)*. Costs include pretreatment, treatment, treatment of biologic and/or technical complications, materials, and laboratory work. (Data from Bragger U, Krenander P, Lang NP: Economic aspects of single-tooth replacement, *Clin Oral Implants Res* 16:335-341, 2005.)

segment, an important goal for the restorative dentist is to provide patients with restorations and soft tissue contours that are in harmony with the adjacent teeth (Figure 11-2). From a surgical perspective, the current concept is to plan for implants to be placed in a position to optimize the emergence profiles of the restoration, achieving proper gingival contours and implant integration.[87,91]

The stability of peri-implant soft tissues is a keystone in selecting the timing for placement of the final restoration. A change in the gingival architecture has been observed after implant placement, regardless of the surgical protocol used and the type of restoration provided. Some studies have reported the frequency of esthetic complications to range from 4% to 16%,[51,55,92] usually associated with exposure of the implant abutment or collar as a result of peri-implant gingival recession. Other studies have quantified the loss of gingival buccal tissues in single implant sites and compared the values to the contralateral natural tooth. Jemt et al.[17] reported that implant crowns on average were 0.7 mm longer than the contralateral natural crowns after 5 years of follow-up (Figure 11-3). However, significant mucosal recession can occur if insufficient bone is present to support the soft tissues (Figures 11-4 to 11-6).

Small and Tarnow[93] evaluated soft tissue remodeling in the period from abutment connection surgery to the 1-year follow-up appointment. They reported a gingival recession of approximately 1 mm, especially during the first 3 months. Similar values were reported by different researchers,[92,94-97] showing that implant restorations on average are about 0.6 to 1 mm longer than their natural tooth counterpart.

A comparable incidence is seen when implants are placed in fresh extraction sockets.[39,40,98-107] Studies by De Rouck et al.[98] and Kan et al.[99] measured the midfacial gingival level before tooth removal and after immediate implant placement and restoration. The two studies reported significant soft tissue loss (0.53 and 0.55 mm, respectively) at the midfacial aspect after 1 year of follow-up. A later report by Kan et al.,[100] in which the same population was studied for a longer period (about 4 years), found that the facial recession continued to increase at each follow-up appointment.

The volume of the gingival embrasure and the presence of adjacent teeth[87] influence the existence of the interproximal papillae. An initial loss of proximal tissues has been reported, although never numerically quantified, when

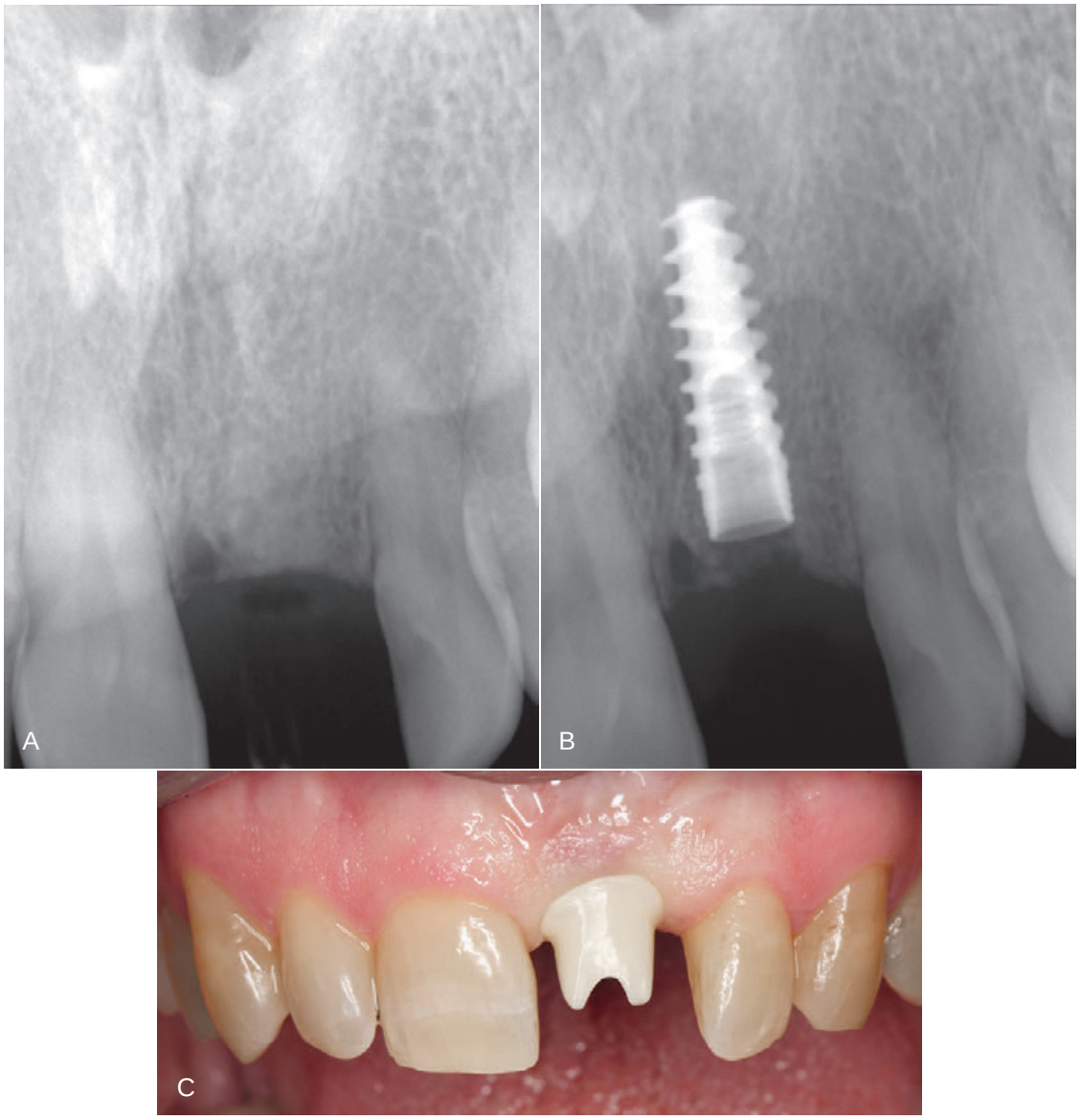
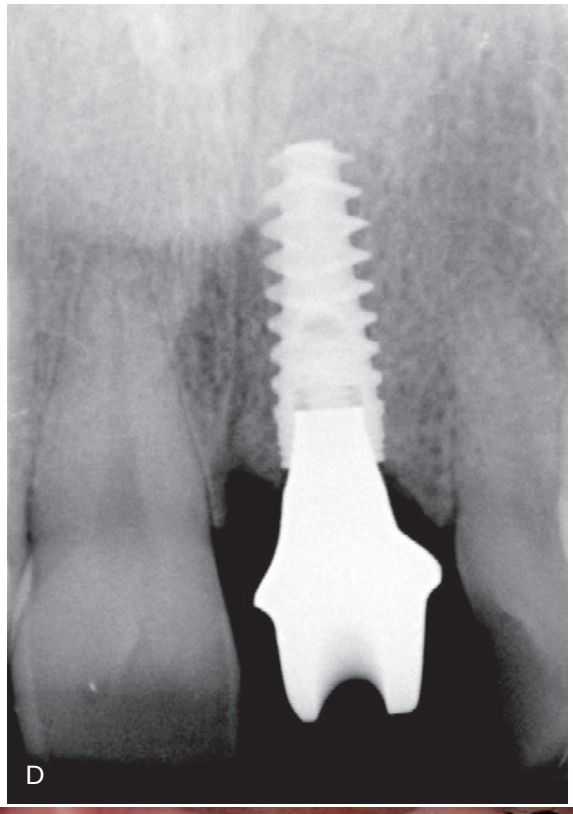


Figure 11-2 **A,** Pretreatment periapical radiograph of maxillary left central incisor area. **B,** Single implant placed in position of missing maxillary left central incisor. **C,** Zirconia custom abutment attached to implant. The mucosa is slightly blanched at this initial placement.

single implants are placed in a delayed fashion[92,96,97]; however, a certain degree of spontaneous papillary regeneration has been observed over time after implant surgery.[108] Some authors have reported preservation of these interproximal tissues if an implant is placed immediately in conjunction with immediate provisionalization performed at the time of tooth extraction and implant placement.[99-100] De Rouck et al.[109] observed that delayed restoration resulted in initial papillary loss and that it took up to 1 year to attain a height comparable to that seen with immediate restoration. The same study showed that midfacial recession was systematically two and one half to three times higher after delayed restoration, pointing to a 0.75-mm additional loss compared with immediate restoration after 1 year. These findings emphasize the importance of



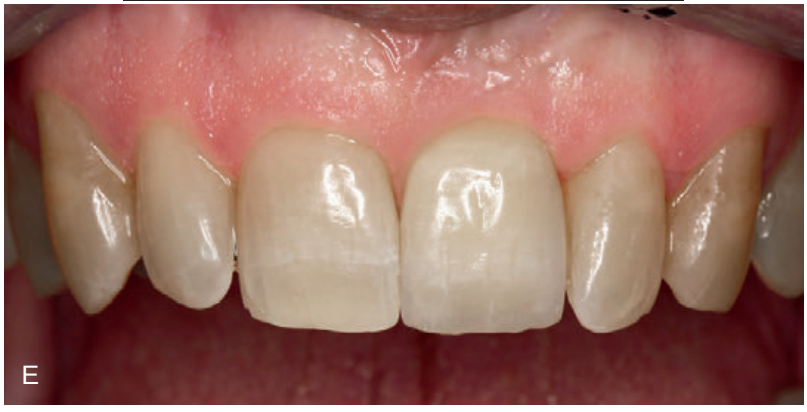


Figure 11-2, cont'd **D,** Zirconia abutment seated into implant. **E,** Frontal view of all-ceramic crown cemented over zirconia abutment, showing acceptable soft tissue contour around the crown and adjacent central incisor.

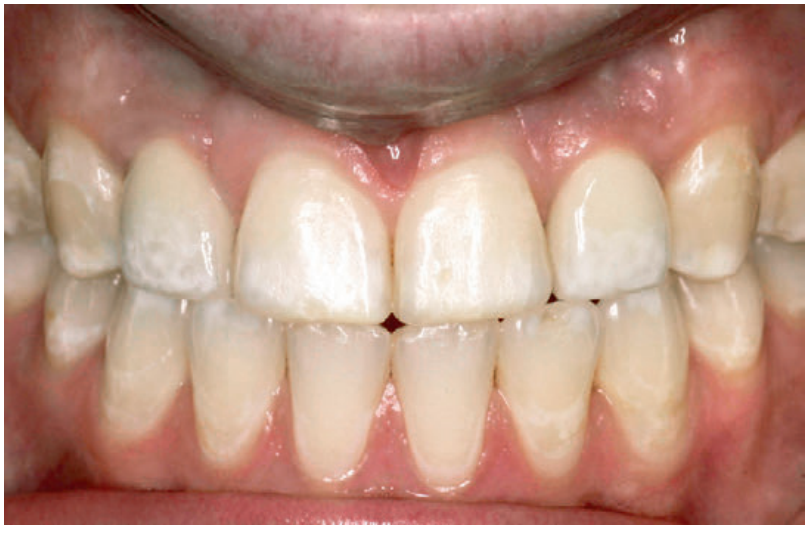


Figure 11-3 Implants were placed in the positions of the congenitally missing lateral incisors after orthodontic treatment. Note that some recession has occurred around the maxillary right lateral incisor crown.

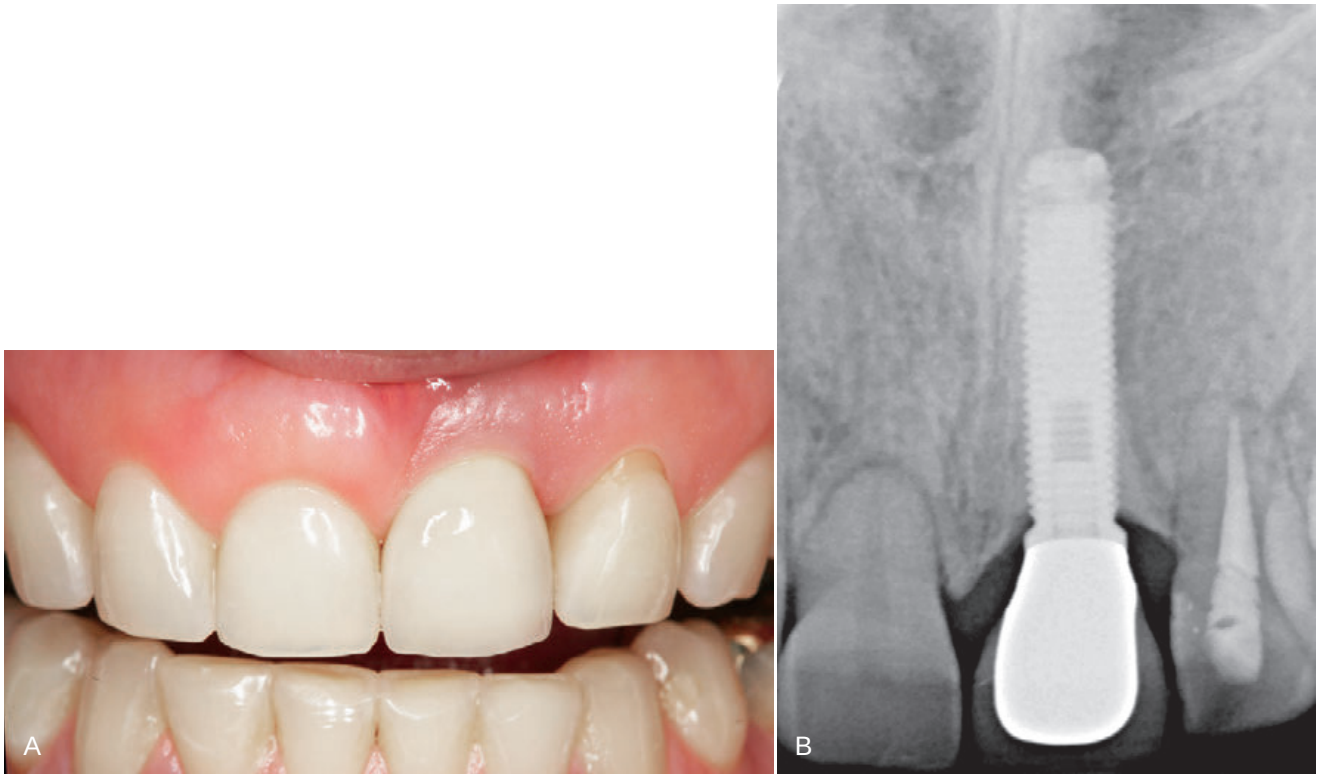


Figure 11-4 **A,** Mucosal recession has occurred around the crown on the maxillary left central incisor implant. **B,** Radiograph of implant and crown shown in **A.**

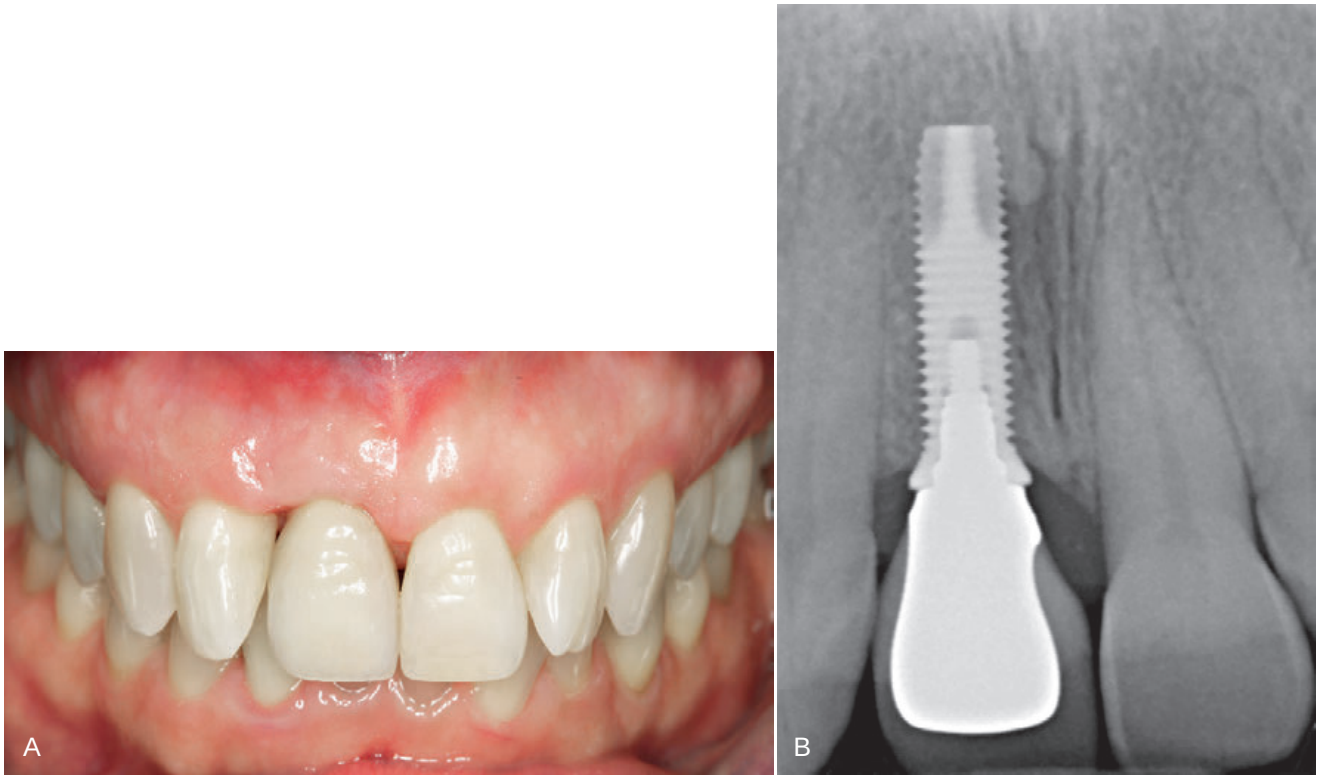


Figure 11-5 **A,** Extraction of a tooth resulted in substantial mucosal recession on both interproximal areas of the maxillary right central incisor, creating open cervical embrasures. **B,** Radiograph of crown cemented over metal abutment where the abutment is narrower than the implant platform (platform switching).

the provisionalization stage in the final esthetic outcome.

SUMMARY

Single tooth replacement by means of a dental implant appears to be a predictable therapy based on current scientific evidence. A low incidence of complications, high degree of patient satisfaction and a comparable financial impact to other treatment alternatives may render implant therapy as the treatment of choice for the replacement of the single failing tooth. Nevertheless, a certain degree of gingival architecture loss can be expected in single implant restorations.

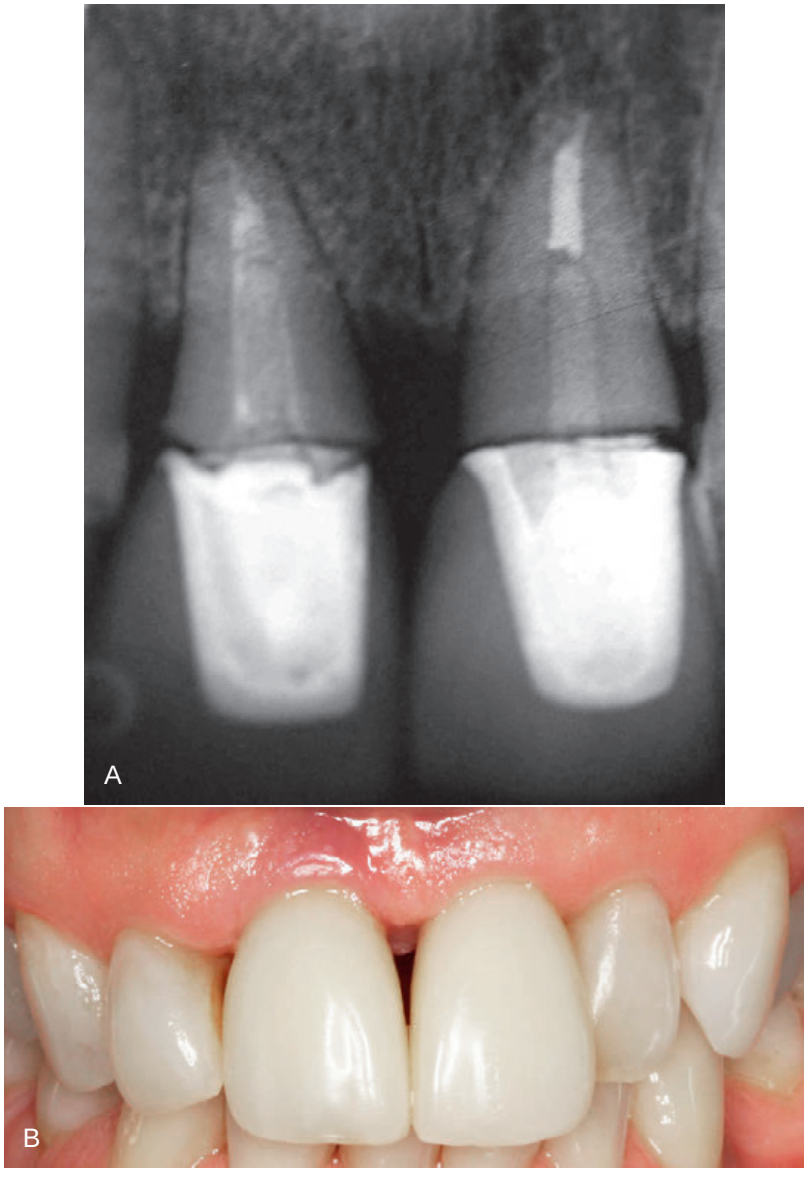


Figure 11-6 **A,** Central incisors required extraction because of periodontal breakdown. **B,** Existing crowns appeared long, with open cervical embrasures, as a result of lack of bone.

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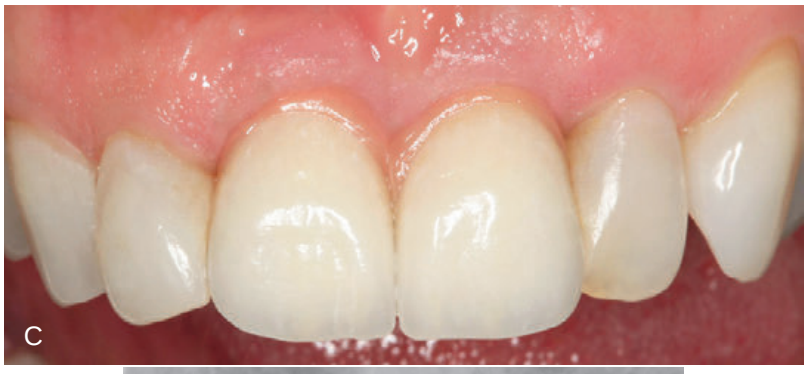

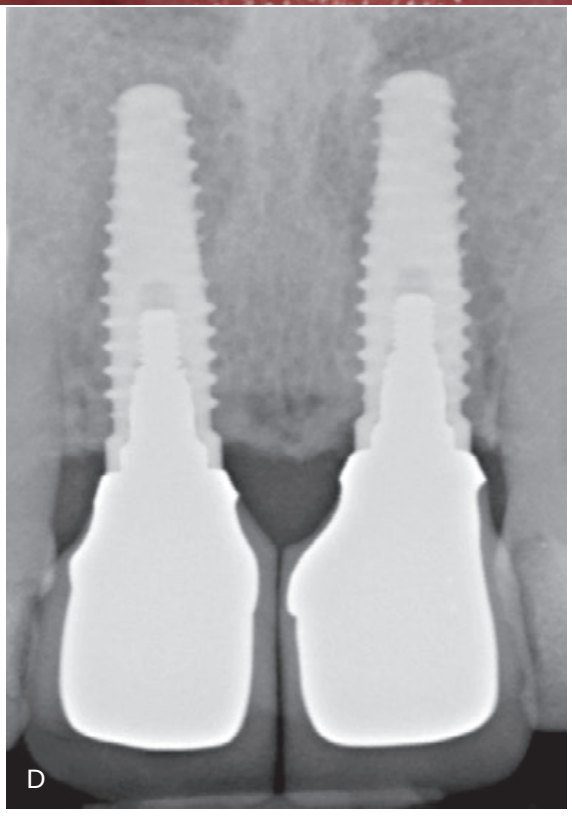

Figure 11-6, cont'd **C,** Metal ceramic crowns were shortened incisally and made with pink ceramic margins to simulate gingiva and to close open cervical embrasures. **D,** Radiograph of cemented crowns shown in **C.**

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