Ronald Younes · Nabih Nader
Georges Khoury *Editors*

Sinus Grafting Techniques

A Step-by-Step Guide

Springer

Highdent laboratory

مرکز تخصصی پروتزهای دندانی

های دنت

طراحی و ساخت انواع پروتزهای دندانی بویژه ایمپلنت

برگزار کننده دوره های آموزشی تخصصی وجامع دندانسازی و...

با ما همراه باشید...

WWW.HIGHDENTlab.com

Ronald Younes • Nabih Nader
Georges Khoury
Editors

Sinus Grafting Techniques

A Step-by-Step Guide

Springer

Editors
Ronald Younes
Department of Oral Surgery
St. Joseph University
Beirut
Lebanon

Georges Khoury
Department of implantology
and bone reconstruction
Paris-Diderot University
Paris
France

Nabih Nader
Department of Oral and Maxillofacial
Surgery
Lebanese University
Beirut
Lebanon

Videos to this book can also be accessed at
http://www.springerimages.com/videos/978-3-319-11448-4

ISBN 978-3-319-11447-7 ISBN 978-3-319-11448-4 (eBook)
DOI 10.1007/978-3-319-11448-4
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014959095

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

This book describes very exhaustively most of the techniques currently used for performing sinus lift elevation procedures and is complemented by numerous useful illustrations and drawings. The book also has a valuable chapter on possible complications and how to treat them. All very useful pieces of information for clinicians willing to learn more on the subject.

Even more interesting to my critical eyes is the chapter on future perspectives where the authors are clearly aware that the amount of knowledge we have today is still insufficient to make reliable recommendations on which could be the most cost-effective procedures to follow when rehabilitating posterior atrophic jaws. We do know how to perform many complex and innovative procedures, though we still do not know, when and if we should perform them and which are the most effective ones. We still do not know if we need to use a graft or not into the sinus and which could be the best graft materials. I will therefore take the opportunity to stress once more the need we still have of reliable clinical research in order to provide the best treatment options to our patients. This book showed how many possible solutions we have, which is good to know, but now we have new priorities: we need to know which among the described procedures are associated with higher success rates, less complications, shorter rehabilitation periods, etc. This book therefore could be a stimulus for the international research community to prioritise some research areas in order to find those clinical answers we badly need.

We know how to do sinus elevation procedures in many different ways, but now we need also to know why we do them, when we should do them and which of the many procedures used are the most effective ones.

Marco Esposito
Freelance Researcher and Associate Professor,
Department of Biomaterials,
The Sahlgrenska Academy at Göteborg University, Sweden

Editor, Cochrane Oral Health Group,
School of Dentistry, The University of Manchester

Editor in chief, European Journal of Oral Implantology

Contents

Contributors

Maroun Boukaram, DDS Department of Periodontology, Faculty of Dentistry, St Joseph University, Beirut, Lebanon

Rufino Felizardo, DDS, PhD Department of Odontology-Anatomy and Radiology unit, Paris-Diderot University and Rothschild Hospital (APHP), Paris, France

Maissa Aboul Hosn, DDS Department of Oral and Maxillo-facial Surgery, Lebanese University, School of Dentistry, Beirut, Lebanon

Georges Khoury, DDS, MSc Department of implantology and bone reconstruction, Paris-Diderot University, Paris, France

Pierre Lahoud, DDS Department of Oral Surgery, Faculty of Dentistry, Saint Joseph University, Beirut, Lebanon

Harry Maarek, MD Department of Otolaryngology-Head and Neck Surgery, Pitie Salpetriere Hospital, Paris, France

Nabih Nader, DDS Department of Oral and Maxillofacial Surgery, School of Dentistry, Lebanese University, Beirut, Lebanon

Ibrahim Nasseh, DDS, PhD, MBA Department of DentoMaxilloFacial Radiology and Imaging, Lebanese University, School of Dentistry, Beirut, Lebanon

Bahige Tourbah Private Practice in Oral Implantology, Oral and Maxillofacial Surgery Clinic, Montpellier, France

Ronald Younes, DDS, PhD Department of Oral Surgery, Faculty of Dentistry, St Joseph University, Beirut, Lebanon

Introduction and Scientific Background of Sinus Floor Elevation (SFE)

1

Ronald Younes, Nabih Nader, and Georges Khoury

Content

In a constantly aging society, the need for maxillary implant rehabilitation is increasing. In fact, the regeneration of the physiological function of the dento-maxillary system is crucial for improvement in life quality.

Concomitantly, especially in elderly people, dental rehabilitation has a considerable effect on the overall morbidity and a resultant socioeconomic impact (Weyant et al. 2004). A successful implant therapy in senior citizens is directly linked with improved overall health and decreased health-care costs (Vogel et al. 2013). Thus, rehabilitation of edentulous patients with oral implants has become a routine treatment modality in the last decades, with reliable long-term results.

However, implant placement may become a challenging procedure in the presence of unfavorable local condition of the alveolar ridge. This problem is especially magnified in the posterior maxilla, where progressive ridge resorption in an apical direction is combined to the progressive sinus pneumatization (Garg 1999) as a consequence of intrasinus positive pressure (Smiler et al. 1992). Moreover, poor bone quality is also often encountered. Following tooth extraction, an initial

R. Younes, DDS, PhD (✉)
Department of Oral Surgery, Faculty of Dentistry, St Joseph University, Beirut, Lebanon
e-mail: ronald.younes@usj.edu.lb; ronald.younes@hotmail.com

N. Nader, DDS
Department of Oral and Maxillofacial Surgery,
School of Dentistry, Lebanese University, Beirut, Lebanon
e-mail: nabih.nader@gmail.com

G. Khoury, DDS, MSc
Department of implantology and bone reconstruction,
Paris-Diderot University, Paris, France
e-mail: dr.georges.khoury@gmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_1

bucco-palatal reduction of bone volume occurs because of the interruption of blood supply to the bone plate and to the absence of occlusal loads (Cawood and Howell 1991). As a result, the sinus floor is closer to the alveolar ridge. Based on the Cawood and Howell classification of bone loss, the residual bone crest may be classified in gradations of I (dentate) to VI (paper thin) (Cawood and Howell 1988).

The resulting alveolar bone atrophy may affect the ability to place implants of adequate size and length. Accordingly, decision-making challenge vastly depends on valid clinical evidence to assess the most favorable treatment modalities. Thus, several attempts have been made in the past years to develop new surgical procedures for the augmentation of the resorbed posterior maxilla to be convenient support for long-term predicable implants. Maxillary sinus floor elevation (SFE) procedure is nowadays the most frequently used bone augmentation technique prior to implant placement, in more of half of the cases (Seong et al. 2013).

Conventional lateral SFE has been developed over three decades ago, initially developed by Tatum (1986a) at the end of the 1970s (1977), and was first published in a clinical study in 1980 by Boyne and James (Boyne and James 1980).

Since, numerous successful techniques have been described to restore maxillary bone height (Smiler 1997). The 1996 Sinus Consensus Conference stated that SFE is a highly predictable and effective therapeutic modality (Jensen et al. 1998). Most publications feature a lateral approach to the sinus cavity. According to the "original technique," a horizontal incision is made in the mucosa at the top of the alveolar crest or slightly palatally to raise a full-thickness flap that is deflected to expose the lateral antral wall of the maxillary sinus where an antrostomy is performed (modification of the Caldwell-Luc technique); access to the maxillary sinus is obtained by drilling a bone window in the lateral sinus wall using round burs, while ensuring that the Schneiderian membrane remains intact. The sinus membrane is then carefully elevated using sinus curettes, mobilized together with the attached bone window, and rotated medially. While rotary instruments are still used for window preparation, the recent development of piezoelectric ultrasonic devices may contribute to reduce intraoperative complications such as membrane perforation (Wallace et al. 2007).

Three variations of the basic SFE were described by Smiler (1997): the hinge osteotomy, the elevated osteotomy, and the complete osteotomy.

After a careful elevation of the sinus membrane from the walls of the sinus cavity, the resulting created space is ready for bone augmentation. The grafting material is steadily inserted in the cavity and subsequently the deflected gingival flap closes the sinus window. Several approaches involve classifications and treatments of membrane tearing as well as adaptations to the closure of the sinus (Vlassis and Fugazzotto 1999; Ardekian et al. 2006). Following SFE, a bone graft maturation time is required (from 5 to 10 months) depending on the grafting material.

Nowadays, the lateral SFE presents a clinically successful technique that offers good insight into the sinus cavity and leads to subsequent modifications in bone height (Chiapasco and Ronchi 1994). However, these advantages involve a secondary surgery site when placing dental implants and thus hold several drawbacks such

as the potential for infections (Schwartz-Arad et al. 2004), particularly in smokers (Barone et al. 2006).

To address these drawbacks, Summers (1994a) described a modification of the original SFE technique, which is a codified transalveolar (crestal) approach, namely, the osteotome sinus floor elevation (OSFE), which was a called "new method" of placing implants into the maxillary bone without drilling. In this technique, the use of the tapered osteotomes with increasing diameter aims to preserve the residual bone tissue instead of loosing it while drilling through a conventional procedure. Moreover, they improve bone density around the implant in case of low bone density, which is often the case in the posterior maxilla. The author (Summers 1994a) concluded that the osteotome technique is superior to drilling for many applications in soft maxillary bone, capable to expand the bone.

The basic procedure involves a crestal incision at the planned implant site and a full-thickness flap that is prepared to expose the alveolar crest. After a preoperative careful measurement of the subsinus residual bone height, the initial osteotomy could be either created manually with osteotomes or by the use of a drill. The subsequent osteotomes are inserted into the implant socket by hand pressure or gentle malleting until the residual bone height (RBH) beneath the maxillary sinus floor is limited to about 2 mm. Then, osteotomes of increasing diameters are placed sequentially until the planned implant diameter is reached. Tapping on the last osteotome results in a greenstick fracture of the sinus floor and lifts the Schneiderian membrane without violating it. Finally, an implant is placed in the prepared site.

In fact, osteotome-mediated transcrestal SFE approach was first proposed by Tatum in the late 1970s who used at that time a crestal approach. His results using this transalveolar technique for SFE with simultaneous placement of implants were later published in 1986 (Tatum 1986).

In his original publication, a special instrument known as "socket former" was used to prepare the implant site leading to a controlled "greenstick fracture" of the sinus floor, moving it in a more apical direction. Root-formed implants were then simultaneously placed and allowed to heal in a submerged manner.

At the time, the author did not use any grafting material to increase and maintain the volume of the elevated area.

Later, an enhanced version of the OSFE in which a bone substitute is added to the osteotomy, namely, the "bone-added osteotome SFE" (BAOSFE) (Summers 1994c) was described. The space underneath the elevated floor is filled with particulate graft material via the implant bed to support the elevated membrane.

The author concludes that both the OSFE and the BAOSFE techniques are suitable solutions of altering the sinus floor so that longer implants can be inserted in a less invasive manner.

Later, to minimize the risk of membrane perforation, some clinicians used an inflatable device or fill the void with augmentation material prior fracturing the sinus wall (Stelzle and Benner 2011; Soltan and Smiler 2005).

Nowadays, several modifications of the original SFE technique have been described (Chen and Cha 2005) either through a lateral or a crestal approach. In both procedures, when it is possible, implant insertion is performed simultaneously after

the desired augmentation height is reached. Most authors make their decision whether to use a simultaneous or staged approach according to the amount of residual bone height (RBH) (Zitzmann and Schärer 1998; Del Fabbro et al. 2013) essential for the initial implant stability. The consensus for selecting a simultaneous implant placement is applicable with a RBH of at least 4–5 mm. However, recent studies indicated successful one-stage approaches with only 1 mm RBH (Peleg et al. 1998; Winter et al. 2002). Taken together, the osteotome technique may provide lower morbidity and operational time but requires greater RBH.

Nevertheless, in SFE, membrane integrity is a primary condition for and measure of success. Furthermore, despite its predictability, the osteotome "blind" technique is associated with a higher possibility of membrane tearing, limited elevation of the sinus mucosa, and fewer control of the operation field.

Apart from the different surgical approaches providing adequate structure for primary implant stability, several additional parameters such as simultaneously or delayed implant placement, time of unloaded healing as well as the use of grafting materials or membranes significantly affect implant survival. The ideal graft material is described as a substance that will change into regular bone under functional loading without resorption and offers either osteoconductive or osteoinductive properties to promote new bone formation, able to support dental implants (Block and Kent 1997).

A broad variety of different grafting materials have been successfully applied in sinus augmentation, including autogenous bone (AB), allografts, xenografts, and alloplasts. AB has long been considered the "gold standard" for atrophic ridge regeneration because of its unique osteogenic, osteoinductive, and osteoconductive properties (Del Fabbro et al. 2004; Tong et al. 1998). AB can be harvested from various donor sites (i.e., ilium, symphysis, mandibular ramus). In the first publications (Boyne and James 1980), the grafting material was initially AB harvested from the iliac crest. Nevertheless, it was shown that AB is subject to high resorption (Wallace and Froum 2003), with up to 49.5 % of bone loss after 6 months. Additionally, the use of AB usually involves a second surgery site with the potential of donor site morbidity (Block and Kent 1997; Smiler and Holmes 1987).

Therefore, in order to avoid the drawbacks related to the use of AB, the development of alternative bone substitutes with osteoconductive properties can represent a valid alternative to AB, providing a scaffold for bone regeneration thus eliminating the need to harvest AB.

Allografts such as demineralized freeze-dried bone allograft (DFDBA) avoid a second surgical site and exhibit osteoinductive and osteoconductive properties (Block and Kent 1997; Hallman et al. 2005). However, it was stated that DFDBA generates unpredictable bone formation with newly-formed bone of low quality and quantity (Block and Kent 1997). The use of xenografts such as bovine bone mineral (Sauerbier et al. 2011; Bassil et al. 2013) and alloplasts such as hydroxyapatite (Mangano et al. 2003) alone or in combination with AB has increased over the past decade. Alloplastic materials are synthetic BS made of biocompatible, inorganic, or organic materials, not derived from a human or animal source. Their main advantage is that they have no potential for disease transmission.

Suchlike bone substitute materials vary in porosity and structure (particular pieces or blocks). Supplementary, some clinicians apply resorbable or non-resorbable membranes to protect the augmented area and prevent soft tissue encleftation in the grafted area.

Thus, membranes may promote guided bone regeneration (GBR) and increase the amount of newly-formed bone (Tarnow et al. 2000, Wallace et al. 2005). Nevertheless, membranes may result in lower vascular supply to the graft, increased risk of infection, and additional cost. It was stated that particulate grafting material that includes AB heals faster and therefore implants can be placed earlier (Peleg et al. 1999). However, other authors (Hallman et al. 2002; Valentini and Abensur 1997) reported about more favorable results for the use of xenografts.

On the other hand, the predictability of SFE has been extensively reported and frequently measured through implant survival rate (ISR) criteria in order to evaluate the bone augmentation success. Numerous systematic evidence-based reviews from 2003 to 2013 were published relative to implant outcomes following SFE (Aghaloo and Moy 2007; Wallace and Froum 2003; Del Fabbro et al. 2004, 2008, 2013; Graziani et al. 2004; Pjetursson et al. 2008; Nkenke and Stelzle 2009; Jensen and Terheyden 2009; Esposito et al. 2010; Klijn et al. 2010). Controversial investigations either found similar survival rates (90 %) for AB and bone substitutes (Del Fabbro et al. 2004, 2008, 2013; Nkenke and Stelzle 2009) or stated that AB is still the gold standard and superior to BS (Klijn et al. 2010).

The use of implants with a textured surface and the placement of a membrane over the antrostomy are associated with increased implant survival rates (Pjetursson et al. 2008). At present, it is difficult to provide an unbiased quantitative estimate of the impact of sinus augmentation on implant survival. This has been underlined by the Sinus Consensus Conference and is because of the almost complete absence of prospective comparative studies (Jensen et al. 1998).

Attempts have been made to conduct meta-analysis of the available literature (Esposito et al. 2010, 2014; Tong et al. 1998; Wallace and Froum 2003; Del Fabbro et al. 2013). However, since survival rates in the posterior maxillae are different from other sites in the mouth, it would be sensible to compare implant survival after SFE to the survival in conventional implant placement in this particular area.

Although SFE has become a frequently used and clinically successful technique, the review of clinical investigations on sinus augmentation is inconsistent and often confounding (Javed and Romanos 2010). Overall, variations in the selection of patients, the surgical procedures as well as the surgeon's skill level account for the low clinical evidence (Aghaloo and Moy 2007).

The predictability of SFE procedure relies on several parameters in addition to the impact of the various SFE treatment modalities. Particular attention was given to the influence of the surgical approach, the residual bone height, the type of implant, its surface and placement, the grafting material, and the use of membranes to provide clinical evidence for prospective treatment regimes.

Since its introduction into clinical practice, the SFE surgical protocol has evolved through the years: harvesting sites, new graft materials, implant surface characteristics, timing of implant placement, and surgical techniques have been introduced in order to simplify the treatment and reduce the morbidity.

Nowadays, maxillary SFE became one of the preferred and better-documented techniques for the management of the atrophic posterior maxilla.

The clinician should keep in mind that SFE's goal is to rehabilitate the resorbed posterior maxilla in order to allow a proper implant placement intended to heal following the basic principle of osseointegration. Therefore, sinus graft consolidation is a fundamental for implant integration. It is important to know that the healing of the sinus graft is a dynamic process occurring several years after SFE.

References

Aghaloo TL, Moy PK (2007) Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 22 Suppl:49–70

Ardekian L, Oved-Peleg E, Mactei EE, Peled M (2006) The clinical significance of sinus membrane perforation during augmentation of the maxillary sinus. J Oral Maxillofac Surg 64: 277–282. doi:10.1016/j.joms.2005.10.031

Barone A, Santini S, Sbordone L, Crespi R, Covani U (2006) A clinical study of the outcomes and complications associated with maxillary sinus augmentation. Int J Oral Maxillofac Implants 21:81–85

Bassil J, Naaman N, Lattouf R, Kassis C, Changotade S, Baroukh B, Senni K, Godeau G (2013) Clinical, histological, and histomorphometrical analysis of maxillary sinus augmentation using inorganic bovine in humans: preliminary results. J Oral Implantol 39:73–80. doi:10.1563/AAID-JOI-D-11-00012

Block MS, Kent JN (1997) Sinus augmentation for dental implants: the use of autogenous bone. J Oral Maxillofac Surg 55:1281–1286

Boyne PJ, James RA (1980) Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1965(38):613–616

Cawood JI, Howell RA (1988) A classification of the edentulous jaws. Int J Oral Maxillofac Surg 17:232–236

Cawood JI, Howell RA (1991) Reconstructive preprosthetic surgery. I. Anatomical considerations. Int J Oral Maxillofac Surg 20:75–82

Chen L, Cha J (2005) An 8-year retrospective study: 1,100 patients receiving 1,557 implants using the minimally invasive hydraulic sinus condensing technique. J Periodontol 76:482–491. doi:10.1902/jop.2005.76.3.482

Chiapasco M, Ronchi P (1994) Sinus lift and endosseous implants–preliminary surgical and prosthetic results. Eur J Prosthodont Restor Dent 3:15–21

Del Fabbro M, Testori T, Francetti L, Weinstein R (2004) Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 24:565–577

Del Fabbro M, Rosano G, Taschieri S (2008) Implant survival rates after maxillary sinus augmentation. Eur J Oral Sci 116:497–506. doi:10.1111/j.1600-0722.2008.00571.x

Del Fabbro M, Wallace SS, Testori T (2013) Long-term implant survival in the grafted maxillary sinus: a systematic review. Int J Periodontics Restorative Dent 33:773–783

Esposito M, Felice P, Worthington HV (2014) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev 13(5):CD008397. doi:10.1002/14651858.CD008397

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington HV, Coulthard P (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev CD008397. doi:10.1002/14651858.CD008397

Garg AK (1999) Augmentation grafting of the maxillary sinus for placement of dental implants: anatomy, physiology, and procedures. Implant Dent 8:36–46

Graziani F, Donos N, Needleman I, Gabriele M, Tonetti M (2004) Comparison of implant survival following sinus floor augmentation procedures with implants placed in pristine posterior maxillary bone: a systematic review. Clin Oral Implants Res 15:677–682. doi:10.1111/j.1600-0501.2004.01116.x

Hallman M, Sennerby L, Lundgren S (2002) A clinical and histologic evaluation of implant integration in the posterior maxilla after sinus floor augmentation with autogenous bone, bovine hydroxyapatite, or a 20:80 mixture. Int J Oral Maxillofac Implants 17:635–643

Hallman M, Sennerby L, Zetterqvist L, Lundgren S (2005) A 3-year prospective follow-up study of implant-supported fixed prostheses in patients subjected to maxillary sinus floor augmentation with a 80:20 mixture of deproteinized bovine bone and autogenous bone Clinical, radiographic and resonance frequency analysis. Int J Oral Maxillofac Surg 34:273–280. doi:10.1016/j.ijom.2004.09.009

Javed F, Romanos GE (2010) The role of primary stability for successful immediate loading of dental implants. A literature review. J Dent 38:612–620. doi:10.1016/j.jdent.2010.05.013

Jensen SS, Terheyden H (2009) Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. Int J Oral Maxillofac Implants 24 Suppl:218–236

Jensen OT, Shulman LB, Block MS, Iacono VJ (1998) Report of the sinus consensus conference of 1996. Int J Oral Maxillofac Implants 13 Suppl:11–45

Klijn RJ, Meijer GJ, Bronkhorst EM, Jansen JA (2010) A meta-analysis of histomorphometric results and graft healing time of various biomaterials compared to autologous bone used as sinus floor augmentation material in humans. Tissue Eng Part B Rev 16:493–507. doi:10.1089/ten.TEB.2010.0035

Mangano C, Bartolucci EG, Mazzocco C (2003) A new porous hydroxyapatite for promotion of bone regeneration in maxillary sinus augmentation: clinical and histologic study in humans. Int J Oral Maxillofac Implants 18:23–30

Nkenke E, Stelzle F (2009) Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. Clin Oral Implants Res 20(Suppl 4):124–133. doi:10.1111/j.1600-0501.2009.01776.x

Peleg M, Mazor Z, Chaushu G, Garg AK (1998) Sinus floor augmentation with simultaneous implant placement in the severely atrophic maxilla. J Periodontol 69:1397–1403. doi:10.1902/jop.1998.69.12.1397

Peleg M, Mazor Z, Garg AK (1999) Augmentation grafting of the maxillary sinus and simultaneous implant placement in patients with 3 to 5 mm of residual alveolar bone height. Int J Oral Maxillofac Implants 14:549–556

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35:216–240. doi:10.1111/j.1600-051X.2008.01272.x

Sauerbier S, Rickert D, Gutwald R, Nagursky H, Oshima T, Xavier SP, Christmann J, Kurz P, Menne D, Vissink A, Raghoebar G, Schmelzeisen R, Wagner W, Koch FP (2011) Bone marrow concentrate and bovine bone mineral for sinus floor augmentation: a controlled, randomized, single-blinded clinical and histological trial–per-protocol analysis. Tissue Eng Part A 17:2187–2197. doi:10.1089/ten.TEA.2010.0516

Schwartz-Arad D, Herzberg R, Dolev E (2004) The prevalence of surgical complications of the sinus graft procedure and their impact on implant survival. J Periodontol 75:511–516. doi:10.1902/jop.2004.75.4.511

Seong W-J, Barczak M, Jung J, Basu S, Olin PS, Conrad HJ (2013) Prevalence of sinus augmentation associated with maxillary posterior implants. J Oral Implantol 39:680–688. doi:10.1563/AAID-JOI-D-10-00122

Smiler DG (1997) The sinus lift graft: basic technique and variations. Pract Periodontics Aesthet Dent 9:885–893; quiz 895

Smiler DG, Holmes RE (1987) Sinus lift procedure using porous hydroxyapatite: a preliminary clinical report. J Oral Implantol 13:239–253

Smiler DG, Johnson PW, Lozada JL, Misch C, Rosenlicht JL, Tatum OH, Wagner JR (1992) Sinus lift grafts and endosseous implants. Treatment of the atrophic posterior maxilla. Dent Clin North Am 36:151–186; discussion 187–188

Soltan M, Smiler DG (2005) Antral membrane balloon elevation. J Oral Implantol 31:85–90. doi:10.1563/0-773.1

Stelzle F, Benner K-U (2011) Evaluation of different methods of indirect sinus floor elevation for elevation heights of 10 mm: an experimental ex vivo study. Clin Implant Dent Relat Res 13:124–133. doi:10.1111/j.1708-8208.2009.00190.x

Summers RB (1994a) A new concept in maxillary implant surgery: the osteotome technique. Compendium (Newtown Pa) 15:152, 154–156, 158 passim; quiz 162

Summers RB (1994c) The osteotome technique: part 3–Less invasive methods of elevating the sinus floor. Compendium (Newtown Pa) 15:698, 700, 702–704 passim; quiz 710

Tarnow DP, Wallace SS, Froum SJ, Rohrer MD, Cho SC (2000) Histologic and clinical comparison of bilateral sinus floor elevations with and without barrier membrane placement in 12 patients: part 3 of an ongoing prospective study. Int J Periodontics Restorative Dent 20:117–125

Tatum H Jr (1986) Maxillary and sinus implant reconstructions. Dent Clin North Am 30:207–229

Tong DC, Rioux K, Drangsholt M, Beirne OR (1998) A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 13:175–182

Valentini P, Abensur D (1997) Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): a clinical study of 20 patients. Int J Periodontics Restorative Dent 17:232–241

Vlassis JM, Fugazzotto PA (1999) A classification system for sinus membrane perforations during augmentation procedures with options for repair. J Periodontol 70:692–699. doi:10.1902/jop.1999.70.6.692

Vogel R, Smith-Palmer J, Valentine W (2013) Evaluating the health economic implications and cost-effectiveness of dental implants: a literature review. Int J Oral Maxillofac Implants 28:343–356

Wallace SS, Froum SJ (2003) Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol 8:328–343. doi:10.1902/annals.2003.8.1.328

Wallace SS, Froum SJ, Cho S-C, Elian N, Monteiro D, Kim BS, Tarnow DP (2005) Sinus augmentation utilizing anorganic bovine bone (Bio-Oss) with absorbable and nonabsorbable membranes placed over the lateral window: histomorphometric and clinical analyses. Int J Periodontics Restorative Dent 25:551–559

Wallace SS, Mazor Z, Froum SJ, Cho S-C, Tarnow DP (2007) Schneiderian membrane perforation rate during sinus elevation using piezosurgery: clinical results of 100 consecutive cases. Int J Periodontics Restorative Dent 27:413–419

Weyant RJ, Pandav RS, Plowman JL, Ganguli M (2004) Medical and cognitive correlates of denture wearing in older community-dwelling adults. J Am Geriatr Soc 52:596–600. doi:10.1111/j.1532-5415.2004.52168.x

Winter AA, Pollack AS, Odrich RB (2002) Placement of implants in the severely atrophic posterior maxilla using localized management of the sinus floor: a preliminary study. Int J Oral Maxillofac Implants 17:687–695

Zitzmann NU, Schärer P (1998) Sinus elevation procedures in the resorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:8–17

Anatomy and Related Pitfalls in Sinus Floor Elevation

2

Rufino Felizardo

Contents

2.1 Maxillary Sinus

The maxillary sinus (sinus maxillaris) is the largest of the paranasal sinuses (air cavities). It is located laterally in the face in both parts of the nasal cavity. This cavity is related to three other cavities: the orbit (roof of the sinus), the oral cavity (floor of the sinus), and the nasal cavity by the medial wall of the sinus. Since the 1980s, odontologists and maxillofacial surgeons have used this natural cavity to compensate for maxillary posterior crestal atrophy and enable prosthodontic fixed solutions using dental implants after sinus floor elevation (SFE) procedures.

Before invading this new territory, we should be aware of the anatomical basis, anatomical variations (e.g., volume, size, septa), arterial blood supplies and

R. Felizardo, DDS, PhD
Department of Odontology-Anatomy and Radiology unit,
Paris-Diderot University and Rothschild Hospital (APHP), Paris, France
e-mail: rufino.felizardo@rth.aphp.fr

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_2

innervations and be able to identify these anatomical features on 3D imaging such as cone beam computed tomography (CBCT) or computed tomography (CT). These data are critical to ensure safe surgery and to avoid anesthetic failure, hemorrhage, or neuropathic injury.

Furthermore, a variant of the normal nasal cavity anatomy and middle meatus variants condition the permeability of the maxillary sinus and increase the risk of maxillary sinusitis after surgery by restriction of the sinus ostium.

2.2 Embryology

The process and patterns of skull pneumatization are not fully understood. The development of the paranasal sinuses begins in the third week of gestation. It continues throughout early adulthood. At 12 weeks, the turbinate structures are established in the nasal cavity and palatal fusion occurs. An embryological channel to the maxillary sinus progressively develops from 11 to 12 weeks lateral to the cartilaginous uncinate process and from the middle meatal groove. This ectodermal invagination from the nasopharynx begins and grows laterally inside the maxillary bone.

Initially filled with fluid, the maxillary sinus becomes pneumatized at birth. At birth it is only a thin groove measuring 7×4×4 mm extending from both sides of the nasal cavity. At 9 months it is a small bean-shaped cavity and progressively forms a pyramidal shape by 5 years (Ogle et al. 2012).

Growth of the sinus after the birth is biphasic, with rapid growth during the first 3 years and then again from the ages of 7–12. Growth between the ages of 3 and 7 occurs at a slower pace and then again after the age of 12, growth slows until early adulthood (Lawson et al. 2008). At the age of 9–12 the floor of the sinus is usually level with the floor of the nose. After this point, the floor of the sinus descends as permanent teeth begin to erupt and pneumatization can be extensive enough to expose the tooth roots, which may have only a thin covering of soft tissue within the sinus (Wang et al. 1994).

The functional roles of the maxillary or paranasal sinuses continue to be elusive (Drettner 1979). The biological role of the sinuses is debated, and a number of possible functions have been proposed. Some of the authors since Galen in 130 AD have mentioned only some of the many functional roles suggested for the paranasal sinuses such as mechanical functions: decreasing the relative weight of the front of the skull, and especially the bones of the face (Onodi 1908; Davis et al. 1996), providing a buffer against blows to the face and protection to the brain (Rui et al. 1960; Davis et al. 1996), and the function of pillars for the dispersal of masticatory forces (O'Malley 1924; Enlow 1968). For others, the functions include air conditioning, filtering, the warming of inspired air for the regulation of intranasal and sinus gas pressures or thermal regulation for the central nervous system (Bremer 1940), and phonation by increasing the resonance of the voice (Zuckerkandl 1885; Leakey and Walker 1997).

2.3 Gross Anatomy

The maxillary sinus is a pyramid-shaped cavity occupying the body of the maxilla. Its apex extends to the zygomatic process of the maxilla (processus zygomaticus), while its baseline forms part of the medial wall of the maxillary sinus and the lateral wall of the nasal cavity (Fig. 2.1).

Initially, the maxilla bone presents a medial wall with a large triangular opening with a downward tip named the hiatus (hiatus maxillaris; Fig. 2.2). Progressively, the lateral wall of the nasal cavity is covered by adjacent bony structures: the lacrimal bone (unguis) anteriorly, the inferior turbinate (concha nasalis inferior) inferiorly, the uncinate process of the ethmoid superiorly, and the vertical part (lamina perpendicularis) of the palatine posteriorly. By connective tissue and mucosa the hiatus was progressively reduced at only one or two small openings named ostia located under the space of a shelf-like structure of the middle turbinate. Frontal sinus and anterosuperior cells of the ethmoid opening are also in the middle meatus (Fig. 2.3).

The posterior wall of the maxillary sinus (tuberosity) is bound by the pterygoid space (fossa) form the first method of vascular and nervous supply.

The anterolateral wall separates the soft tissues of the cheek from the sinus and was the principal method of sinus floor elevation by canine fossa (related to the ancient name of the levator labii anguli muscle, the canine muscle, in reference to the canine appearance when contracted; Fig. 2.4).

The superior wall of the sinus forms the most important part of orbital floor. In the case of traumatic injury to the eyeball, this floor can be broken or disrupted and the pressure evacuates downward to protect the ocular globe (Fig. 2.5).

In the superior wall of the maxillary sinus we found the infraorbitalis canal for nervous fibers of the anterosuperior teeth descending into the anterolateral wall.

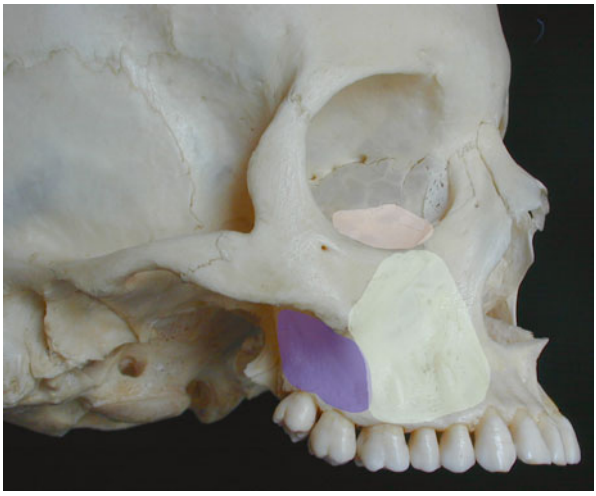


Fig. 2.1 Lateral view of the maxillary bone with the external walls of the maxillary sinus: orbital floor (*pink*), anterior wall (*yellow*), posterior wall (*purple*)

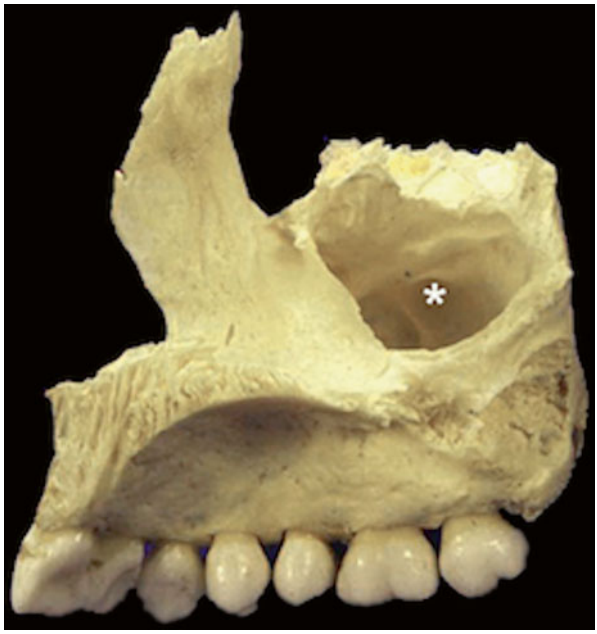


Fig. 2.2 Medial view of the isolated maxillary bone with the large triangular opening of sinus (*asterisk*): the hiatus of the maxillary bone

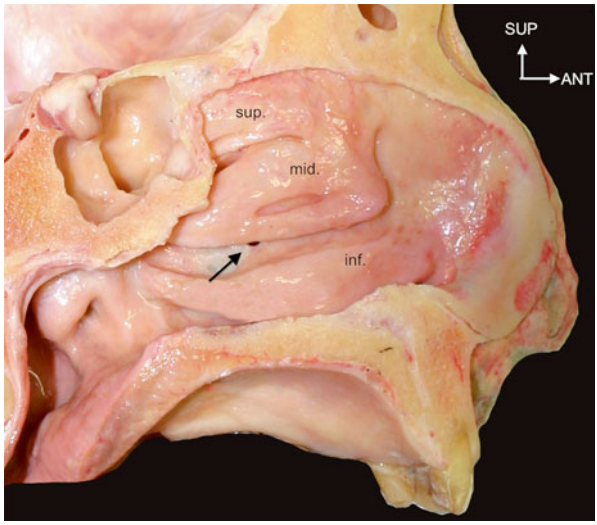


Fig. 2.3 Lateral wall of the nasal fossa with three turbinates (superior, middle, and inferior) and under the middle turbinate the ostium of the maxillary sinus (*arrow*)

Finally, the infraorbitaris foramen permits the passing of sensitive nervous fibers and vascular bundles to the cheek tissues (Fig. 2.6).

The last wall of the maxillary sinus forms the alveolar process of the maxillary bone with great variations in relation to the teeth roots and apices, sometimes between the teeth and between the roots such as a procident sinus.

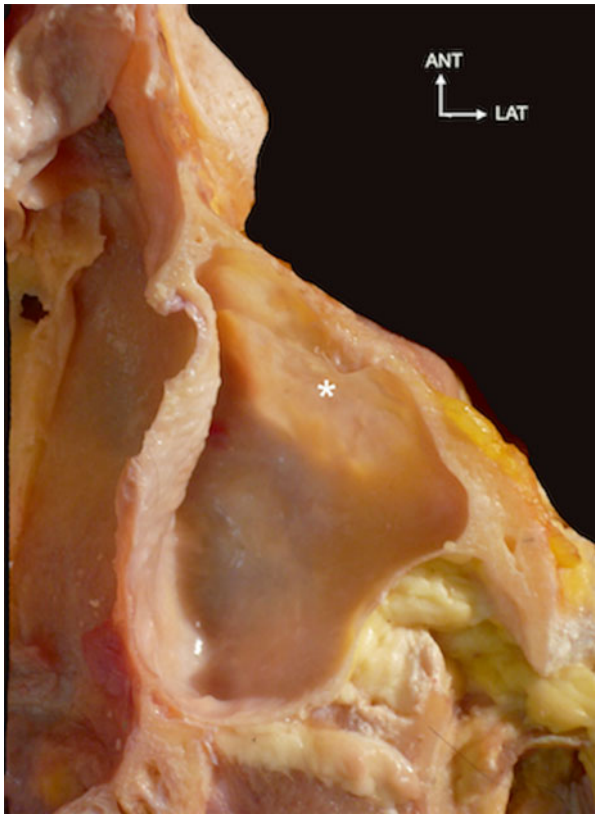


Fig. 2.4 Horizontal section of the maxillary sinus. See the thinness of the anterior wall of the sinus (*asterisk* indicates the canine fossa)

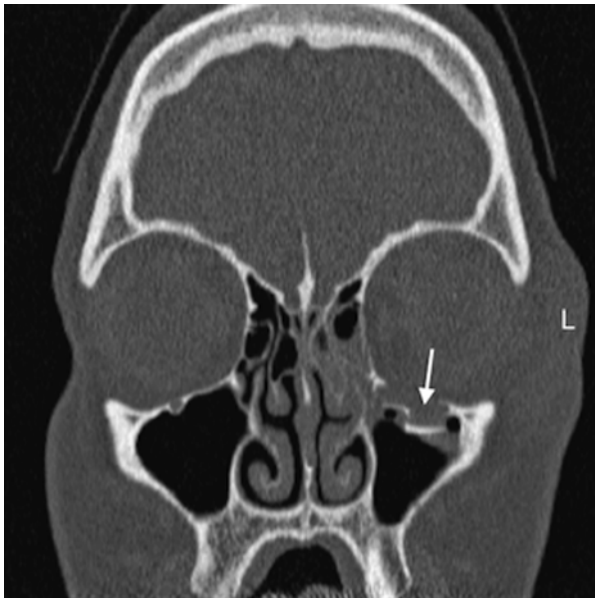


Fig. 2.5 Eye-ball traumatism with fracture (*arrow*) of the orbital floor in the direction of the maxillary sinus

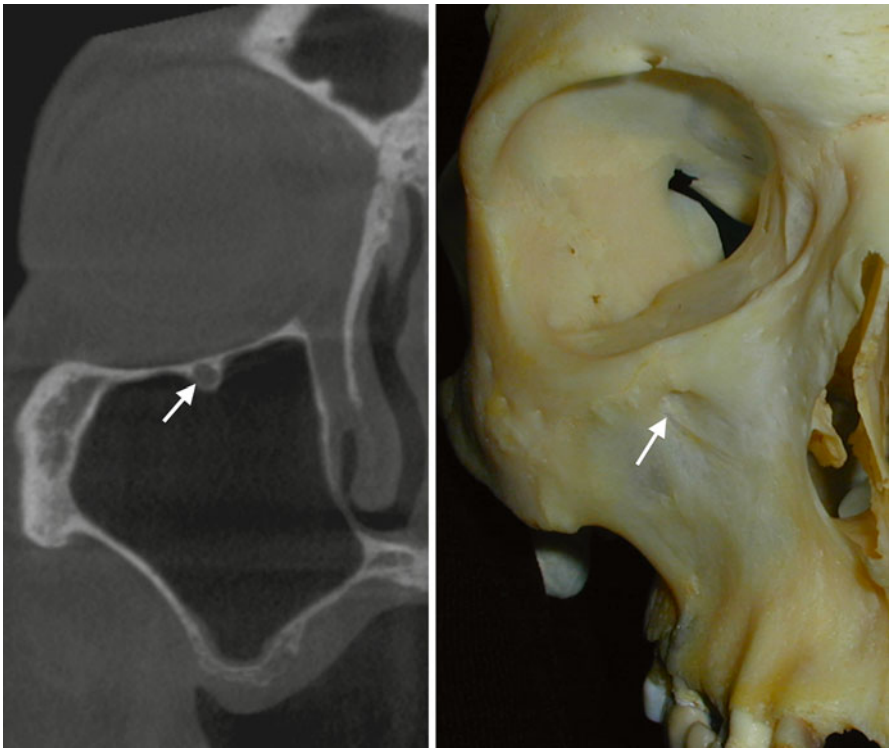


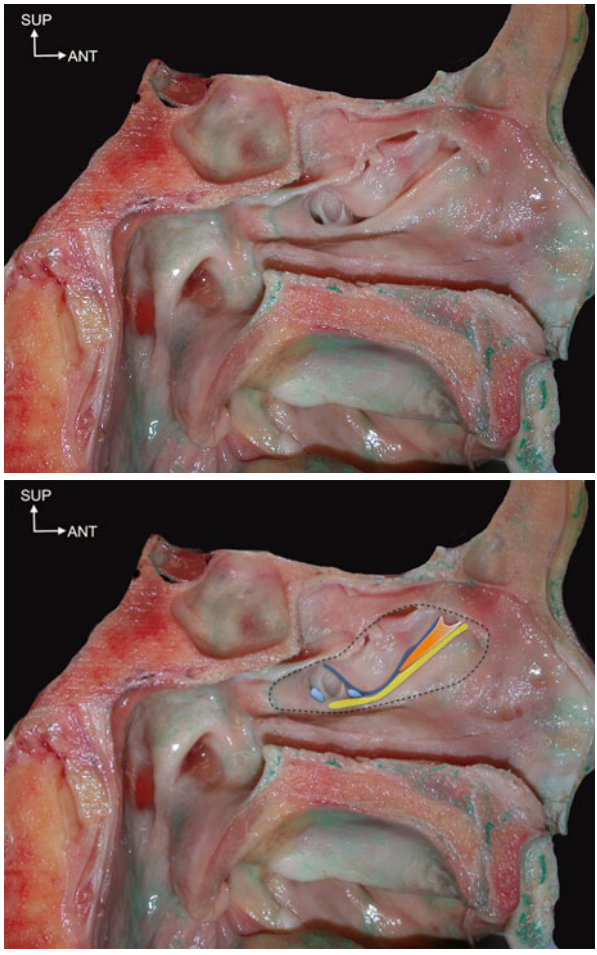
Fig. 2.6 Infraorbital canal on a coronal CT and its endpoint in the infraorbital foramen in the skull (*white arrows*)

The space under the middle turbinate is an anatomical complex with from anterior to posterior the uncinate process, the infundibulum, and the ethmoid bulla. At the inferior extremity of the infundibulum we found the oval-shaped maxillary sinus ostium. One or more accessory ostia can exist in 10 % of cases (Jog and McGarry 2003).

The middle meatus extends between the middle and the inferior conchae. The upper and anterior part of the middle meatus leads into a funnel-shaped passage that runs upward into the corresponding frontal sinus. This passage, the infundibulum, constitutes the channel of communication between the frontal sinus and the nasal cavity.

On the lateral wall of the middle meatus a deep curved groove or gutter that commences at the infundibulum and runs from above downward and posteriorly is seen. The groove is termed the hiatus semilunaris and it is the opening of the anterior ethmoid cells and the maxillary sinus. The slit-like opening of the maxillary sinus lies in the posterior part of the hiatus semilunaris (Figs. 2.7 and 2.8).

The upper boundary of the hiatus semilunaris is prominent and bulging. It is called the bulla ethmoidalis. Above the bulla is the aperture of the middle ethmoidal cells.



Figs. 2.7 and 2.8 Lateral view of the ostiomeatal complex under the middle concha (sectioned along the *dotted line*). Uncinate process (*yellow line*), infundibula (*orange zone*), ethmoid bulla (*blue line*), and two ostia of the maxillary sinus (*light blue*)

The orifice by means of which the great sinus communicates with the middle meatus lies in the medial wall of the sinus much nearer the roof than the floor, a position highly unfavorable for the escape of fluids that may collect in the cavity.

Sometimes, a second orifice circular in the outline will be found, situated lower down. When it is present it opens into the middle meatus immediately above the middle point of the attached margin of the inferior concha.

2.4 Sinus Vascularization

The maxillary sinus is embedded in numerous anastomoses of various arteries receiving blood supply, in reverse order we found the superior alveolar arteries (through the tuberosity), the greater palatine artery (posterior and medial wall), the

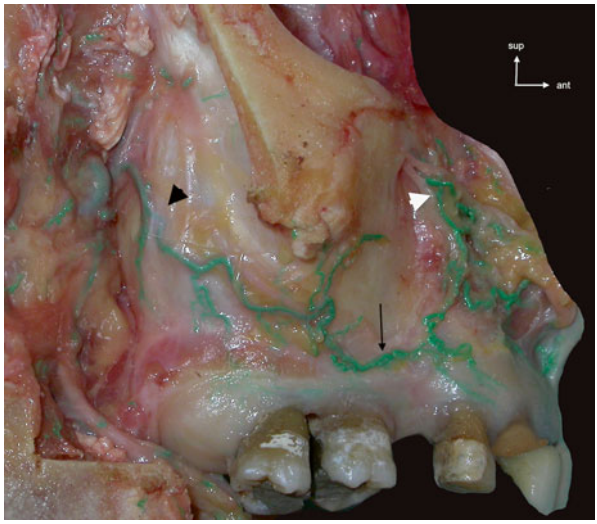


Fig. 2.9 External vascularization of the lateral walls of the maxillary sinus (arteries injected with green latex). Anastomosis (*thin arrow*) between the alveolar posterosuperior artery (*black arrowhead*) and infraorbitalis artery (*white arrowhead*)

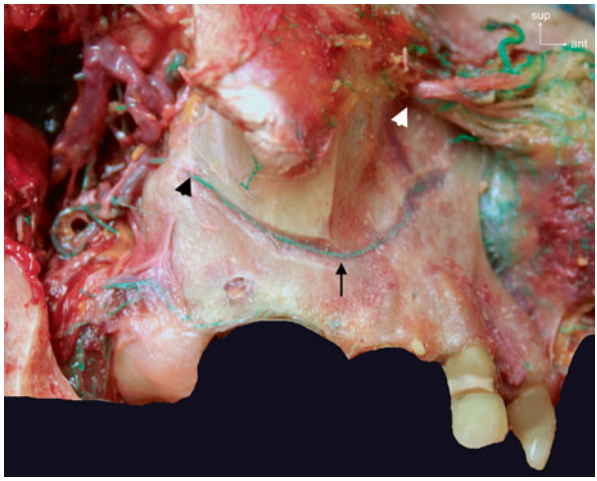


Fig. 2.10 Vascularization of the lateral walls of the maxillary sinus (arteries injected with green latex). Intraosseous anastomosis (*thin arrow*) between the alveolar posterosuperior artery (*black arrowhead*) and infraorbitalis artery (*white arrowhead*)

sphenopalatine artery, the pterygopalatine, the infraorbital artery in the anterior wall and posterior lateral nasal artery in the medial wall.

The anatomical course of the anterior maxillary wall and the alveolar process arteries is essential for sinus lift procedures. During these surgeries certain intraosseous vessels may be cut, causing bleeding complications in approximately 20 % of osteotomies (Elian et al. 2005).

Since the study by Solar et al. (1999) was published it has been well established that the lateral maxilla is supplied by the branches of the posterior superior alveolar artery and the infraorbital artery, which form two kinds of anastomosis in the lateral wall: intraosseous in 66 % of patients in Rodella et al. (2010) (Figs. 2.9 and 2.10) and in 100 % of cases in Traxler et al. (1999) (Fig. 2.11).

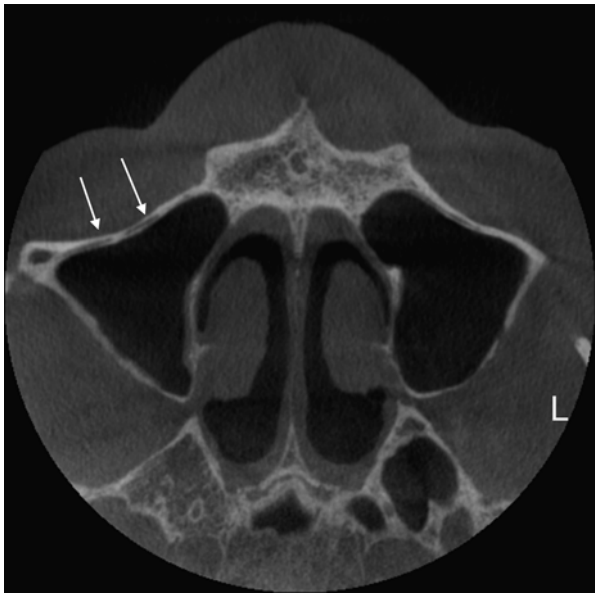


Fig. 2.11 CBCT axial section of the maxillary sinus with intraosseous artery in the canine fossa (*white arrows*)

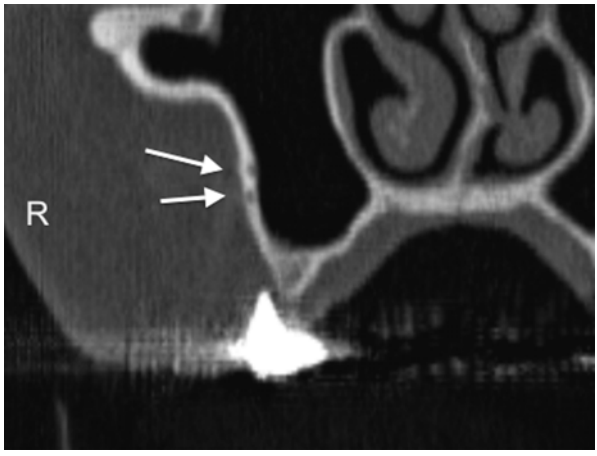


Fig. 2.12 Two intraosseous arteries in the same lateral wall of the maxillary sinus (*white arrows*)

Some variations such as two parallel arteries (Figs. 2.12 and 2.13) were found by Rodella et al. (2010) in 10 % of anatomical subjects in her study or an extraosseous anastomosis could be observed in 44 % of cases by. Traxler et al. (1999).

Arteries had a mean diameter of 1.6 mm and the mean distance between the intraosseous anastomosis and the alveolar ridge was 19 mm in anatomical studies versus 16 mm from the alveolar ridge in CT studies (Mardinger et al. 2007; Elian et al. 2005).

Only intraosseous arteries can be identified on CT in 53 % of cases (Elian et al. 2005) to 55 % (Mardinger et al. 2007) versus 100 % in cadaveric anatomical studies. CBCT studies give the same data with 52.8 % anastomosis observed by Jung et al. (2011) on CBCT of 250 patients.

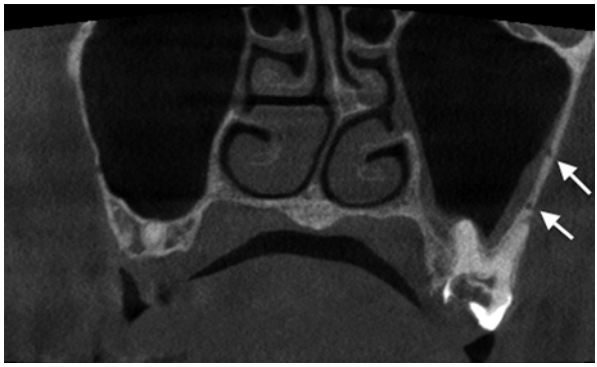


Fig. 2.13 Double intraosseous artery in the lateral wall of the maxillary sinus (*white arrows*)

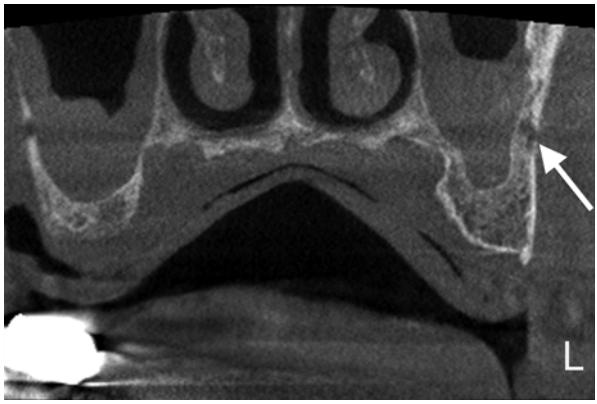


Fig. 2.14 Large intraosseous artery in the sclerotic sinus wall (*white arrows*)

Geha and Carpentier (2006) observed that intraosseous anastomosis sometimes occurs at the interface of the sinus membrane and the internal side of the sinus wall. In the case of osseous sclerosis induced by chronic sinusitis conditions, this type of anatomical variation could be embedded and finally became intraosseous and well-defined on CBCT or CT (Fig. 2.14).

The venous system is collected either by a single trunk, which is a continuation of the sphenopalatine vein, or by three venous plexuses: the anterior and posterior pterygoid plexuses, and the alveolar plexus. The anterior and posterior pterygoid plexuses converge through the lateral pterygoid muscle and connect with the alveolar plexus, which drains partly into the maxillary vein and partly into the facial vein (Dargaud et al. 2001).

2.5 Sinus Innervation

The posterior superior alveolar nerve, a branch of the infraorbital nerve, is divided into two branches, one for the tuberosity and sinus antrum and another one, the lowest, to reach the molar teeth apices.

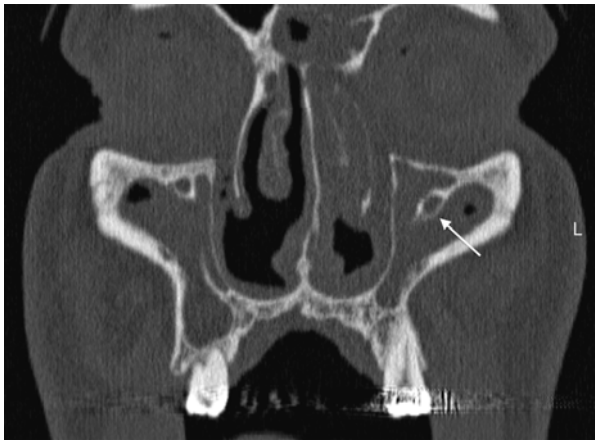


Fig. 2.15 Coronal CT view of the anatomical variation of the infraorbitalis canal (*white arrow*) detached from the orbital floor through the maxillary sinus

In the roof of the sinus, the infraorbital canal permits the passing of infraorbital sensitive nerves (Fig. 2.15) and gives off two other nerves: the middle superior alveolar nerve, not constant, coursing along the postero- or anterolateral wall of the sinus to the premolar apices; and the anterior superior alveolar nerve, given off 15 mm before the infraorbital foramen, for the incisal and canine apices. These nerves can sometimes cross the surgical way of the sinus lift procedures in the canine fossa (Fig. 2.16). Some neuropathic pain can result from the section and aberrant healing of these nerves during this type or surgery (Hillerup 2007).

2.6 Anatomical Variations

2.6.1 Maxillary Sinus Size and Volume

The maxillary sinus shows considerable variations in some cases limited to the maxillary area or it communicates with other facial bones. In humans, the volume of the maxillary sinus is close to 15 cm^3. CT studies in various populations show variations within a large range. Uchida et al. (1998) on 38 sinus CTs found an average volume of 13.6 ± 6.4 cm^3 within a range from 3.3 to 31.8 cm^3. In other populations, Sahlstrand-Johnson et al. (2011), in her study of 110 sinus CTs, found that the maxillary sinuses are larger in males than in females (18 vs 14.1 cm^3) with a mean volume of 15.7 ± 5.3 cm^3 and a range 5 to 34 cm^3. Thus, if the maxillary sinus varies extremely in size, the authors cannot find any statistical correlation between this volume and with age, but only sinus pneumatization increasing with tooth loss.

According to the literature, the dimensions of the sinus vary and range from 22.7 to 35 mm in mesiodistal width, 36–45 mm in vertical height, and 38–45 mm deep anteroposteriorly (van den Bergh et al. 2000; Uthman et al. 2011; Teke et al. 2007).

In some rare cases, we have found an hypoplasia of the maxillary sinus sometimes misdiagnosed as chronic sinusitis on panoramic radiographs (Figs. 2.17 and 2.18).

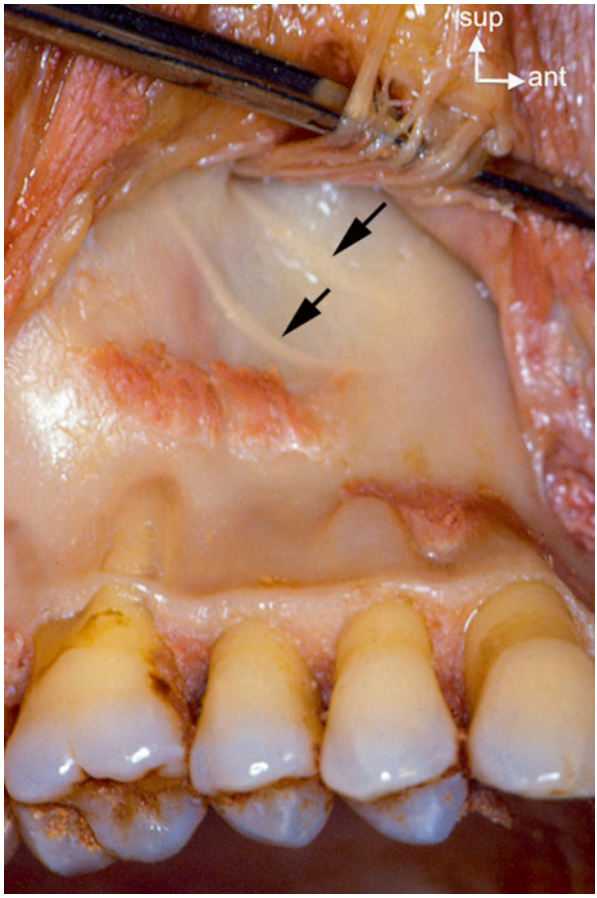


Fig. 2.16 Anatomical view of the canine fossa in the anterior lateral wall of the maxillary sinus with the passage of anterior and middle superior alveolar nerves (*arrows*)

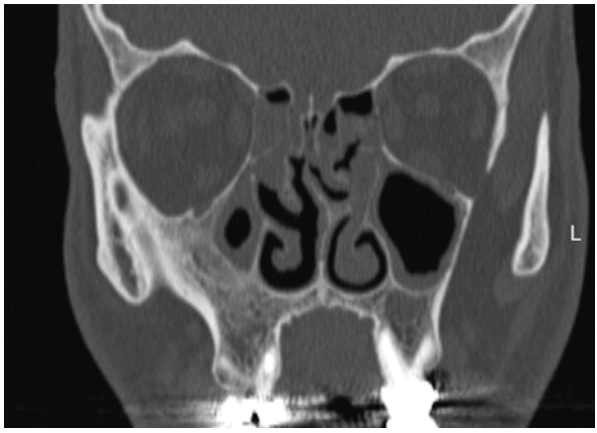


Fig. 2.17 Coronal CT view of the right microsinus

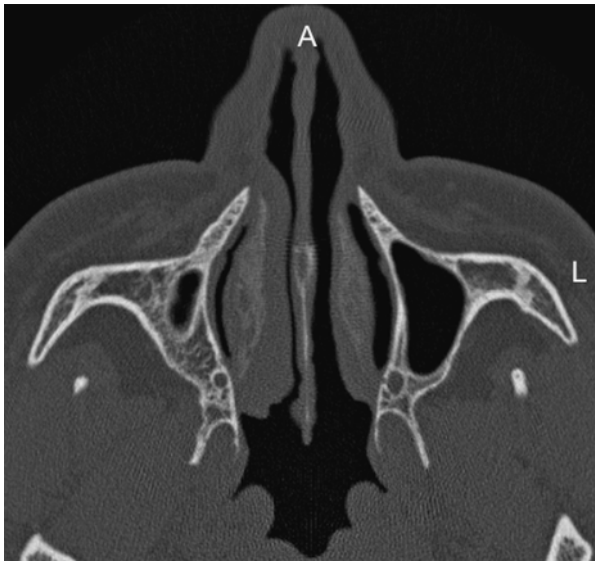


Fig. 2.18 Axial CT image of the right microsinus

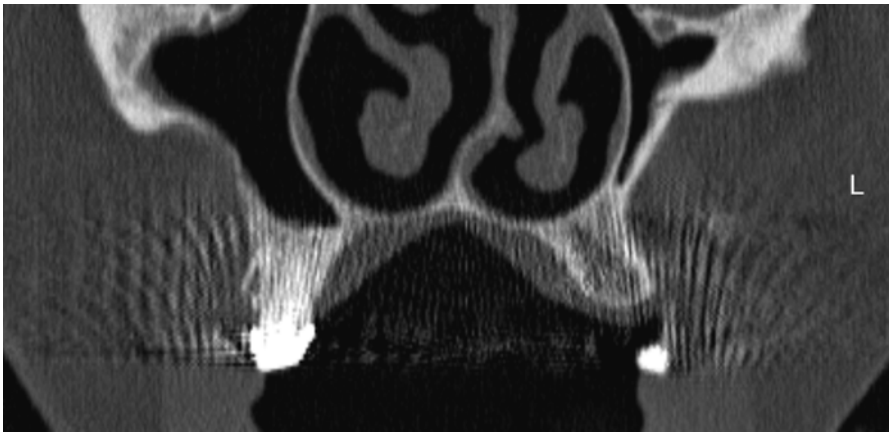


Fig. 2.19 Close proximity of the internal and external walls of the left maxillary sinus (coronal CT scan view)

Some authors have found a prevalence of unilateral hypoplasia of 7 % on CT (Kantarci et al. 2004) to 10.4 % (Bolger et al. 1990). This hypoplasia may be related to the aberrant anatomy of the uncinate process.

Computed tomography or CBCT could be used to evaluate the distance between the medial and lateral walls of the maxillary sinus before surgery to prevent sinus membrane perforation and estimate the volume of grafting material (Fig. 2.19). In radiological studies the minimal width ranged from 12 mm (Sahlstrand-Johnson et al. 2011) to 13.4 mm at half-height (Uthman et al. 2011). Angulation formed

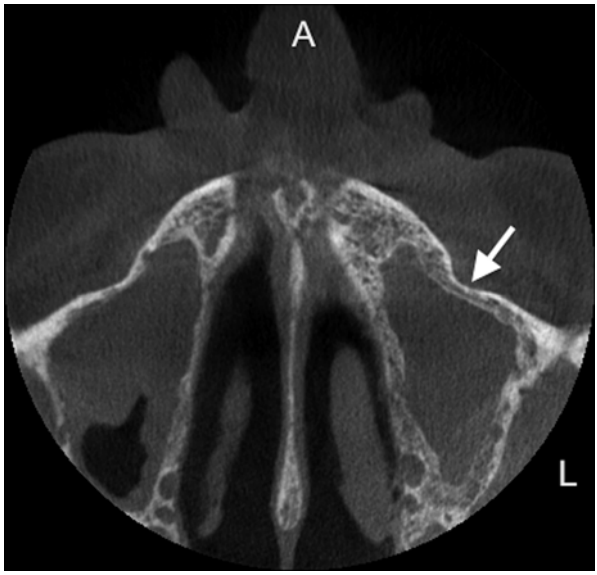


Fig. 2.20 Axial CBCT image of the sclerotic walls of the left maxillary sinus in this case of chronic sinusitis (*white arrow*)

between these two walls constituted for Cho et al. 2001 a factor of increasing risk of membrane perforation. They found a significant positive correlation if the angle was 30° or less in 37.5 % of cases of perforation

2.6.2 Sinus Walls

Extreme pneumatization of the maxillary sinus can increase the volume and thinning of the sinus wall. At the canine fossa, with the Caldwell–Luc method of sinus surgery, the bone thickness reported by Kawarai et al. 1999 was 1.1 mm ± 0.4 mm.

In the case of chronic sinusitis, the inflammatory process of the soft tissue can create a wall thickening in 97.3 % of cases with 2.6-mm wall thickness on average in diseased sinuses (Joshua et al. 2013) and 2.0 ± 0.9 mm vs 0.98 ± 0.2 mm in the control group (Fig. 2.20) (Deeb et al. 2011).

2.6.3 Septa

The presence of septa at the inner surface of the maxillary cavity is a frequent cause of Schneiderian membrane perforation during sinus lift surgery and complicates the luxation of the lateral window.

Preoperative evaluation by CBCT or CT of septa led to modifications of the surgical approach (Krennmair et al. 1997; Betts and Miloro 1994).

In some cases high septa lead to partial or complete division of the sinus cavity (Fig. 2.21).

We can found numerous anatomical, radiological or surgical studies on the prevalence, location, and size of the maxillary sinus septa.

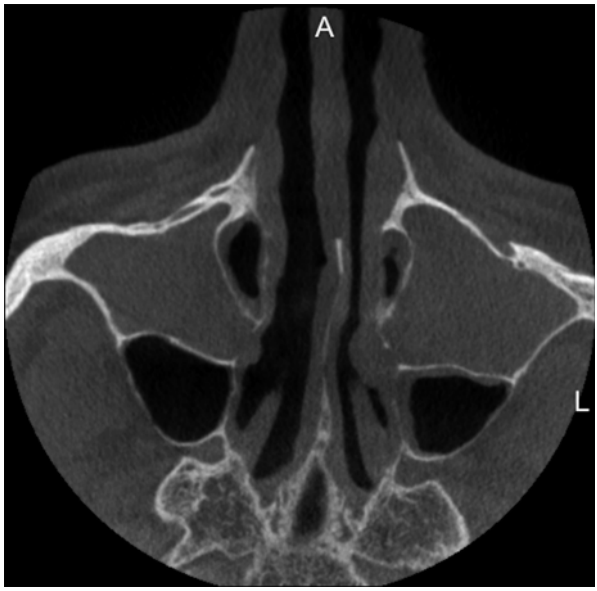


Fig. 2.21 Complete bilateral septa in the maxillary sinus with mucosal hyperplasia only in the anterior compartment

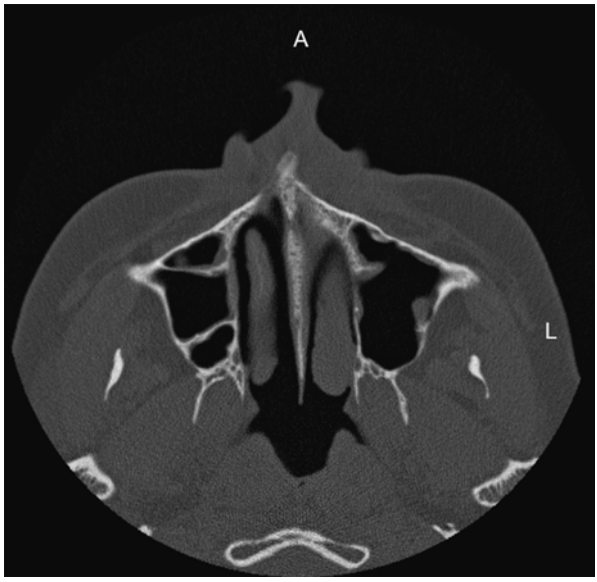


Fig. 2.22 Axial CT image of multiple septa inside the maxillary sinuses

Defined by Ogle et al. (2012) as a strut of bone that is at least 2.5 mm in height, they divided the septa into primary septa, which are found between the roots of the second premolar and first molar, between the first and second molar, or distal to the roots of the third molar, and the secondary septa, which are caused by pneumatization following dental extractions (Fig. 2.22).

Since the study by Underwood (1910), the prevalence of septa observed in anatomical studies has varied from 18.5 % (Krennmair et al. 1997) to 39 % (Ella et al. 2008).

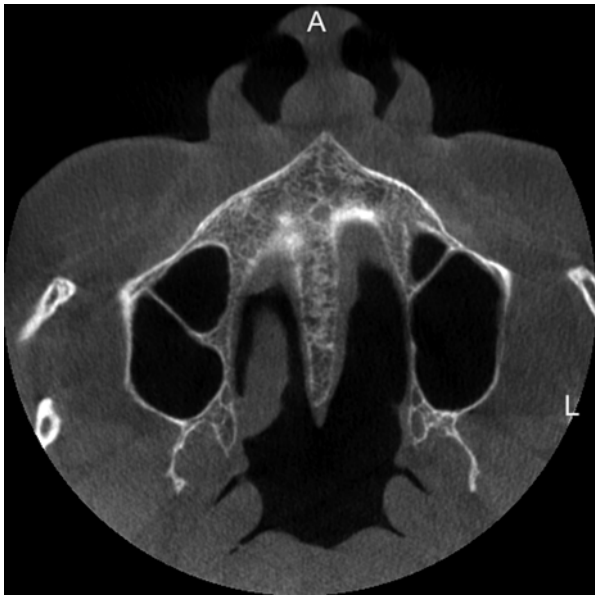


Fig. 2.23 Axial CT image of the posteriorly oriented maxillary sinus septa

In surgical or clinical observation studies, this prevalence is about 27.7 % according to Krennmair et al. (1997) and 57.6 % for Jensen and Greer (1992) in only 26 patients.

However, it is essentially by CT studies that septa could be evaluated before surgery. The literature shows more than 20 radiological studies in 2D and 3D, from panoramic radiographs to CT and CBCT, with a large range of prevalence in different populations, since Lugmayr et al. in 1996, who found 13 % of septa in a study of 200 CTs of the sinus to Orhan et al. (2013) with 58 % of septa in CBCTs of 554 sinuses.

Maestre–Ferrin et al. (2011) showed in a comparative study that panoramic radiographs vs CTs than 2D images (conventional radiographs) led to an erroneous diagnosis in 46.5 %.

Frequently, only one sinus presents a septum (24.6 % in one sinus and 13.7 % in two according to Neugebauer et al. 2010). 8.7 % of their patients had up to three septa per sinus in a large series of 1,029 patients. However, van Zyl and van Heerden (2009) observed multiple septa in 64 % of patients presenting this anatomical configuration.

It is necessary to note that results from the literature can vary with the methods used to identify and determine the minimum height of a bony structure, image resolution (best resolution with CBCT vs CT), and the definition of septa criteria.

The mean septal height observed in CBCT was: 7.3 ± 5.08 mm in 74.7 % of cases according to Neugebauer et al. (2010), with a maximum of 36 mm.

The middle and posterior regions of the sinus are the most frequent locations of septa; 76.9 % of the septa in the study by Neugebauer et al. (2010) are found in the molar region, 66.6 % according to Koymen et al. (2009).

In the large majority, septa orientation was found transversally in a buccopalatal direction (74.7 % for Neugebauer et al. 2010), but sagittal orientation is also seen and varies from 3.7 % (Park et al. 2011) to 25.3 % of cases (Neugebauer et al. 2010) (Figs. 2.23 and 2.24).

A recent review of the literature by Wen et al. (2013) led to the proposal of a first sinus septa classification and treatment approach based on the difficulties defined by

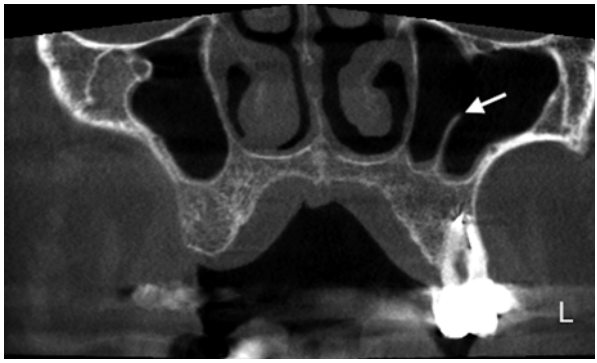


Fig. 2.24 Frontal view on CT of the anteroposterior septa of the left maxillary sinus (*white arrow*) forming a barrier inside the sinus

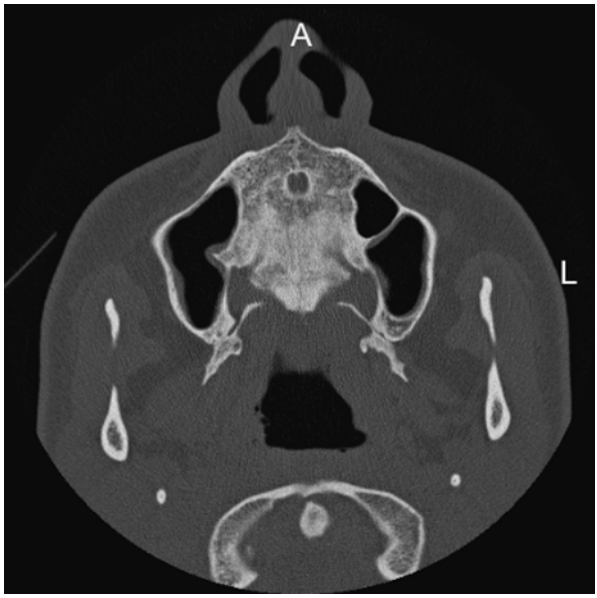


Fig. 2.25 Axial CT of a patient with a sinus septum behind the canine fossa, the surgical method for sinus lift

location of septa, number, size (greater or smaller than 6 mm), and orientation (mediolateral or anteroposterior; Figs. 2.25, 2.26, and 2.27).

Anatomical variations of the nasal cavity and ostiomeatal complex can lead to or increase the risk of sinusitis after surgery (Marsot Dupuch and Meyer 2001).

All of them should be evaluated on CBCT or CT before intervention, and not only the permeability of the maxillary sinus ostia, but all the anatomical conditions leading to a narrowing of these ostia.

We found:

- Narrowing of the infundibulum by Haller's cells from the ethmoid on the internal and inferior wall of the orbit (Fig. 2.28).
- Laterally deviated uncinate process, sometimes pneumatized (rare variation 1–2 % by extension of anterior ethmoid cells into the uncinate process).

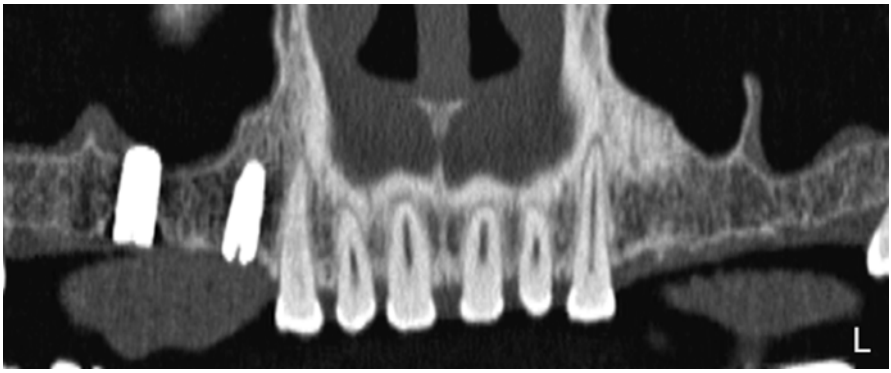


Fig. 2.26 Panoramic CT of a patient with a sinus septum behind the canine fossa, the surgical method for sinus lift

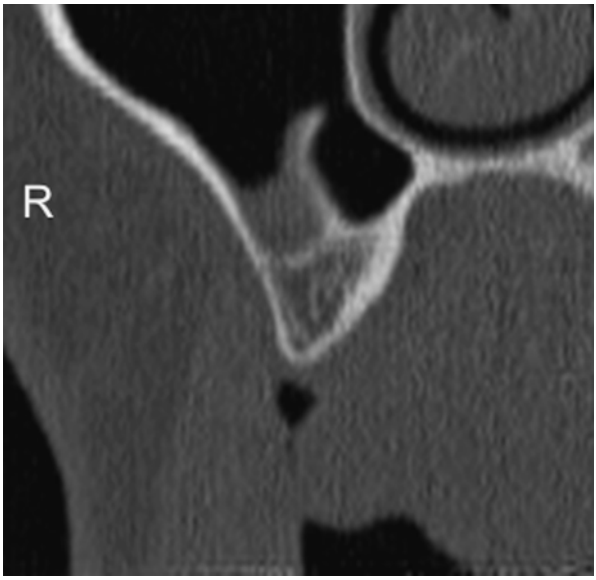


Fig. 2.27 Coronal CT of a patient with a sinus septum behind the canine fossa, surgical method for sinus lift

- Concha bullosa by pneumatization of the middle turbinate present in 30 % of the population. This variation reduces the middle meatus and mucociliary clearance (Fig. 2.29).
- Paradoxal (i.e., inverted) convexity or rotation of the middle turbinate in 11 % of the population (Fig. 2.30).
- Septal deviation in the nasal cavity and bony spicules (Fig. 2.31).

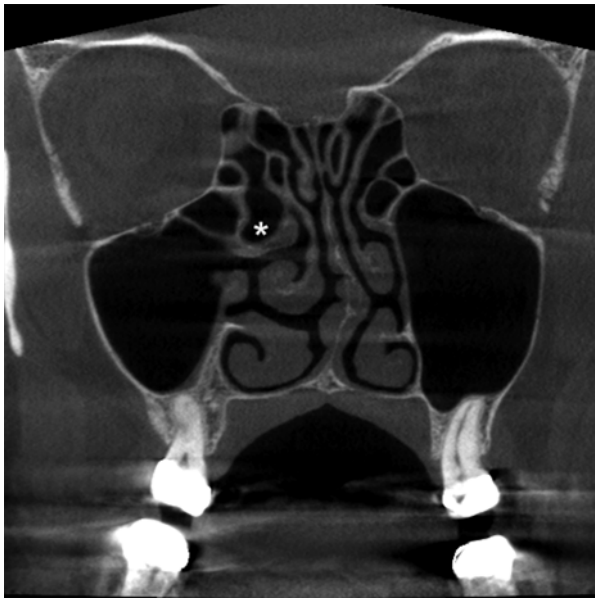


Fig. 2.28 Coronal CBCT view of the procidence of the anterior ethmoidal cells (*asterisk*) above the maxillary sinus ostia

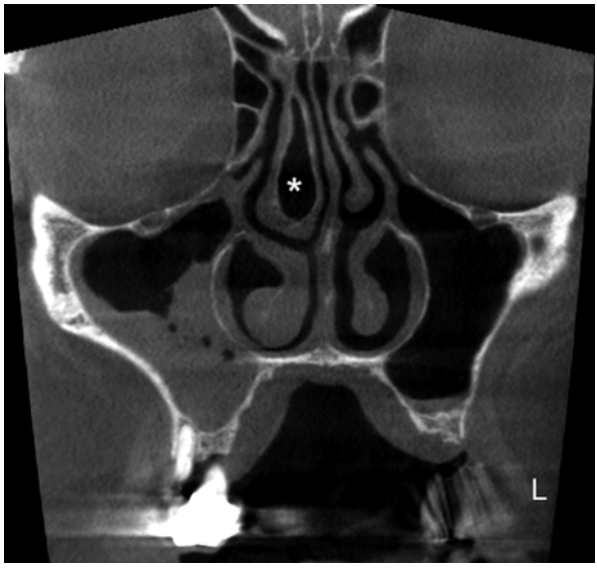


Fig. 2.29 Coronal CBCT view of concha bullosa (*asterisk*) of the right middle turbinate

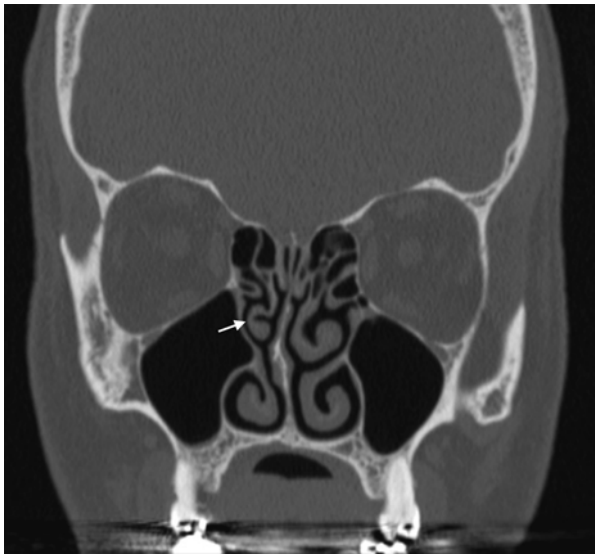


Fig. 2.30 CT, coronal view of the patient with the right middle turbinate inverted (*arrow*)

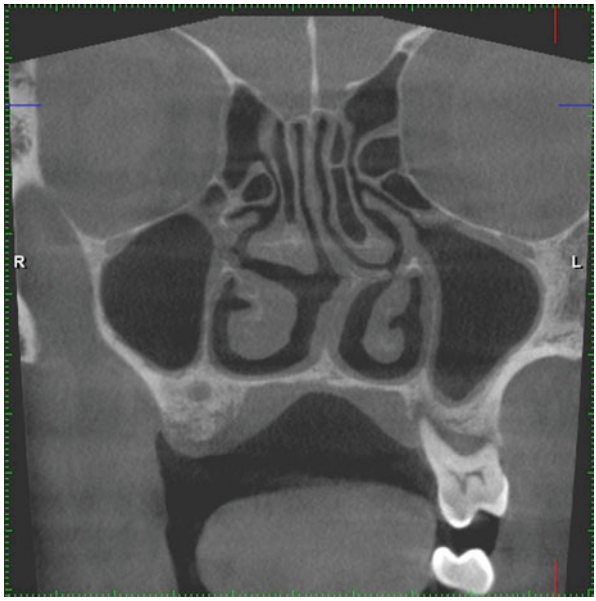


Fig. 2.31 Septal deviation in left nasal cavity

References

Betts NJ, Miloro M (1994) Modification of the sinus lift procedure for septa in the maxillary antrum. J Oral Maxillofac Surg 52(3):332–333

Bolger WE, Woodruff WW Jr, Morehead J, Parsons DS (1990) Maxillary sinus hypoplasia: classification and description of associated uncinate process hypoplasia. Otolaryngol Head Neck Surg 103((5(Pt 1))):759–765

Bremer JL (1940) The pneumatization of the head of the common fowl. J Morphol 67:143–157
Cho SC, Wallace SS, Froum SJ, Tarnow DP (2001) Influence of anatomy on Schneiderian membrane perforations during sinus elevation surgery: three-dimensional analysis. Pract Proced Aesthet Dent 13(2):160–163
Dargaud J, Lamotte C, Dainotti JP, Morin A (2001) Venous drainage and innervation of the maxillary sinus. Morphologie 85(270):11–13
Davis WE, Templer J, Parsons DS (1996) Anatomy of the paranasal sinuses. Otolaryngol Clin North Am 29(1):57–74
Deeb R, Malani PN, Gill B, Jafari-Khouzani K, Soltanian-Zadeh H, Patel S, Zacharek MA (2011) Three-dimensional volumetric measurements and analysis of the maxillary sinus. Am J Rhinol Allergy 25(3):152–156
Drettner B (1979) The role of the nose in the functional unit of the respiratory system. Rhinology 17(1):3–11
Elian N, Wallace S, Cho SC, Jalbout ZN, Froum S (2005) Distribution of the maxillary artery as it relates to sinus floor augmentation. Int J Oral Maxillofac Implants 20(5):784–787
Ella B, Sédarat C, Noble Rda C, Normand E, Lauverjat Y, Siberchicot F, Caix P, Zwetyenga N (2008) Vascular connections of the lateral wall of the sinus: surgical effect in sinus augmentation. Int J Oral Maxillofac Implants 23(6):1047–1052
Enlow DH (1968) Wolff's law and the factor of architectonic circumstance. Am J Orthod 54(11):803–822
Geha N, Carpentier P (2006) Les boucles artérielles du sinus maxillaire. J Paradontol Implantol Orale 25(2):127–141
Hillerup S (2007) Iatrogenic injury to oral branches of the trigeminal nerve: records of 449 cases. Clin Oral Investig 11(2):133–142
Jensen OT, Greer R (1992) Immediate placement of osseointegrating implants into the maxillary sinus augmented with mineralized cancellous allograft and Gore-Tex: second-stage surgical and histologic findings. In: Laney WR, Tolman DE (eds) Tissue integration in oral orthopedic and maxillofacial reconstruction. Quintessence, Chicago, pp 321–333
Jog M, McGarry GW (2003) How frequent are accessory sinus ostia? J Laryngol Otol 117:270–272
Joshua BZ, Sachs O, Shelef I, Vardy-Sion N, Novack L, Vaiman M, Puterman M (2013) Comparison of clinical data, CT, and bone histopathology in unilateral chronic maxillary sinusitis. Otolaryngol Head Neck Surg 148(1):145–150
Jung J, Yim JH, Kwon YD, Al-Nawas B, Kim GT, Choi BJ, Lee DW (2011) A radiographic study of the position and prevalence of the maxillary arterial endosseous anastomosis using cone beam computed tomography. Int J Oral Maxillofac Implants 26(6):1273–1278
Kantarci M, Karasen RM, Alper F, Onbas O, Okur A, Karaman A (2004) Remarkable anatomic variations in paranasal sinus region and their clinical importance. Eur J Radiol 50(3):296–302
Kawarai Y, Fukushima K, Ogawa T, Nishizaki K, Gunduz M, Fujimoto M, Masuda Y (1999) Volume quantification of healthy paranasal cavity by three-dimensional CT imaging. Acta Otolaryngol Suppl 540:45–49
Koymen R, Gocmen-Mas N, Karacayli U, Ortakoglu K, Ozen T, Yazici AC (2009) Anatomic evaluation of maxillary sinus septa: surgery and radiology. Clin Anat 22(5):563–570
Krennmair G, Ulm C, Lugmayr H (1997) Maxillary sinus septa: incidence, morphology and clinical implications. J Craniomaxillofac Surg 25(5):261–265
Lawson W, Patel ZM, Lin FY (2008) The development and pathologic processes that influence maxillary sinus pneumatization. Anat Rec (Hoboken) 291(11):1554–1563
Leakey M, Walker A (1997) Early hominid fossils from Africa. Sci Am 276(6):74–79
Lugmayr H, Krennmair G, Holzer H (1996) The morphology and incidence of maxillary sinus septa. Rofo 165(5):452–454
Maestre-Ferrín L, Carrillo-García C, Galán-Gil S, Peñarrocha-Diago M, Peñarrocha-Diago M (2011) Prevalence, location, and size of maxillary sinus septa: panoramic radiograph versus computed tomography scan. J Oral Maxillofac Surg 69(2):507–511
Mardinger O, Abba M, Hirshberg A, Schwartz-Arad D (2007) Prevalence, diameter and course of the maxillary intraosseous vascular canal with relation to sinus augmentation procedure: a radiographic study. Int J Oral Maxillofac Surg 36(8):735–738

Marsot Dupuch K, Meyer B (2001) Les variantes anatomiques des sinus de la face. In: Marsot Dupuch K (ed) Les sinus de la clinique à l'image. Sauramps Médical, Montpellier

Neugebauer J, Ritter L, Mischkowski RA, Dreiseidler T, Scherer P, Ketterle M, Rothamel D, Zöller JE (2010) Evaluation of maxillary sinus anatomy by cone-beam CT prior to sinus floor elevation. Int J Oral Maxillofac Implants 25(2):258–265

O'Malley JF (1924) Evolution of the nasal cavities and sinuses in relation to function. J Laryngol Otol 39:57–64

Ogle OE, Weinstock RJ, Friedman E (2012) Surgical anatomy of the nasal cavity and paranasal sinuses. Oral Maxillofac Surg Clin North Am 24(2):155–166

Onodi A (1908) The optic nerve and the accessory cavities of the nose. Contribution to the study of canalicular neuritis and atrophy of the optic nerves of nasal origin. Ann Otol Rhinol Otolaryngol 18:1–52

Orhan K, Kusakci Seker B, Aksoy S, Bayindir H, Berberoğlu A, Seker E (2013) Cone beam CT evaluation of maxillary sinus septa prevalence, height, location and morphology in children and an adult population. Med Princ Pract 22(1):47–53

Park YB, Jeon HS, Shim JS, Lee KW, Moon HS (2011) Analysis of the anatomy of the maxillary sinus septum using 3-dimensional computed tomography. J Oral Maxillofac Surg 69(4):1070–1078

Pogrel MA, Kaplan MJ (1986) Surgical approach to the pterygomaxillary region. J Oral Maxillofac Surg 44(3):183–187

Regev E, Smith RA, Perrott DH, Pogrel MA (1995) Maxillary sinus complications related to endosseous implants. Int J Oral Maxillofac Implants 10(4):451–461

Rodella LF, Labanca M, Boninsegna R, Favero G, Tschabitscher M, Rezzani R (2010) Intraosseous anastomosis in the maxillary sinus. Minerva Stomatol 59(6):349–354

Rui R, Den L, Gourlaouen L (1960) Contribution à l'étude du rôle des sinus paranasaux. Rev Laryngol Otol Rhinol (Bord) 81:796–839

Sahlstrand-Johnson P, Jannert M, Strömbeck A, Abul-Kasim K (2011) Computed tomography measurements of different dimensions of maxillary and frontal sinuses. BMC Med Imaging 11:8

Solar P, Geyerhofer U, Traxler H, Windisch A, Ulm C, Watzek G (1999) Blood supply to the maxillary sinus relevant to sinus floor elevation procedures. Clin Oral Implants Res 10(1):34–44

Teke HY, Duran S, Canturk N, Canturk G (2007) Determination of gender by measuring the size of the maxillary sinuses in computerized tomography scans. Surg Radiol Anat 29(1):9–13

Traxler H, Windisch A, Geyerhofer U, Surd R, Solar P, Firbas W (1999) Arterial blood supply of the maxillary sinus. Clin Anat 12(6):417–421

Uchida Y, Goto M, Katsuki T, Soejima Y (1998) Measurement of maxillary sinus volume using computerized tomographic images. Int J Oral Maxillofac Implants 13(6):811–818

Underwood AS (1910) An inquiry into the anatomy and pathology of the maxillary sinus. J Anat Physiol 5:354

Uthman AT, Al-Rawi NH, Al-Naaimi AS, Al-Timimi JF (2011) Evaluation of maxillary sinus dimensions in gender determination using helical CT scanning. J Forensic Sci 56(2):403–408

van den Bergh JP, ten Bruggenkate CM, Disch FJ, Tuinzing DB (2000) Anatomical aspects of sinus floor elevations. Clin Oral Implants Res 11(3):256–265

van Zyl AW, van Heerden WF (2009) A retrospective analysis of maxillary sinus septa on reformatted computerised tomography scans. Clin Oral Implants Res 20(12):1398–1401

Wang RG, Jiang SC, Gu R (1994) The cartilaginous nasal capsule and embryonic development of human paranasal sinuses. J Otolaryngol 23(4):239–243

Wen SC, Chan HL, Wang HL (2013) Classification and management of antral septa formaxillary sinus augmentation. Int J Periodontics Restorative Dent 33(4):509–517

Zuckerkandl E (1885) Anatomie normale et pathologique des fosses nasales et de leurs annexes pneumatiques. Masson, Paris

Clinical and Radiological Assessment and Planning in Sinus Floor Elevation

3

Ibrahim Nasseh and Ronald Younes

Contents

I. Nasseh, DDS, PhD, MBA (✉)
Department of DentoMaxilloFacial Radiology and Imaging,
Lebanese University, School of Dentistry, Beirut, Lebanon
e-mail: ibrahim.nasseh@gmail.com

R. Younes, DDS, PhD
Department of Oral Surgery, Faculty of Dentistry,
St Joseph University, Beirut, Lebanon
e-mail: ronald.younes@usj.edu.lb, ronald.younes@hotmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_3

3.1 Introduction

With relatively invasive surgical techniques such as sinus floor elevation (SFE) procedures, a precise clinical and radiographic diagnosis is required to perform a convenient dental implant planning.

Panoramic radiographs are routinely used as preoperative imaging evaluation to plan maxillary implant rehabilitation. This technique is more useful than periapical radiographs for complete visualization of the maxillary sinus and evaluation of the remaining alveolar bone.

However, panoramic has inherent limitations for the three-dimensional (3D) visualization of the anatomical structures and related pathologies.

Computed tomography (CT), and more recently cone beam CT (CBCT), can precisely visualize the sinus complexity in 3D, with low irradiation to the patient.

The purpose of this chapter is to:

- Present the different radiographic techniques available, with the advantages and limitations of each.
- Present to surgeons and practitioners the radiographic appearance of the maxillary sinus in multiple orientation scanning and the key features influencing the decision-making for a predictable SFE.
- Be familiar with the pre-, per-, and post-radiographic parameters of a successful SFE.

3.2 Radiographic Techniques for the Maxillary Sinus

Multiple projections are necessary to exhibit all areas of the maxillary sinus clearly. Although a number of sinus projections have been described, radiologists fail to agree on the number of projections needed for adequate and complete sinus visualization.

3.2.1 The Periapical Radiograph

The intraoral periapical radiograph provides the most detailed, though limited, view of the floor of the maxillary antrum. It is considered as the first step before further radiographic techniques are performed.

3.2.2 The Panoramic Radiograph

The panoramic radiograph shows both maxillary sinuses, revealing larger internal structure than the periapical image and parts of the inferior, posterior, and anteromedial walls. It is not recommended to compare the internal radiopacities of the right and left sinus in the panoramic image because of variations that result from overlapping phantom images of other structures.

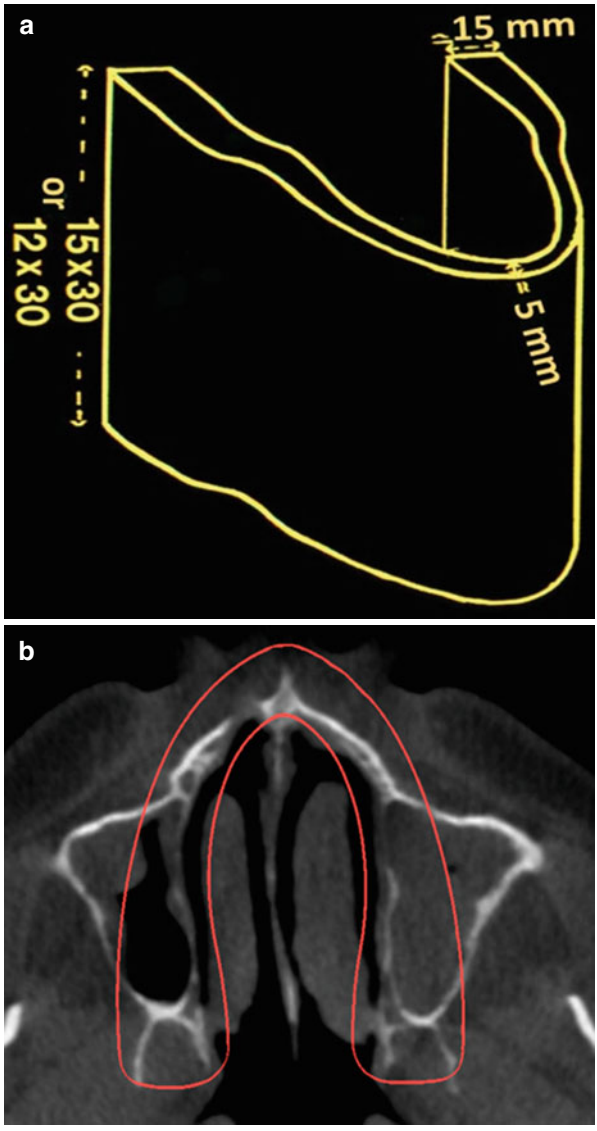


Fig. 3.1 (**a**) Usual dimensions and form of a panoramic focal trough. (**b**) The slice thickness does not cover the entire volume of the maxillary sinus

The panoramic technique is based on tomographic section, which thickness matches the convexity of the mandibular arches. The slice thickness, or focal trough, thus sharpening the image of anatomical structures concerned, is of the order of 25 mm maximum in the molar regions to decrease gradually towards the incisor region where it reached on average 5–10 mm (Fig. 3.1a).

If one considers that the average depth of the maxillary sinus is approximately 40–50 mm, panoramic image could ignore pathological formations of posterior topography or in the internal sinus parts (“false negative”) (Fig. 3.1b).

That is why it is considered that panoramic image does not allow reliable or complete radiological representation of the maxillary sinuses even if it is the starting point of every sinus examination (Chomenko 1985).

On another side, it has been established that panoramic views of the posterior maxilla will underestimate the amount of bone available for implant placement and will therefore overestimate the number of clinical situations requiring SFE.

3.2.3 The Waters' View

Specialized skull views are usually the next step in the sinus exploration. The standard series of conventional plain film techniques include the occipitomental (Waters), lateral, submentovertex, and Caldwell (PA) skull views.

The most interesting one remains the Waters projection. It is optimal for visualization of the maxillary sinuses, especially to compare internal radiopacities, as well as the frontal sinuses and ethmoid air cells. If the Waters' view is made with the mouth open, the sphenoid sinuses may also be visualized. Table 3.1 shows the differences between periapical, panoramic, and Waters projections (Chomenko 1985).

Although the Waters' view visualizes the maxillary sinus better than any other view, it fails to delineate the anterior and posterior sinus walls because they overlap. Also, the relationship of the sinus floor to teeth is poorly demonstrated. Table 3.2 is a comparison between panoramic and Waters' view (Chomenko 1985).

Table 3.1 Sinus area best demonstrated by panoramic, Waters, and periapical projections (Chomenko 1985)

View	Sinus area best seen
Periapical (or occlusal films)	Relationship of teeth to sinus floor.
Panoramic	Inferior wall (floor), teeth-sinus relationship.
Waters	Medial wall, boundary of anterior and posterior walls, medial and lateral extents.

Table 3.2 Comparison of panoramic and Waters' view for maxillary sinuses (Chomenko 1985)

Panoramic	Waters' view
Actual anatomic boundaries of sinus not seen	Lateral and medial walls form, respectively, lateral and medial sinus outlines on film
Anterior, posterior, and medial walls not seen	Lateral wall distinguished from medial wall
Tooth-sinus relationship shown clearly	Tooth-sinus relationship obscured
Shadow superimposition of nasal structure	No superimposition of nasal structure
Radiographic variation between right and left sinuses considerable	Radiographic comparison between right and left sinuses possible
Anteroposterior aspect of sinus depicted (standard position)	Mediolateral aspect of sinus depicted

3.2.4 Computed Tomography and Cone Beam Computed Tomography

Computed tomography (CT) is replacing conventional tomography for investigations and evaluation of sinus diseases because it offers considerable advantages over them. It is now considered an essential presurgical diagnostic method.

Because CT provides multiple sections through the sinuses in different planes with high-resolution images, they contribute significantly to delineate the extent of disease and the final diagnosis. CT examination is appropriate to determine the extent of disease, for superior visualization of the ostiomeatal complex (the region of the ostium of the maxillary sinus and the ethmoidal ostium) and nasal cavities, as well as for demonstrating any reaction in the surrounding bone to sinus disease.

Although CT is considered as the "gold standard" in imaging for visualization of the maxillary sinus, since the late 1990s, cone beam computed tomography (CBCT) is gaining increasing popularity in this respect (Bremke et al. 2009; Cakli et al. 2012; Fatterpekar et al. 2008; Ziegler et al. 2002). In implant dentistry, recent guidelines recommend the use of CBCT for three-dimensional treatment planning, especially prior to SFE – for evaluating both residual alveolar and sinus conditions (Benavides et al. 2012; Harris et al. 2012).

CBCT provides a three-dimensional volumetric dataset with an isotropic resolution of 300/400 μm. The geometric accuracy and the resolution are sufficient for clinical usage and comparable to a CT image with however a lower dose than that of a CT examination of the same region.

3.2.5 Magnetic Resonance Imaging

MRI provides superior visualization of the soft tissues, especially the extension of infiltrating neoplasms into the sinuses or surrounding soft tissues, or the differentiation of retained fluid secretions from soft tissue masses in the sinuses.

3.3 What to Look for on a CBCT Examination?

If a SFE procedure is indicated, a variety of anatomical factors may influence the decision, design of the lateral window and choice of graft material. Information on bone density, bone cortical walls, and bone resorption in the alveolar processes is important for planning functionally and aesthetically optimal prosthetic treatment. Information on associated dental-sinus pathologies is also important.

3.3.1 Sinus Condition

The first thing to look at is the density of the sinus. A normal sinus will appear as a low-density homogenous cavity.

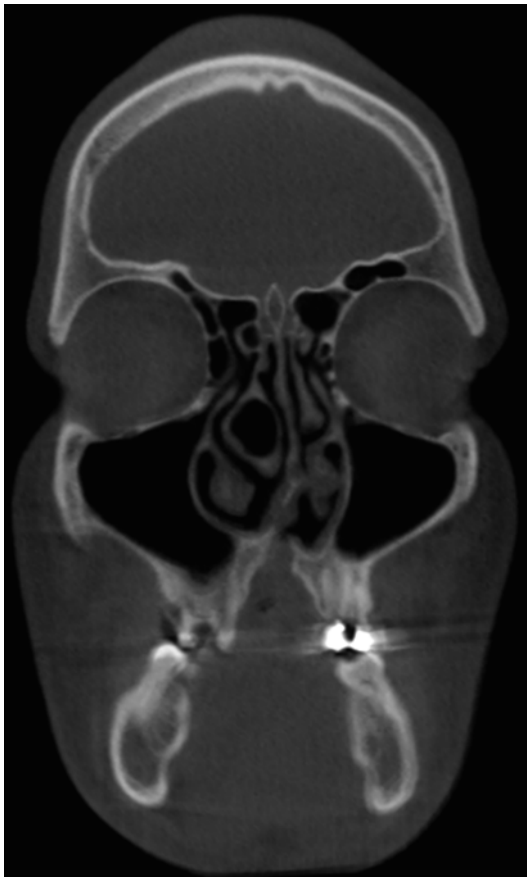


Fig. 3.2 The osteomeatal complex

3.3.2 Ostium

The maxillary sinus communicates with the homolateral nasal fossa by means of a natural ostium located posterosuperiorly on the medial surface (Fig. 3.2).

Determining the position and the integrity of the osteomeatal complex is essential when planning SFE procedures.

The mesiobuccal and medial bone walls are the ones most often involved in SFE. An accessory ostium may sometimes be found on the medial wall. When this occurs, it should be identified before any maxillary sinus-elevation procedure is performed, to avoid detaching the mucosa up to this point.

Unfortunately, a small "field of view" (FOV) is often used to visualize only the inferior part of the maxillary sinus and its relation to the remaining bone where implants will be placed. Guidelines suggest that extending the FOV to include the osteomeatal complex may be justified to avoid postoperative complications resulting from a compromised drainage system (Harris et al. 2012). An adequate FOV in CBCT technique should allow precise evaluation of its numerous components,

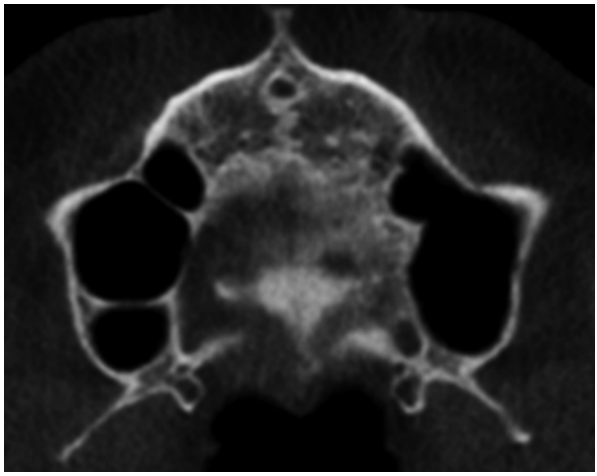


Fig. 3.3 Axial view – double septa in the right maxillary sinus

revealing any irregularities in development (e.g., conchae bullosa, septum deviation, or inflammation involving the maxillary sinus ostium) (Fig. 3.2). Respecting the structure of the ostium is essential for a successful SFE.

3.3.3 Septa

Septa (Fig. 3.3) are the most frequent anatomic variations within the maxillary sinus. They were first described by Underwood in 1910 and, therefore, have sometimes been referred to as Underwood's septa (Underwood 1910).

It has been reported that they increase the risk of sinus membrane perforation during SFE. If septa are present on the sinus floor, they can complicate both the inversion of the bone plate and elevation of the sinus membrane. One of the possible complications associated with perforation of the sinus membrane is the development of maxillary sinusitis (Quiney et al. 1990; Ueda and Kaneda 1992; Zimbler et al. 1998).

If septa are encountered on the antral floor, some authors recommend cutting them with a narrow chisel and removing them with a hemostat, so the bone graft can be placed over the entire antral floor without interruption (Boyne and James 1980). Therefore, a modification of the conventional surgical technique is required when septa are present (Betts and Miloro 1994).

Tables 3.3 and 3.4 propose some clinical recommendations related to the height of vertical and horizontal sinus septa.

3.3.4 Vascularization

Three arteries supply blood to the maxillary sinus: the infraorbital artery, the posterior lateral nasal artery, and the posterior superior alveolar artery (PSAA). While

Table 3.3 Influence of vertical septa height on the SFE procedure

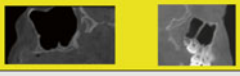
VERTICAL SEPTUM 	OUR RECOMMENDATIONS
* SHORT & SMOOTH	➢ Reflect the membrane to bypass the septum, and then proceed to the other sinus compartment.
* INTERMEDIATE	➢ Reflect the membrane from the septum base to the top, to have enough freedom. Then either bypass it or cut it from its base.
* LONG OR COMPLETE	➢ Reflect the membrane from two different entries (either crestal or lateral). No need to bypass the septum; the sinus is considered as two different sinus cavities (or compartments)

Table 3.4 Influence of horizontal septa dimensions on the SFE procedure

HORIZONTAL SEPTUM 	OUR RECOMMANDATIONS
* SHORT	➢ Reflect the membrane to bypass it.
* INTERMEDIATE	➢ Reflect the membrane from the septum base to the top, to have enough freedom. Then either bypass it or cut it from its base to reach the medial wall.
* LONG	➢ The most difficult situation. • If the width of the buccal compartment is enough to place a convenient implant diameter, surrounded by bone, especially from the palatal side, we don't have to graft the medial compartment. • If the width of the buccal compartment is insufficient, we have either to bypass it or do an osteotomy on its base.

their presence should be investigated to avoid hemorrhages during SFE, severe hemorrhages tend to be rare, as the main arteries do not run inside the surgical area.

The progressive atrophy of the alveolar ridge with age and tooth loss results in changes in the blood supply to that area. The maxilla is very densely vascularized in young, dentate individuals. In older, edentulous populations, the number of vessels and vessel diameter decreases, while the tortuosity of the vessels increases (Elian et al. 2005; Ulm et al. 1995; Watzek et al. 1993).

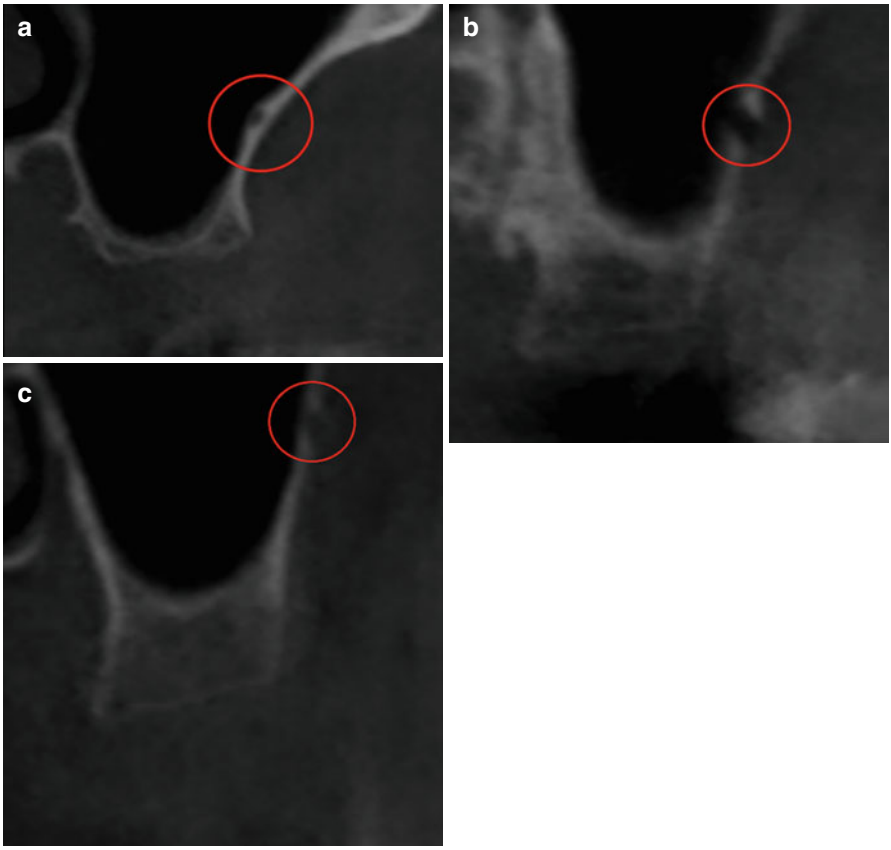


Fig. 3.4 Coronal view – The posterior superior alveolar artery. (**a**) PSAA is located between the Schneiderian membrane and the osseous wall. (**b**) PSAA is situated within the thickness of the osseous wall. (**c**) PSAA is on the external aspect of the lateral wall. (**a**–**c**) *Circle* denotes structure

To confirm the radiographic presence of the canal, one must examine the axial and coronal images. In coronal views, the PSAA appears as a circular or oval low-density structure that is fully or partially embedded within the thickness of the lateral wall of the maxillary sinus. It has to be seen along the sinus border while scrolling the axial views (Noujeim et al. 2014).

The radiographic location can be divided in three categories (Fig. 3.4):

1. PSAA is located between the Schneiderian membrane and the osseous wall.
2. It is situated within the thickness of the osseous wall.
3. The canal is on the external aspect of the lateral wall (Noujeim et al. 2014).

The canal can radiographically be identified in over 50 % of examined CT images, equally between the right and left side. The canal is between 1 and 2 cm superior to the alveolar crest (average height = 16.4 mm) (Noujeim et al. 2014). Different studies achieve almost the same results (Elian et al. 2005; Ilgüy et al. 2013).

Table 3.5 proposes recommendations based on some parameters of PSAA.

Table 3.5 Influence of the posterior superior alveolar artery on the SFE procedure

The posterior superior alveolar artery	
Height Influence the design of the window	Adjust within the limitations of the basic principles of window design surgery The design should be appropriate enough to reflect the membrane, contain the grafting material, and place an adequate implant when indicated
Location Adjust the height of the window trap	Intraosseous: the separation is better with the piezoelectrical device to avoid bleeding Extraosseous: the reflection is possible manually, when performed carefully
Diameter	Small: minimal risk of bleeding Big: the risk of bleeding is higher

3.3.5 The Schneiderian Membrane

The Schneiderian (mucous) membrane lines the inner walls of the sinus and in turn is covered by pseudo-stratified columnar ciliated epithelium. Serum-mucosa glands are located in the lamina directly underneath, especially next to the ostium opening. The sinus membrane appears to be the main carrier of bone reformation after SFE, as multiple experimental studies suggested (Troedhan et al. 2012).

Normally, the thickness of the Schneiderian membrane varies from 0.13 to 0.5 mm (Tiziano 2012). However, inflammation or allergic phenomena may cause its thickening, either generally or locally (Fig. 3.5). In such cases, it may be necessary for an ENT to restore the sinus to a physiologic state before SFE can be carried out (see Chap. 4).

Mucosal thickening is the most frequently observed abnormality (66.0 %). It is generally associated with some kind of irritation, such as odontogenic pathology or allergic phenomena. Nonvital posterior maxillary teeth, periodontal abscesses, retained roots, embedded or impacted teeth, extensively carious teeth, and oroantral fistulae could be etiological factors in pathologies of odontogenic origin (Rege et al. 2012).

During osteotomy, the membrane should not be perforated:

- By mechanical burs
- By uncontrolled use of the piezoelectrical devices

Table 3.6 shows the influence of the sinus membrane thickness on SFE.

3.3.5.1 Mucocele

Mucoceles of maxillary sinus are fairly rare (3–10 %). They have been described in association with neoplasia, trauma, surgery, inflammatory process (e.g., cystic fibrosis), and congenital abnormalities. Mucoceles are consequent to an obstruction of the sinus ostia and drainage pattern, with accumulation of mucus within the sinus cavity. Continual accumulation causes it to expand from the pressure. Sinus walls may be remodeled or completely de-ossified and eroded (Sreedharan et al. 2011).

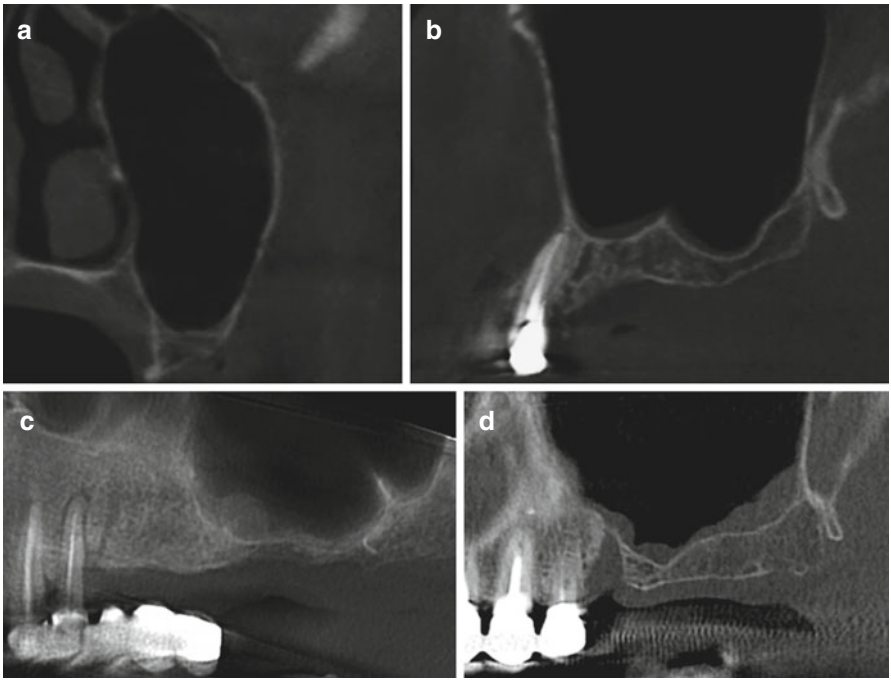


Fig. 3.5 The Schneiderian membrane appearance. (**a**) Normal mucosa, (**b**) flat mucosal thickening, (**c**) spherical thickening, and (**d**) irregular thickening

Table 3.6 Influence of the sinus membrane thickness on the SFE procedure

Thick membrane	Thin membrane
Reduced risk of membrane perforation during both reflection and osteotomy steps	During reflection, caution is required to liberate progressively the membrane in all directions rather than proceeding in one direction

The appearance of mucoceles is well described. Their image is a smooth expansile low-attenuation lesion arising in the maxilla. The majority is homogenous and isodense with the brain and typically shows a rounded bony outline (Fig. 3.6). Most mucoceles do not show contrast enhancement, and in fact, the administration of contrast medium is rarely necessary.

An opaque maxillary sinus without bone erosion invites the diagnosis of sinusitis, retention cysts, and antrochoanal polyps. With expansion and bone destruction, the differential diagnosis include malignant conditions like adenoid cystic carcinoma, plasmacytoma, rhabdomyosarcoma, lymphoma, schwannoma, and tumors of dental origin (Sreedharan et al. 2011).

The recommended treatment for maxillary sinus mucoceles with no extension to soft tissues of the cheek is endoscopic evacuation with wide middle meatal antrostomy. A Caldwell-Luc approach may be needed for mucoceles that have

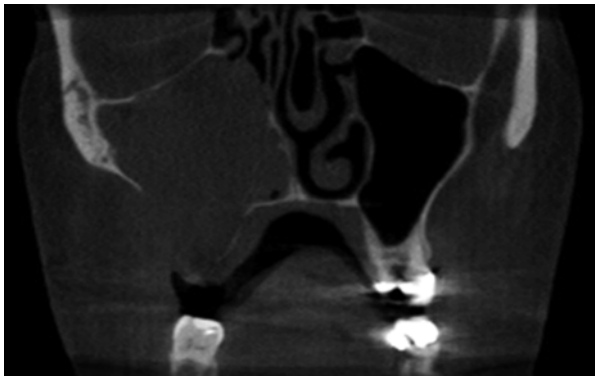


Fig. 3.6 Mucocele

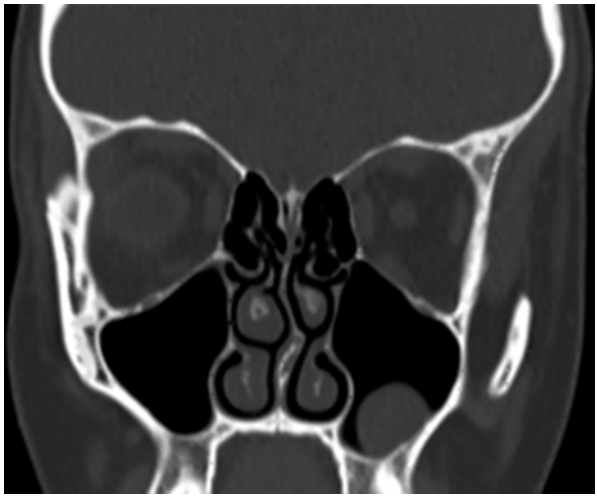


Fig. 3.7 Mucous retention cyst

extended into facial soft tissues, pterygomaxillary fossa, or those which have not been satisfactorily evacuated by endoscopic sinus surgery (Har-El 2001).

3.3.5.2 Mucous Retention Cyst

Mucous retention cysts of the maxillary sinus are an asymptomatic lesion incidentally found during the examination of images. On radiographs, they are radiopaque dome-shaped structures with a distinctly rounded edge (Fig. 3.7). They are slow-growing lesions, but mucosal and cortical integrity is preserved. Their etiology is unclear.

In most cases, it resolves spontaneously and requires no treatment. Clinical and radiographic examinations are essential to define alternative treatments and to rule out other pathologies, such as mucocele, polyps, and sinusitis (Donizeth-Rodrigues et al. 2013).

During SFE, the mucous retention cyst could be blown out without consequence to the result.

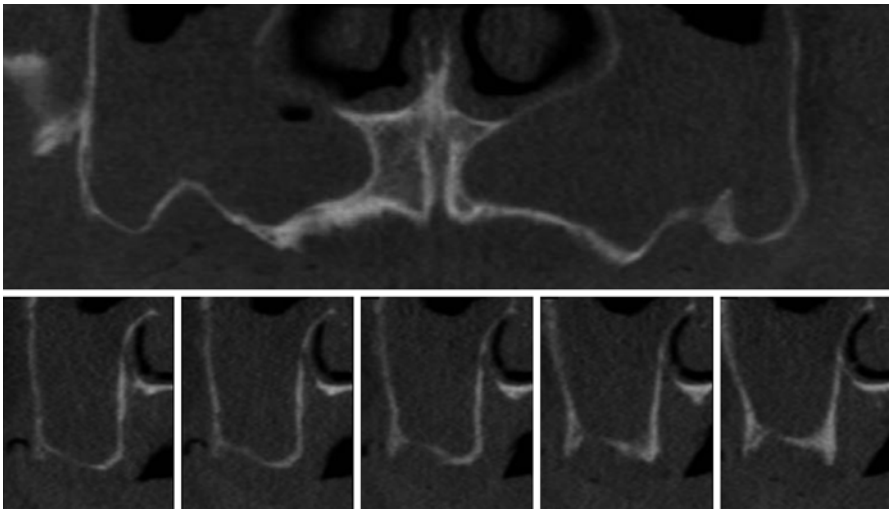


Fig. 3.8 A very huge sinus, extending in all planes, from the midline to the tuberosity

3.3.6 Bucco-palatal Distance

Successful graft consolidation relies on the progressive apposition of newly formed vital bone, followed by functional remodeling and progressive replacement of the grafting material by vital tissue. This process requires the presence of a stable scaffold, adequate angiogenesis (blood supply), and the migration of osteogenic cells. These events could be influenced in situations where the dimensions of the maxillary sinus cavity or the lateral window are excessive (Fig. 3.8).

The results of a study conducted by Avilla et al. (2010) concluded that the proportion of vital bone formation after sinus augmentation is inversely proportional to the bucco-palatal distance of the maxillary sinus. This information may be considered for the clinical decision of the type of SFE procedure (see Table 3.7) and the timing for implant placement (Avila et al. 2010).

3.3.7 Residual Bone Volume = Residual Bone Height (RBH) + Residual Bone Width (RBW)

Height and width of residual bone measures (Fig. 3.9) will help to select the optimal SFE technique to use and/or whether an additional augmentation technique should be combined with the SFE (e.g., onlay block) (Shanbhag et al. 2014). (See Chaps. 5 and 6 on lateral and crestal SFE.)

Augmentation is generally recommended when RBH is <4–6 mm (Del Fabbro et al. 2012; Esposito et al. 2010; Pjetursson et al. 2008), mostly associated with molar and second premolar sites (Kopecka et al. 2012; Pramstraller et al. 2011).

Table 3.7 Influence of the sinus bucco-palatal distance on the SFE procedure

Wide sinus	Narrow sinus
A wide sinus will favor a lateral SFE	A narrow sinus will favor a crestal SFE
During the reflection of the membrane, it will be more difficult to reach the medial wall and to fill properly the sinus	It will be difficult to reflect the membrane from the lower (and lateral) parts of the sinus, but it is easier to fill it by grafting material

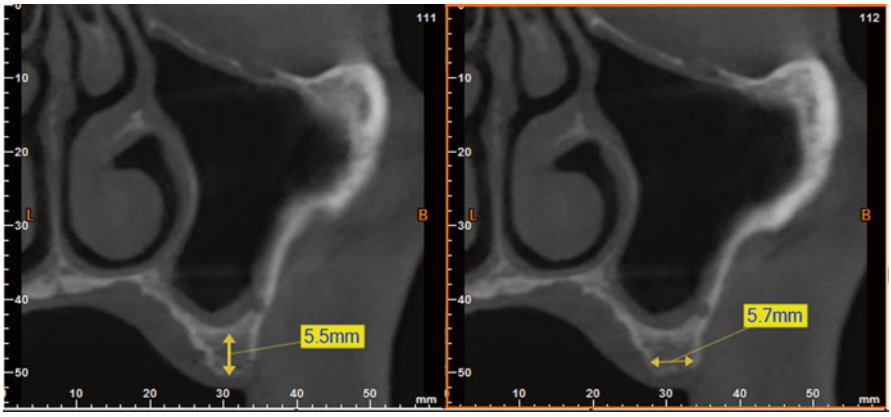


Fig. 3.9 Residual bone volume

Moreover, reduced RBH is reported to correlate with a thinner sinus membrane and an increased risk of perforation during SFE (Ardekian et al. 2006; Yilmaz and Tözüm 2012).

3.3.8 Quality of Residual Bone

The quantity and the quality (density) of available bone influence the clinical success of dental implants. Computed tomography (CT) allows precise three-dimensional evaluation of anatomic structures and direct measurement of bone density, expressed in Hounsfield units (HU), characteristics that provide important information about the bone (Silva et al. 2012).

Since CBCT has replaced CT in several areas of dentistry for evaluating mineralized tissues, it was important to determine whether it would be reliable in assessing bone density.

Some studies showed that the intensity values were variable for CBCT imaging using different CBCT scanners, whereas CT showed stable HU values, so CBCT provides less accurate qualitative values for HU (Mah et al. 2010; Nackaerts et al. 2011).

Nevertheless, other authors claimed the opposite and considered CBCT images useful for estimating bone density (Naitoh et al. 2010). They found overestimated values of HU, but concluded that CBCT could be considered a diagnostic tool for bone density evaluation (Aranyarachkul et al. 2005).

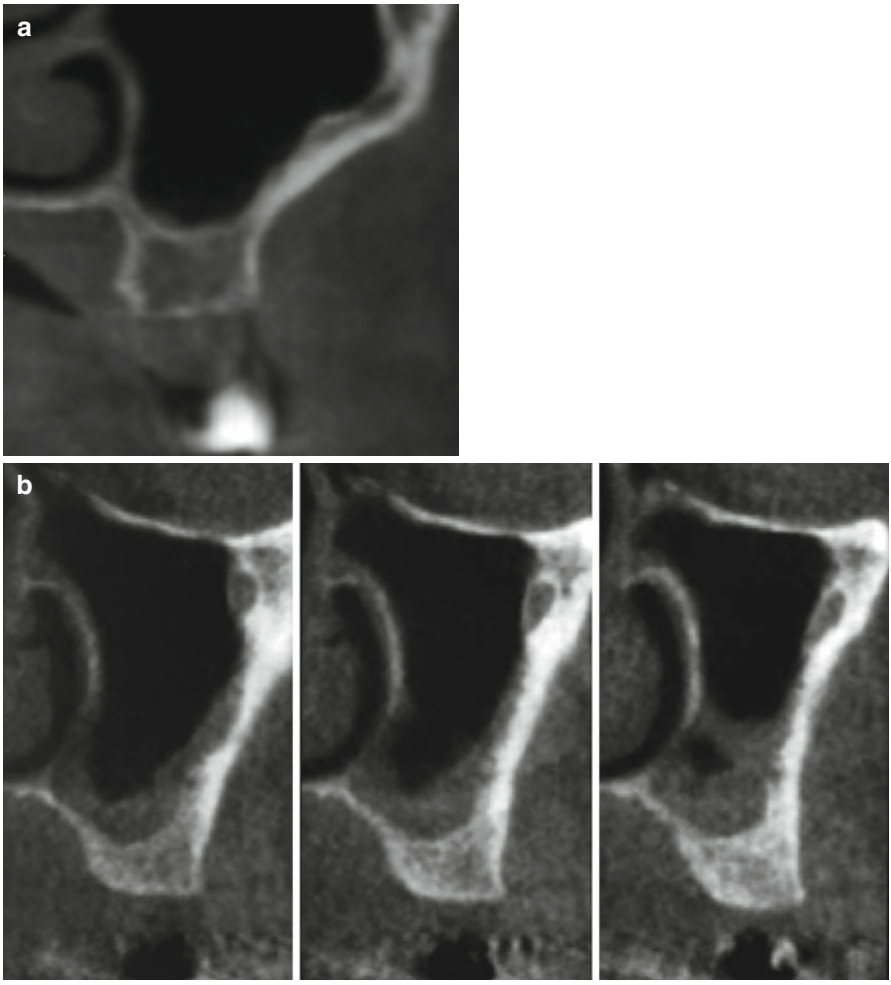


Fig. 3.10 (**a**) Prominent zygoma buttress, (**b**) thick buccal wall

Studies conclude that the HU derived from CBCT and from CT are not identical. The bone density value in HU on CBCT images can give higher values than that obtained on CT images. Improvements in the CBCT technique and the development of new software that allows uniform correction in CBCT images could contribute to reducing the differences between scanners, so that CBCT images can become a more reliable tool for bone density assessment.

3.3.9 Zygomatic Bone and Buccal Wall Influence on SFE

A thick buccal wall combined with a low zygoma position is in favor of avoiding a complete osteotomy (Fig. 3.10). We should use a repositioned window trap.

A prominent zygoma buttress will be a serious obstacle for the upper position of the window trap and especially difficult in case of resorbed ridges limiting the height of the window. The reduced bony window will then be problematic for an adequate reflection of the membrane.

3.4 Post-grafting Imaging

3.4.1 Timing

3D imaging (CT/CBCT) is a reliable modality, which can serve as a good follow-up tool to assess postoperative results and pathology and is highly recommended.

A scan study is usually performed after at least a 5-month period depending mostly on the grafting material to get reliable radiographic information, particularly to plan implant placement in case of a delayed approach.

Nevertheless, it has been suggested that bone consolidation and remodeling occurs in all three dimensions within a period of 8–10 months postoperatively (Peleg et al. 1999).

3.4.2 Radiographic Changes After SFE

3.4.2.1 Remodeling

The study of Anduze-Acher et al. showed the lack of significant change in the sinus membrane dimension following SFE using a lateral approach in partially edentulous patients (Anduze-Acher et al. 2013).

It has been shown in patients without signs of maxillary sinusitis that the effects of the augmentation procedure on maxillary sinus performance are of no clinical significance (Timmenga et al. 2003) and that the mucociliary function is preserved even during the surgical procedure (Griffa et al. 2010).

However, others studies show in contrast a significant increase in sinus membrane thickness following SFE (Pommer et al. 2011).

3.4.2.2 Shrinkage of the Graft

Various graft materials have been used for sinus augmentation, including autografts, allografts, and synthetic bone grafts (Kent and Block 1989; Moy et al. 1993; Smiler et al. 1992). Autogenous bone was considered to be the material of choice, but its use is avoided due to its uncontrolled resorption (Aaboe et al. 1995; Haas et al. 1998).

However, other bone substitute (BS) like deproteinized bovine bone appears to undergo slow or even no resorption for up to 6 years, as confirmed by clinical biopsies and even 14-year post-grafting (Hallman et al. 2001; Meijndert et al. 2005; Piattelli et al. 1999; Schlegel and Donath 1998).

Therefore, some authors suggest the use of a composite graft. The graft volume is better preserved after the addition of deproteinized bovine bone and the volumetric reduction is significantly influenced by the ratio used (Jensen et al. 2012).

Radiological studies reported a decrease in graft height 1–3 years after SFE when using a mixture of 1:2 ratio, but subsequent changes were minimal. A significantly

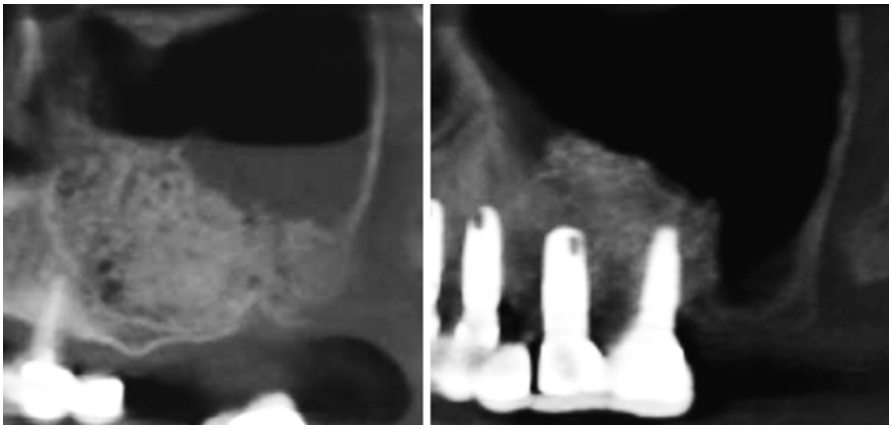


Fig. 3.11 Shrinkage of the graft (**a**) at the time of SFE, (**b**) after 3 years

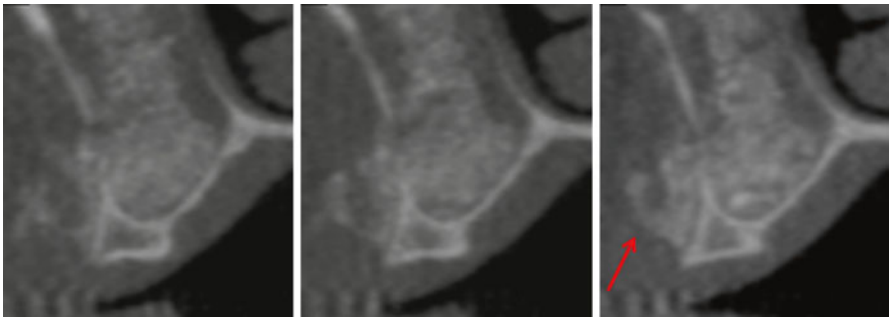


Fig. 3.12 Anarchical particulate bone substitute spreading in the sinus cavity. *Arrow* indicate bone substitute outside the sinus

greater maintenance of bone height was found in intraoral grafts when compared to allografts (Hallman and Zetterqvist 2004; Hatano et al. 2004).

The overall height of bone graft decreased during the first 2–3 years after SFE. Thereafter, only minor changes occurred (Fig. 3.11). However, graft height up to 96 months after augmentation was higher than that observed preoperatively. These findings suggest that implant loading promotes osteogenesis over the long term (Keller et al. 1994; Nyström et al. 1993). Implant loading may exert a stabilizing effect on the maintenance of bone graft height (Listrom and Symington 1988).

Overall, graft height decreased during the first 2–3 years after SFE, but subsequent changes were minimal. Long-term stability of sinus-graft height represents an important factor for implant success (Hatano et al. 2004).

3.4.3 Unfavorable Radiographic Situations Following SFE

1. Spreading of particulate bone substitute in the sinus cavity (Fig. 3.12).
2. Sinus reaction after bone grafting (Fig. 3.13).
3. The implant is not covered by the grafting material (Fig. 3.14).

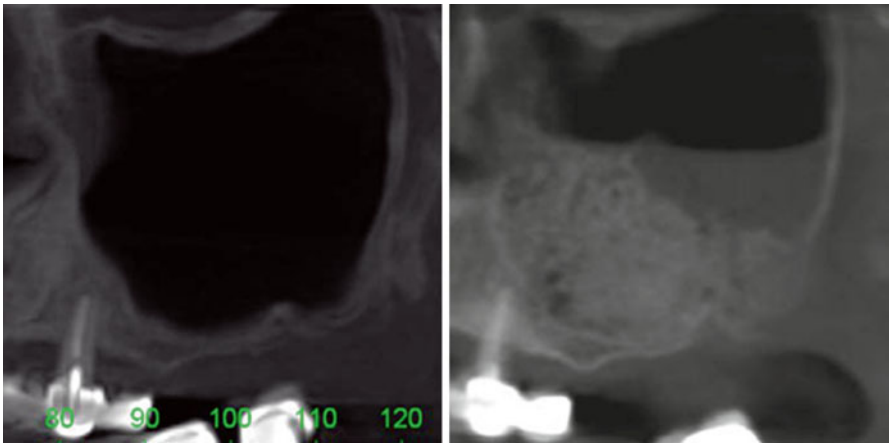


Fig. 3.13 Pre- and post-SFE. Note the sinus reaction after 1 month

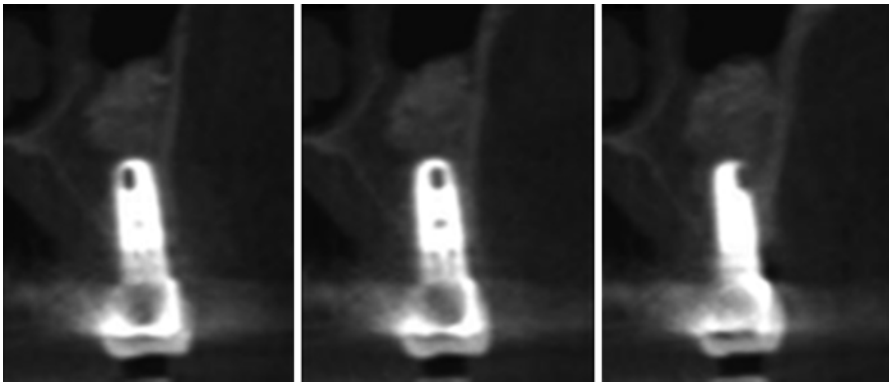


Fig. 3.14 The palatal side of the implant is not completely surrounded by grafting material

Conclusion

Remarkable for its image resolution and low-dose produced x-rays, the cone beam CT (CBCT) stands out as the technique of choice in all fields of maxillofacial diagnosis, especially in cases of potential SFE.

CBCT allows three-dimensional visualization of the complete anatomy of the maxillary sinus, associated pathologies that could escape a 2D examination and postoperative treatment outcomes of the SFE various bone grafting techniques.

In conjunction and synergy with the clinical evaluation, imaging of the maxillary sinus must cover the entire nasal sinus volume, hence the need to use a large field CBCT device including the sinus and the maxillary dental arch, allowing a complete visualization of the sinus (with the osteomeatal complex) and an effective detection of possible apical and/or periodontal lesions impacting one way or another on the sinus condition.

Finally, one should note that technical progress does not replace the competence in reading CBCT images that the dental surgeon must acquire through continuing education seminars and international guidelines. CBCT technology more than ever commits the responsibility of the practitioner who can no longer "ignore" a lesion on the grounds that it is outside the scope of his professional expertise.

References

Aaboe M, Pinholt EM, Hjørting-Hansen E (1995) Healing of experimentally created defects: a review. Br J Oral Maxillofac Surg 33(5):312–318

Anduze-Acher G, Brochery B, Felizardo R, Valentini P, Katsahian S, Bouchard P (2013) Change in sinus membrane dimension following sinus floor elevation: a retrospective cohort study. Clin Oral Implants Res 24:1123–1129

Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I et al (2005) Bone density assessments of dental implant sites: 2. quantitative cone-beam computerized tomography. Int J Oral Maxillofac Implants 20(3):416–424

Ardekian L, Oved-Peleg E, Mactei EE, Peled M (2006) The clinical significance of sinus membrane perforation during augmentation of the maxillary sinus. J Oral Maxillofac Surg 64(2):277–282

Avila G, Wang HL, Galindo-Moreno P, Misch CE, Bagramian RA, Rudek I, Benavides E, Moreno-Riestra I, Braun T, Neiva R (2010) The influence of the bucco-palatal distance on sinus augmentation outcomes. J Periodontol 81(7):1041–1050

Benavides E, Rios HF, Ganz SD, An CH, Resnik R, Reardon GT, Feldman SJ, Mah JK, Hatcher D, Kim MJ, Sohn DS, Palti A, Perel ML, Judy KW, Misch CE, Wang HL (2012) Use of cone beam computed tomography in implant dentistry: the international congress of oral implantologists consensus report. Implant Dent 21(2):78–86

Betts NJ, Miloro M (1994) Modification of the sinus lift procedure for septa in the maxillary antrum. J Oral Maxillofac Surg 52:332–333

Boyne PJ, James RA (1980) Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 38:613–616

Bremke M, Sesterhenn AM, Murthum T, Al Hail A, Bien S, Werner JA (2009) Digital volume tomography (DVT) as a diagnostic modality of the anterior skull base. Acta Otolaryngol 129(10):1106–1114

Cakli H, Cingi C, Ay Y, Oghan F, Ozer T, Kaya E (2012) Use of cone beam computed tomography in otolaryngologic treatments. Eur Arch Otorhinolaryngol 269(3):711–720

Chomenko AG (1985) Atlas for maxillofacial pantomographic interpretation. Quintessence Int, Chicago

Del Fabbro M, Corbella S, Weinstein T, Ceresoli V, Taschieri S (2012) Implant survival rates after osteotome-mediated maxillary sinus augmentation: a systematic review. Clin Implant Dent Relat Res 14(Suppl 1):e159–e168

Donizeth-Rodrigues C, Fonseca-Da Silveira M, Gonçalves-De Alencar AH, Garcia-Santos-Silva MA, Francisco-De-Mendonça E, Estrela C (2013) Three-dimensional images contribute to the diagnosis of mucous retention cyst in maxillary sinus. Med Oral Patol Oral Cir Bucal 18(1):e151–e157

Elian N, Wallace S, Cho SC, Jalbout ZN, Froum S (2005) Distribution of the maxillary artery as it relates to sinus floor augmentation. Int J Oral Maxillofac Implants 20(5):784–787

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington HV, Coulthard P (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev 17;(3):CD008397

Fatterpekar GM, Delman BN, Som PM (2008) Imaging the paranasal sinuses: where we are and where we are going. Anat Rec (Hoboken) 291(11):1564–1572

Griffa A, Berrone M, Boffano P, Viterbo S, Berrone S (2010) Mucociliary function during maxillary sinus floor elevation. J Craniofac Surg 21(5):1500–1502

Haas R, Donath K, Födinger M, Watzek G (1998) Bovine hydroxyapatite for maxillary sinus grafting: comparative histomorphometric findings in sheep. Clin Oral Implants Res 9(2):107–116

Hallman M, Zetterqvist L (2004) A 5-year prospective follow-up study of implant-supported fixed prostheses in patients subjected to maxillary sinus floor augmentation with an 80:20 mixture of bovine hydroxyapatite and autogenous bone. Clin Implant Dent Relat Res 6(2):82–89

Hallman M, Cederlund A, Lindskog S, Lundgren S, Sennerby L (2001) A clinical histologic study of bovine hydroxyapatite in combination with autogenous bone and fibrin glue for maxillary sinus floor augmentation. Results after 6 to 8 months of healing. Clin Oral Implants Res 12(2):135–143

Har-El G (2001) Endoscopic management of 108 sinus mucoceles. Laryngoscope 111(12): 2131–2134

Harris D, Horner K, Gröndahl K, Jacobs R, Helmrot E, Benic GI, Bornstein MM, Dawood A, Quirynen M (2012) E.A.O. Guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the european association for osseointegration at the medical university of Warsaw. Clin Oral Implants Res 23(11):1243–1253

Hatano N, Shimizu Y, Ooya K (2004) A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 15(3):339–345

Ilgüy D, Ilgüy M, Dolekoglu S, Fisekcioglu E (2013) Evaluation of the posterior superior alveolar artery and the maxillary sinus with CBCT. Braz Oral Res 27(5):431–437

Jensen T, Schou S, Svendsen PA, Forman JL, Gundersen HJG, Terheyden H, Holmstrup P (2012) Volumetric changes of the graft after maxillary sinus floor augmentation with Bio-Oss and autogenous bone in different ratios: a radiographic study in minipigs. Clin Oral Implants Res 23:902–910

Keller EE, Eckert SE, Tolman DE (1994) Maxillary antral and nasal one-stage inlay composite bone graft: preliminary report on 30 recipient sites. J Oral Maxillofac Surg 52(5):438–447

Kent JN, Block MS (1989) Simultaneous maxillary sinus floor bone grafting and placement of hydroxylapatite-coated implants. J Oral Maxillofac Surg 47(3):238–242

Kopecka D, Simunek A, Brazda T, Rota M, Slezak R, Capek L (2012) Relationship between subsinus bone height and bone volume requirements for dental implants: a human radiographic study. Int J Oral Maxillofac Implants 27(1):48–54

Listrom RD, Symington JM (1988) Osseointegrated dental implants in conjunction with bone grafts. Int J Oral Maxillofac Surg 17(2):116–118

Mah P, Reeves TE, McDavid WD (2010) Deriving Hounsfield units using grey levels in cone beam computed tomography. Dentomaxillofac Radiol 39(6):323–335

Meijndert L, Raghoebar GM, Schüpbach P, Meijer HJ, Vissink A (2005) Bone quality at the implant site after reconstruction of a local defect of the maxillary anterior ridge with chin bone or deproteinised cancellous bovine bone. Int J Oral Maxillofac Surg 34(8):877–884

Moy PK, Lundgren S, Holmes RE (1993) Maxillary sinus augmentation: histomorphometric analysis of graft materials for maxillary sinus floor augmentation. J Oral Maxillofac Surg 51(8):857–862

Nackaerts O, Maes F, Yan H, Couto Souza P, Pauwels R, Jacobs R (2011) Analysis of intensity variability in multislice and cone beam computed tomography. Clin Oral Implants Res 22(8):873–879

Naitoh M, Aimiya H, Hirukawa A, Ariji E (2010) Morphometric analysis of mandibular trabecular bone using cone beam computed tomography: an in vitro study. Int J Oral Maxillofac Implants 25(6):1093–1098

Noujeim M, Nasseh I, Hayek E, Moarbes M, Khawam K, Hadchiti W, Bouchard P, Bechara B (2014) Location of postero-superior alveolar artery and correlation with maxillary sinus anatomy. Int J Periodontics Restorative Dent, accepted for publication

Nyström E, Kahnberg KE, Albrektsson T (1993) Treatment of the severely resorbed maxillae with bone graft and titanium implants: histologic review of autopsy specimens. Int J Oral Maxillofac Implants 8(2):167–172

Peleg M, Chaushu G, Mazor Z, Ardekian L, Bakoon M (1999) Radiological findings of the post-sinus lift maxillary sinus: a computerized tomography follow-up. J Periodontol 70: 1564–1573

Piattelli M, Favero GA, Scarano A, Orsini G, Piattelli A (1999) Bone reactions to anorganic bovine bone (Bio-Oss) used in sinus augmentation procedures: a histologic long-term report of 20 cases in humans. Int J Oral Maxillofac Implants 14(6):835–840

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35(8 Suppl):216–240

Pommer B, Dvorak G, Jesh P, Palmer RM, Watzek G, Gahleitner A (2011) Effect of maxillary sinus floor augmentation on sinus membrane thickness in CT. J Periodontol 83:551–556

Pramstraller M, Farina R, Franceschetti G, Pramstraller C, Trombelli L (2011) Ridge dimensions of the edentulous posterior maxilla: a retrospective analysis of a cohort of 127 patients using computerized tomography data. Clin Oral Implants Res 22(1):54–61

Quiney RE, Brimble E, Hodge M (1990) Maxillary sinusitis from dental osseointegrated implants. J Laryngol Otol 104:333–334

Rege IC, Sousa TO, Leles CR, Mendonça EF (2012) Occurrence of maxillary sinus abnormalities detected by cone beam CT in asymptomatic patients. BMC Oral Health 12:30

Schlegel AK, Donath K (1998) BIO-OSS – a resorbable bone substitute? J Long Term Eff Med Implants 8(3–4):201–209

Shanbhag S, Karnik P, Shirke P, Shanbhag V (2014) Cone-beam computed tomographic analysis of sinus membrane thickness, ostium patency, and residual ridge heights in the posterior maxilla: implications for sinus floor elevation. Clin Oral Implants Res 25:755–760

Silva IM, Freitas DQ, Ambrosano GM, Bóscolo FN, Almeida SM (2012) Bone density: comparative evaluation of Hounsfield units in multislice and cone-beam computed tomography. Braz Oral Res 26(6):550–556

Smiler DG, Johnson PW, Lozada JL, Misch C, Rosenlicht JL, Tatum OH Jr, Wagner JR (1992) Sinus lift grafts and endosseous implants. Dent Clin North Am 36(1):151–186

Sreedharan S, Kamath MP, Hegde MC, Bhojwani K, Alva A, Waheeda C (2011) Giant mucocoele of the maxillary antrum: a case report. Indian J Otolaryngol Head Neck Surg 63(1):87–88

Timmenga NM, Raghoebar GM, van Weissenbruch R, Vissink A (2003) Maxillary sinus floor elevation surgery a clinical, radiographic and endoscopic evaluation. Clin Oral Implants Res 14(3):322–328

Tiziano T (2012) Maxillary sinus surgery: anatomy and advanced diagnostic imaging. Int Dent Afr Ed 2(5):6–15

Troedhan A, Kurrek A, Wainwright M (2012) Biological principles and physiology of bone regeneration under the schneiderian membrane after sinus lift surgery: a radiological study in 14 patients treated with the transcrestal hydrodynamic ultrasonic cavitational sinus lift (intralift). Int J Dent 2012:576238

Ueda M, Kaneda T (1992) Maxillary sinusitis caused by dental implants: report of two cases. J Oral Maxillofac Surg 50:285–287

Ulm C, Solar P, Gsellman B, Matejka M, Watzek G (1995) The edentulous maxillary alveolar process in the region of the maxillary sinus-a study of physical dimension. Int J Oral Maxillofac Surg 24:279–282

Underwood AS (1910) An inquiry into the anatomy and pathology of the maxillary sinus. J Anat Physiol 44:354–369

Watzek G, Ulm C, Solar P, Matejka M (1993) Surgical criteria for endosseous implant placement. Pract Periodontics Aesthet Dent 5:87–94

Yilmaz HG, Tözüm TF (2012) Are gingival phenotype, residual ridge height, and membrane thickness critical for the perforation of maxillary sinus? J Periodontol 83(4):420–425

Ziegler CM, Woertche R, Brief J, Hassfeld S (2002) Clinical indications for digital volume tomography in oral and maxillofacial surgery. Dentomaxillofac Radiol 31(2):126–130

Zimbler MS, Lebowitz RA, Glickman R, Brecht LE, Jacobs JB (1998) Antral augmentation, osseointegration, and sinusitis: the otolaryngologist's perspective. Am J Rhinol 12: 311–316

4 Otorhinolaryngological Assessment and Physiopathology of the Maxillary Sinus Prior to Bone Augmentation

Harry Maarek and Bahige Tourbah

Contents

H. Maarek (✉)
Department of Otolaryngology-Head and Neck Surgery,
Pitie Salpetriere Hospital, Paris, France
e-mail: hmaarek001@rss.fr

B. Tourbah
Private Practice in Oral Implantology, Oral and Maxillofacial Surgery Clinic,
Montpellier, France
e-mail: bahigetourbah@gmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_4

4.1 Introduction

Predictable results in implant-supported prosthetic rehabilitation are made possible through constant technical progress and compliance with contraindications. If the implant rehabilitation of the posterior maxilla involves opening the maxillary sinus wall for a bone augmentation procedure, it is essential to check for preexisting sinonasal disease, with the assistance of an ear, nose, and throat (ENT) specialist to avoid any uneventful healing.

Proper function of the maxillary sinus depends on a delicate balance between mucus production, transport by ciliated epithelium, sinus ventilation, and sustainable drainage through the ostium. Therefore, before planning a sinus floor elevation procedure (SFE), surgeons must consider its impact on sinus physiology in order to avoid unwelcome complications that may compromise the final result. An (ENT) specialist should be a primary figure in the approach to any SFE as his cooperation will be precious during the various steps necessary to ensure the success of surgery:

1. A first preventive-diagnostic step aimed at excluding any naso-sinusal diseases that may lead to failure of surgery
2. A second preventive-therapeutic step aimed at correcting any pathological findings that represent reversible contraindications to a sinus lift
3. A third diagnostic-therapeutic step (if needed) aimed at ensuring the prompt diagnosis and appropriate treatment of any possible sinus lift-related naso-sinusal complications

4.2 Medical History

As with all surgical procedures, all patients who undergo sinus floor elevation (SFE) are committed to a thorough evaluation of their systemic medical health. The type of anesthesia and the general health of the patient are all critical factors that must be reviewed to establish candidancy. Led by the oral surgeon, a medical history will be taken in search of sinonasal symptoms to attempt to find signs suggestive of sinusitis, such as nasal obstruction, purulent anterior rhinorrhea (purulent nasal secretions) or posterior rhinorrhea (with productive cough), a heaviness in the face (painful or not painful), reduced sense of smell, or even nasal bleeding (Fig. 4.1). *A rhinosinus dysfunction* will be suspected if there are more than three infectious episodes per year, especially if the patient remains symptomatic between the episodes. The other circumstance requiring a preimplant ENT evaluation is the discovery of *endosinus x-ray abnormalities* during the preimplant assessment (Beaumont et al. 2005).

4.3 Management of Rhinosinus Dysfunction

The diagnostic approach to sinonasal disease, based on the medical history, endonasal endoscopy, and reading of the sinus CT images, will enable the ENT to restore the maxillary sinus prior to the implant through medical and/or surgical

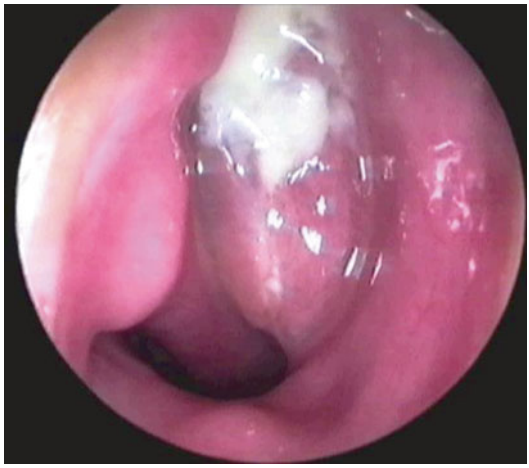


Fig. 4.1 Right nasal fossa showing acute maxillary sinusitis

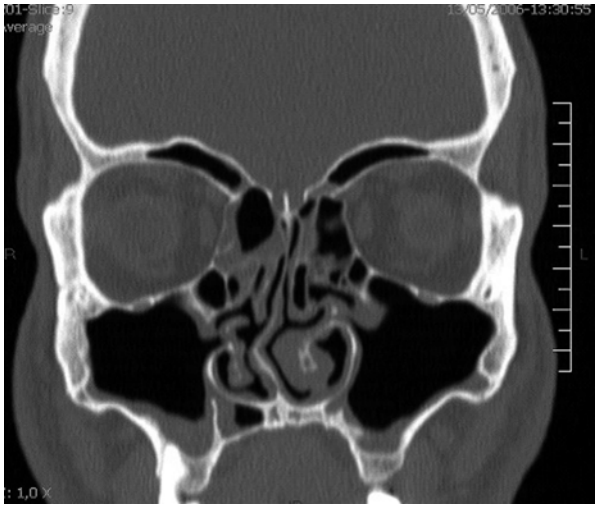


Fig. 4.2 Coronal CT scan. Anatomical and functional abnormalities in the ostiomeatal complex

treatment of the following infectious or inflammatory diseases (Pignataro et al. 2008; Torretta et al. 2011):

- Anatomical and functional changes in the ostiomeatal complex (high and posterior septal deviation, concha bullosa, reverse curvature of the middle turbinate, large Haller cell, anatomical change in the uncinate, synechia of the middle turbinate), responsible for anterior localized sinusitis (Fig. 4.2)
- Killian's antrochoanal polyp, foreign bodies destabilizing the maxillary sinus, and endosinus mycotic diseases (Fig. 4.3)
- Acute or chronic rhinosinusitis, localized (Fig. 4.4) or diffused (Fig. 4.5), with or without superinfection, with or without polyposis
- Sinonasal polyposis outside of stages 3 and 4 of the Rouviere classification (Fig. 4.6)

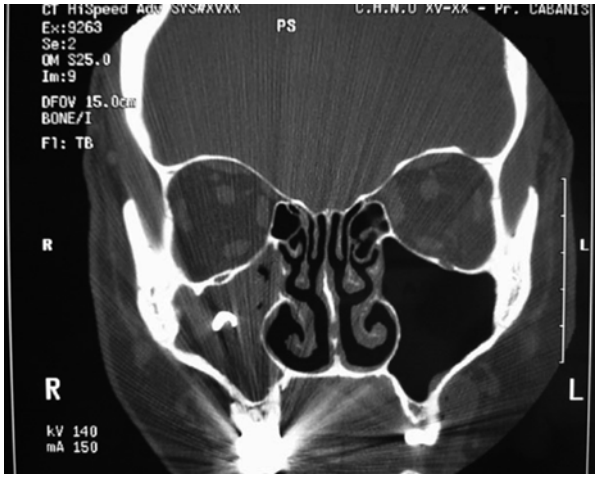


Fig. 4.3 Coronal CT scan showing an Aspergillosis of the maxillary sinus

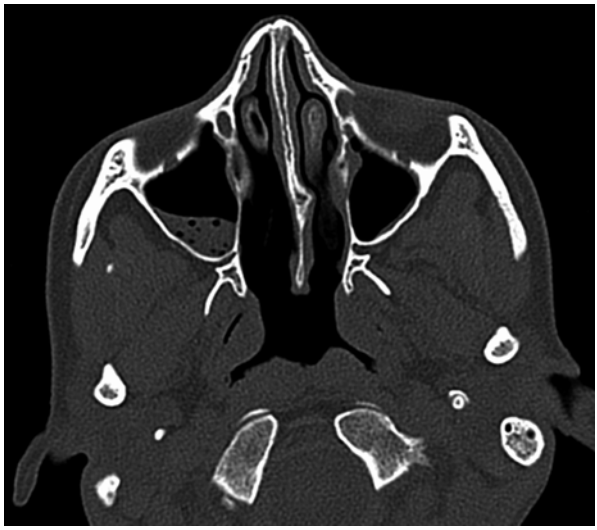


Fig. 4.4 Unilateral maxillary sinusitis on the right side

Endoscopic and radiological control in the third week will ensure the physiological restoration of the sinus in the case of medical treatment. Endoscopic endonasal surgery supplements, if needed for the medical treatment, will allow continuation of the implant plan in the case of normalization of the mucosa of the maxillary sinus after the 6th week following surgery.

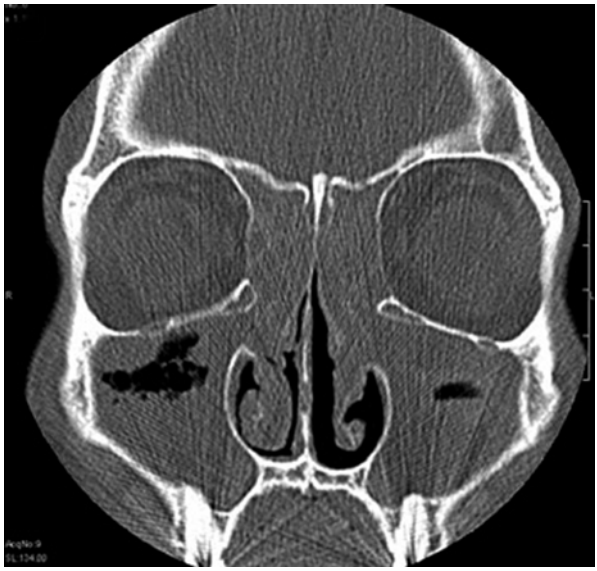


Fig. 4.5 Axial CT scan diffuse bilateral maxillary sinusitis

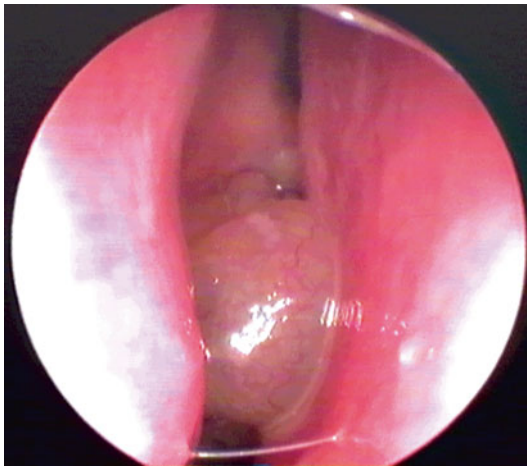


Fig. 4.6 Presence of a nasal polyposis in the right nasal fossa

4.4 Treatment of Endosinus Abnormalities During the Preimplant Radiological Assessment

They are detectable when reading the panoramic or DentaScan images and are represented by the mucosal abnormalities of the maxillary sinus and bone abnormalities of the floor. They require us to take them into account, even in the absence of a sinonasal history, in asymptomatic patients.

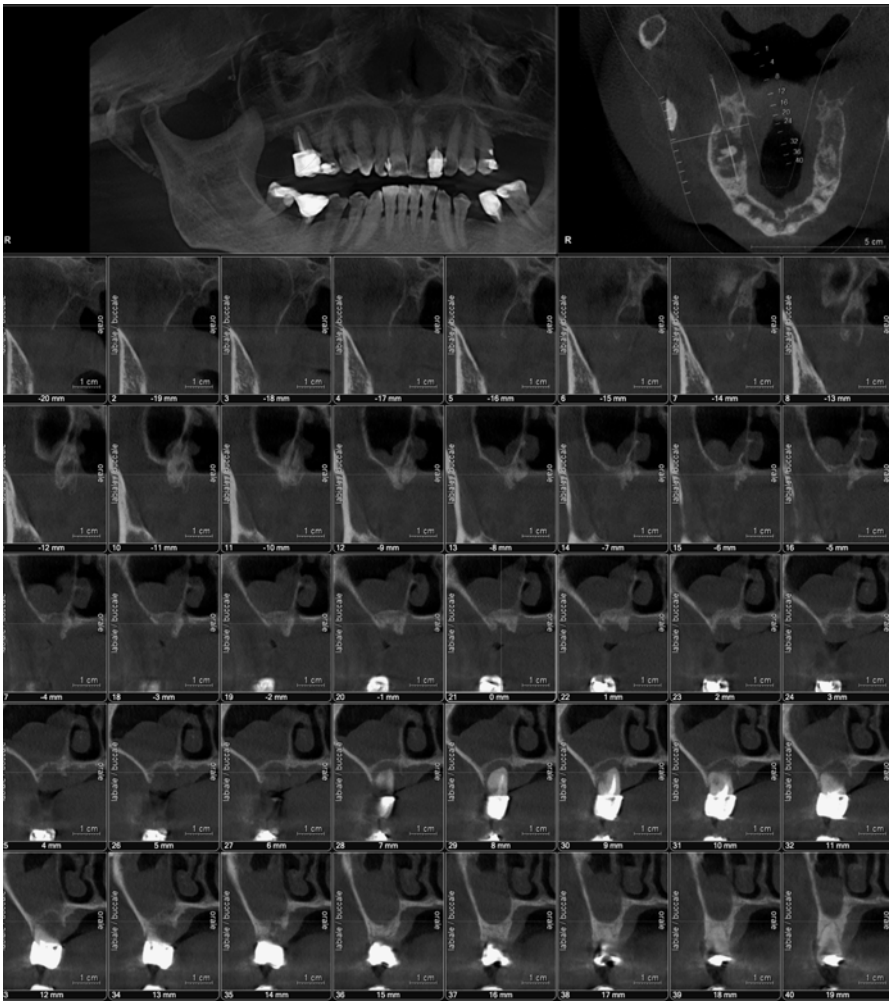


Fig. 4.7 Cone beam CT. Non-cystic polypoid opacity of the maxillary sinus

4.4.1 Mucosal Abnormalities of the Sinus Floor

They are represented by polypoid or hypertrophic opacities.

4.4.1.1 Polypoid Opacities

- Non-cystic polypoid opacities (usually associated with hypertrophy of the endosinus mucosa) are indolent and are represented by antrochoanal polyps in their incipient form, and polypoid opacities reacting to submucosal foreign bodies or prior tooth root disease (Fig. 4.7).
- Cystic polypoid opacities, or antral pseudocyst, or submucosal polyp affect 12 % of the population and generally do not involve mucosal hypertrophy (Mardinger et al. 2007) (Fig. 4.8).

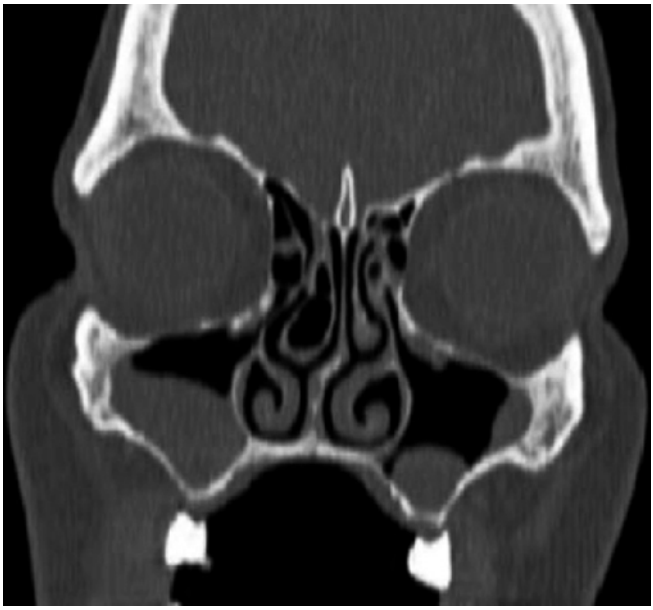


Fig. 4.8 Coronal CT scan showing at the left side a mucosal cyst and at the right side a pseudopolyps

The problem is represented by the ascent of these opacities, during sinus filling, and the risk of impaction of these opacities in the ostium of the maxillary sinus, with the risk of progression to confined sinusitis (importance of seeing the ostiomeatal complex via CT images, since the DentaScan visualizes curved panoramic reconstruction of only the lower 1/3 of the sinus). The parameters to consider are the estimated height of the enhancement, the vertical dimension of the opacity, and the position of the ostium compared to the floor, the ostium being located at 2.5 cm plus or minus 5 mm in the anatomical study of M. Gosau et al. (2009).

We have become accustomed to allowing crestal and lateral fillings if the height of the opacity does not exceed the lower 1/3 of the maxillary sinus (Figs. 4.9, 4.10, and 4.11), because the margin of safety is sufficient for enhancements less than 14 mm.

If the opacity exceeds the lower half of the sinus, we only allow crestal filling because this type of filling enhances the neo-floor less than 4 mm.

If the opacity reaches the lower 2/3 of the maxillary sinus, we do not allow any filling, and prior restoration of the maxillary sinus through middle meatotomy is required. This can be performed, to reduce the surgical steps, during the same procedure as the lateral filling (Felisati et al. 2010).

4.4.1.2 Mucosal Hypertrophies

Mucosal hypertrophies of the lining, isolated, do not represent a contraindication to perform a maxillary antrostomy, insofar as they do not destabilize the sinus function, and instead represent a guarantee of durability of the mucosa when it is lifted (Fig. 4.12).

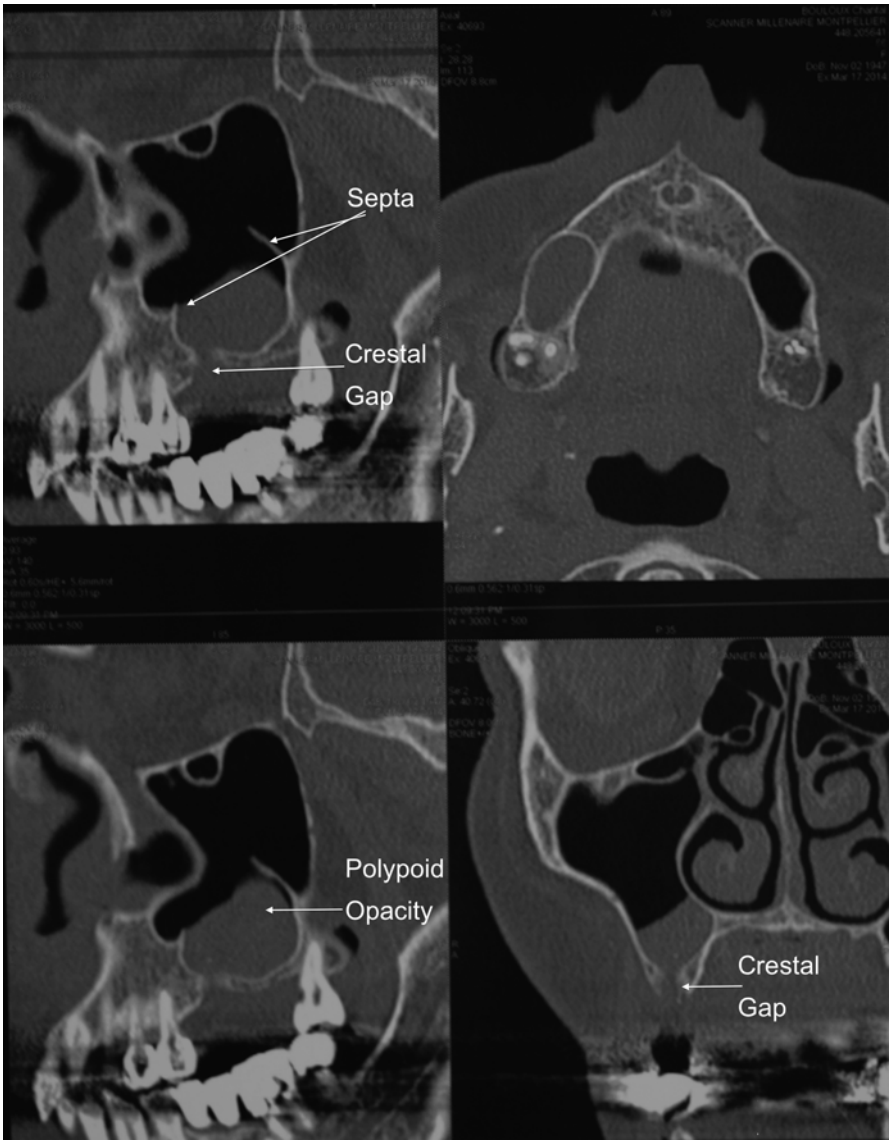


Fig. 4.9 Non-cystic polypoid opacity in reaction to the non-osseointegrated implant

4.4.2 Localized Bone Abnormalities of the Floor

Localized bone abnormalities of the floor are comprised either by the septa (Maestre-Ferrin et al. 2010) (Fig. 4.9) or by crestal gaps (Ogunsalu 2005) (Fig. 4.9). It is not the sinus physiology that is of concern, but the technical difficulties of filling, with the risk of large perforations of the mucosa. They therefore represent relative contraindications to the extent that surgery to restore the sinus floor can be proposed as

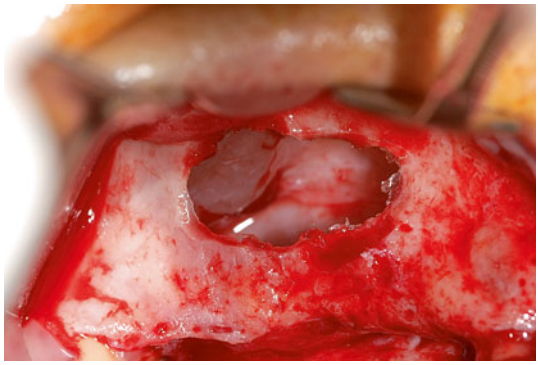


Fig. 4.10 Polypoid opacity lifted during sinus grafting procedure

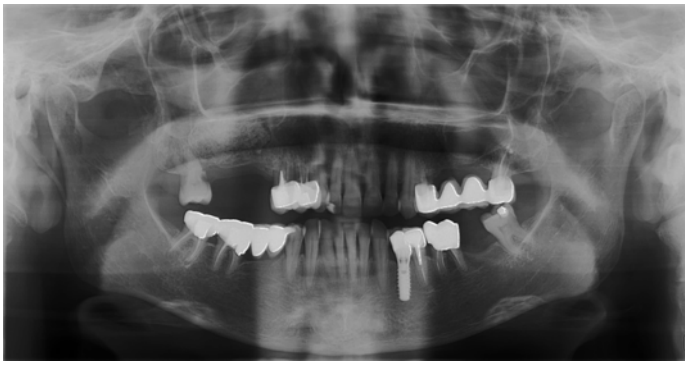


Fig. 4.11 Successful sinus grafting after lifting the polypoid opacity

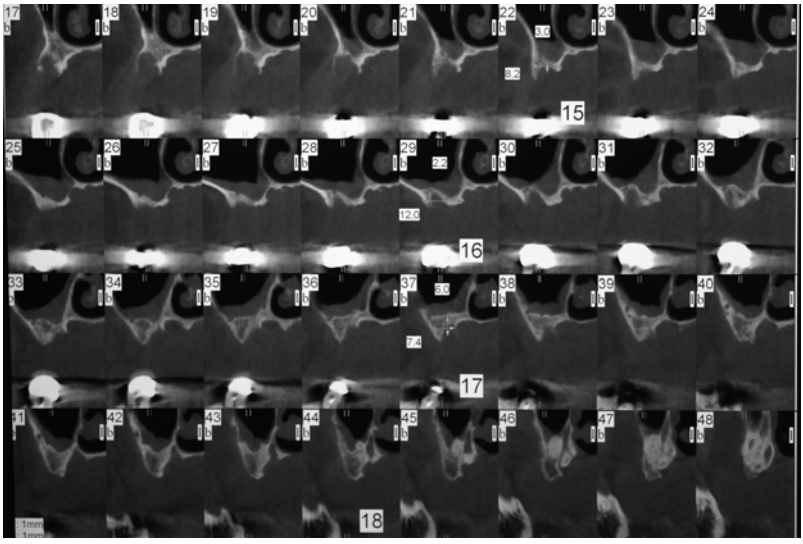


Fig. 4.12 DentaScan. Mucosal hypertrophy of the right maxillary sinus

a first step. These bone abnormalities should be differentiated from extensive bone changes, which represent absolute contraindications (see Sect. 5.4).

4.5 Absolute Endosinusal Contraindications

4.5.1 These Are Infectious or Inflammatory Sinonasal Diseases (with or Without Sinonasal Polyposis) with High Potential for Recurrence

- Congenital mucociliary drainage disorder (cystic fibrosis, Kartagener's syndrome, Young's syndrome)
- Acquired or drug-induced immune deficiency
- Systemic granulomatous rhinosinusitis (sarcoidosis, Wegener) and vasculitis (Churg-Strauss syndrome)
- Sinonasal polyposis of stage 3 and 4 in the Rouviere classification

4.5.2 Nonfunctional Middle Meatotomies with Persistent Change in Sinus Ventilation and Mucociliary Drainage, Preventing Detachment of the Sinus Mucosa

In order to avoid a post-operatory disruption of the sinus physiology, the middle meatal antrostomy should not be made too large and should communicate with the natural ostium.

4.5.3 Benign Sinonasal Tumor with Degenerative Potential (Inverted Papilloma) and Malignant Tumor Disease (Primary or Metastatic)

These pathologies interfere with sinonasal homeostasis, both before and after treatment.

4.5.4 Extensive and Unrepairable Bone Changes of the Sinus Walls, of Traumatic, Postradiation, or Surgical Origin

This will include maxillary dysplasia and advanced osteoporotic disease, as well as large gaps of the bony floor, on closed oroantral fistula. Patients with a history of Caldwell-Luc surgery can benefit from sinus filling, if the functional status of the sinus is preserved in the absence of mucocele or excessive alteration of the anterolateral wall.

4.6 Summary Table

A decision support based on the different clinical situations encountered in the pre-implant ENT evaluation is summarized in Fig. 4.13.

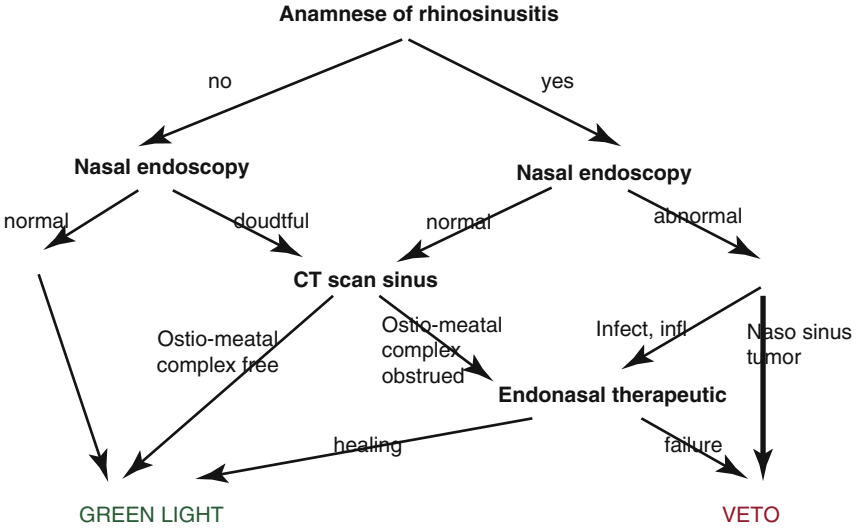


Fig. 4.13 Decision-chart guide during the preoperative ENT evaluation

Conclusion

Whenever naso-sinusal diseases or preexisting radiological abnormalities are suspected, the role of ENT specialists is essential in the evaluation and management of candidates for SFE. It involves identifying potential sinus contraindications while allowing, in some cases, maintaining the implant plan by restoring the sinus physiology. Their involvement in all three preventive-diagnostic, preventive-therapeutic, and diagnostic-therapeutic steps makes it possible to identify any presumably irreversible or potentially reversible contraindications to SFE and resolve (when possible) the pathological processes or anatomical impairments potentially leading to surgical failure, as well as ensure the early detection and treatment of any postoperative complications that may compromise good surgical outcome. The availability of a multidisciplinary approach, involving a skilled ENT specialist, not only increases the probability of a better procedural outcome but also provides a good medicolegal guarantee for the practitioners attempting an SFE.

References

Beaumont C, Zafiropoulos GG, Rohman K, Tatakis DN (2005) Prevalence of maxillary sinus disease and abnormalities in patients scheduled for sinus lift procedures. J Periodontol 76:461–467

Felisati G, Borloni R, Chiapasco M, Lozza P, Casentini P, Pipolo C (2010) Maxillary sinus elevation in conjunction with transnasal endoscopic treatment of rhino-sinusal pathoses: preliminary results on 10 consecutively treated patients. Acta Otorhinolaryngol Ital 30: 289–293

Gosau M, Rink D, Driemel O, Draenert G (2009) Maxillary sinus anatomy: a cadaveric study with clinical implications. Anat Rec (Hoboken) 292:352–354

Maestre-ferrin L, Galan-gili S, Rubio-serrano M, Penarrocha-diago M, Penarrocha-oltra D (2010) Maxillary sinus septa: a systematic review. Med Oral Patol Oral Cir Bucal 15:383–386

Mardinger O, Manor I, Mijiritsky E, Hirshberg A (2007) Maxillary sinus augmentation in the presence of antral pseudocyst: a clinical approach. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 103:180–184

Ogunsalu C (2005) Dental implant therapy in the treatment of an oroantral communication after exodontia. Implant Dent 14:232–236

Pignataro L, Mantovani M, Torretta S, Felisati G, Sambataro G (2008) ENT assessment in the integrated management of candidate for (maxillary) sinus lift. Acta Otorhinolaryngol Ital 28:110–119

Torretta S, Mantovani M, Testori T, Cappadona M, Pignataro L (2011) Importance of ENT assessment in stratifying candidates for sinus floor elevation: a prospective clinical study. Clin Oral Implants Res 100:57–62

Lateral Sinus Grafting Approach: Overview and Recent Developments

5

Ronald Younes and Maroun Boukaram

Contents

5.1 History of Sinus Floor Elevation Procedure (SFE)

With the increased popularity of dental implant therapy for the replacement of missing teeth, a need arose for a method to provide patients with bony support for these implants in cases where alveolar ridges volume were insufficient for implant placement.

Electronic supplementary material The online version of this chapter 10.1007/978-3-319-11448-4_5 contains supplementary material, which is available to authorized users. Videos can also be accessed at http://www.springerimages.com/videos/978-3-319-11448-4.

R. Younes, DDS, PhD (✉)
Department of Oral Surgery, Faculty of Dentistry, St Joseph University, Beirut, Lebanon
e-mail: ronald.younes@usj.edu.lb; ronald.younes@hotmail.com

M. Boukaram, DDS
Department of Periodontology, Faculty of Dentistry, Saint Joseph University, Beirut, Lebanon
e-mail: dr_mboukaram@hotmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_5

Initially, in the 1960s, Boyne proposed (lecture in the US Navy dental school, 1965–1968) the use of bone grafting of the maxillary sinus to increase osseous tissue for prosthetic purposes in order to increase the bulk of bone for subsequent maxillary ridge reduction for optimal prosthodontic interarch distance (Boyne 1969).

The sinus floor elevation (SFE) technique remains the most commonly used technique for the implant rehabilitation of an atrophic posterior maxilla, presented in 1977 by Tatum in a series of lectures, using a modified Caldwell-Luc approach (Tatum 1977).

It was first published by Boyne and James (1980) who reported a similar Caldwell-Luc surgical two-stage procedure to gain access to the maxillary sinus floor from its lateral aspect and elevate the sinus membrane in patients with large, pneumatized sinus cavities as a preparation for the placement of blade implants. A confined space was created, allowing autogenous particulate cancellous bone and marrow graft to be implanted into the sinus floor. The maxillary sinus was grafted using autogenous particulate iliac bone at the first stage of surgery. Approximately 3 months later, during the second stage, the blade implants were placed and later used to support fixed or removable reconstruction.

Several years later, Tatum (1986) was the first author to publish a one stage sinus grafting technique (with simultaneous implant placement). These implants were loaded after 6 months of healing time.

Wood and Moore (1988) described for the first time a SFE procedure using autogenous bone (AB) harvested from intraoral sites, and subsequent placement of implant SFE procedure relies on the principle of performing an osteotomy to create a bony window in the lateral sinus wall to gain access to the maxillary sinus.

5.2 Preoperative Evaluation

A comprehensive history and physical examination should be performed before initiating surgical treatment. Pertinent positives in the history such as recent upper respiratory infection, chronic sinus disease, chronic sinus/facial pain, otitis media, history of nasal/sinus surgery, history of prior attempts at maxillary reconstruction, and history of smoking are important to note. Research has shown that the complication rate for SFE performed on smokers is similar to the complication rate for the general population (Levin et al. 2004). However, there is evidence that smokers with implants placed in sinus-grafted bone have an increased failure rate when compared with nonsmokers (Kan et al. 1999).

A preoperative computed tomography (CT) scan or a cone beam CT is strongly recommended to assess the existing bone volume, rule out preexisting sinus disease, and evaluate for the presence of bony septae (Cote et al. 2011).

Pre-op evaluation is imperative to achieve a successful SFE procedure with a good prognosis. Suspicious cases should be referred to ENT physician in order to avoid later uneventful complications.

5.3 Surgical Procedure

5.3.1 Anesthesia

Since a long-lasting sedation is needed during this surgery, it is recommended to have a nerve block of the posterior superior alveolar nerve (also called "retromolar anesthesia") to allow analgesia of the whole operative area. A complementary anesthesia is performed in the canine fossa region for the middle superior alveolar nerve block to obtain a sedation of the premolar region. Moreover, palatal infiltration is performed for the sedation of the palatal region.

A local anesthetic with epinephrine (articaine, lidocaine) is usually administrated.

Local anesthesia can be used with or without intravenous sedation. General anesthesia is sometimes used if indicated.

5.3.2 Pre-op Medication

Conventionally, prophylactic antibiotics and steroids are administered before starting the procedure.

- *Steroids* reduce the postoperative edema and enhance the patient's comfort.
- Prophylactic *antibiotics* help to reduce bacterial contamination through a maximal plasmatic concentration and to maintain an efficient concentration during the surgery.
  There is no solid evidence to suggest whether the surgeon should use these medications preoperatively.
- *Anxiolytics* may be used before the surgery can prove to be a safe and effective method, administrated to fearful patients in order to avoid the fear of the patient provoked by the surgery. Hydroxyzine (Atarax) has a rapid onset of action (15 min), a half-life of 3–7 h, and duration of action of 4–6 h. It is supplied in 10, 25, 50, and 100 mg caps, with an average dosage of 50–100 mg.

Before starting the surgery it is recommended to have the patient rinse and expectorate with chlorhexidine or povidone iodine (Betadine®) *mouthwash* for 30 s in order to reduce dental plaque and oral bacteria.

5.3.2.1 Detailed Medication

- *Corticoids*
  - Tablet form: prednisolone (prednisone®, medrol®): 1mg/Kg/day administrated 1 hour before surgery and for 2 or 3 days after.
  - Intramuscular injectable suspension: Betamethasone (Diprofos®) usual adult dose 1 to 2 ml (single injection prior to surgery).
- *Antibiotics*: The association "amoxicillin + clavulanic acid" is recommended for sinus augmentation as it inactivates resistant bacteria in cases where penicillinases are thought to be present.

Posology: 1 g (875 mg amoxicillin with clavulanate 125 mg), 1 h prior to surgery, then two tablets twice a day for 8–15 days depending on the case.
- In case of allergy to penicillin, levofloxacine 500 mg once daily; erythromycin ethylsuccinate 400 mg, three times daily; or azithromycin 500 mg once daily is then indicated.
- *Anxiolytics*: 1 day then 1 h prior to surgery, benzodiazepine (Valium 20 mg) or hydroxyzine (1 mg/Kg) (Atarax®).
- *Analgesics* (*pain killers*): two tablets every 6 h of a combination of (paracetamol 500 + codeine 30 mg +/−caffeine).
- *Mouthwash*: Chlorhexidine (0.12–0.2 %) twice a day for 2 weeks or povidone iodine (1 %) (Betadine® Mouth/Throat – 1 %) two to three times/day.
- *Topical nasal decongestant*.
- *Xylometazoline hydrochloride 0.1 %* (Otrivine®): nasal spray 1 puff twice a day should be used in each nostril for the first 5 days. This nasal spray helps relieve congestion in a few minutes and the effect of the medicine lasts for up to 10 h. It causes blood vessel vasoconstriction, thereby decreasing blood flow of the sinuses, reducing swelling and the feeling of congestion.
- Mometasone furoate monohydrate 50 mcg (Nasonex®) (nasal spray) is an anti-inflammatory corticosteroid: 1 puff twice daily (in both nostrils) for the first 2–4 weeks.

5.3.2.2 Post-op Instructions
- Patients are instructed to avoid blowing their nose ≥7 days to prevent increased pressure in the operated sinus.
- Dentures are not allowed to be worn until they had been adjusted and refitted not earlier than 2 weeks postoperatively when sutures were removed.
- After that, they are relined periodically with a soft tissue conditioner.
- Patients are required to follow a soft diet.

5.3.3 Instrumentation

Numerous instruments have been introduced for both osteotomy preparation and membrane elevation.

Rotary Instruments
These instruments are most commonly used to create the osteotomy through which the sinus floor is accessed.

- Round burs (1.4–2.3 mm) are normally used to outline the shape of the lateral window.
- Large round shape instruments are efficient and safe for trimming the buccal wall plate.
- Large diameter diamond burs (fine grit) would carry a lower risk of membrane perforation.
- In order to reduce the risk of membrane perforation, piezosurgical devices are advisable, especially when we are nearby the Schneiderian membrane.

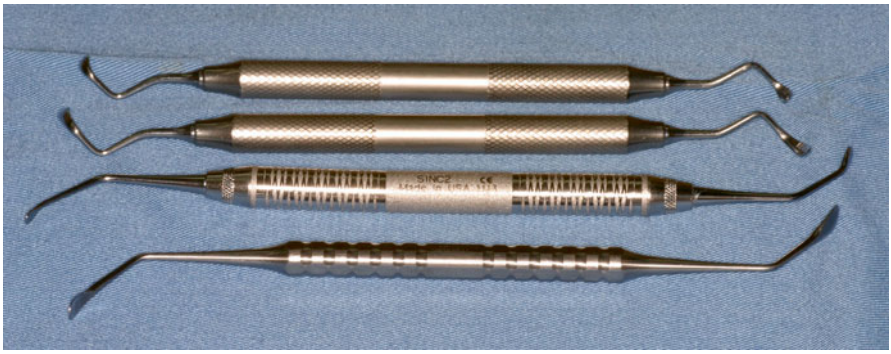


Fig. 5.1 Surgical curettes used to reflect the Schneiderian membrane from the maxillary sinus floor

- *Bone scrapers* could be used to carve into the anterior sinus wall to create an antrostomy for SFE in a simple and very safe procedure. It enables the collection of variable amounts of easily handled particulate bone graft that is highly useful to mix with the selected BS. Piezoelectric tips are also available for bone collection (Fig. 5.17 and 5.34).
- *Sinus lift curettes*: They are commonly used to separate/reflect and elevate the Schneiderian membrane from the maxillary bone; in most situations smaller instruments are first used to liberate the sinus membrane from the osseous wall, while larger instruments are used to expand the elevated space (Fig. 5.1).
- *Piezoelectric device and corresponding tips* (Please see details in the section: Piezoelectric surgery in SFE)

5.3.4 Technique Description

5.3.4.1 Flap Design

The flap design depends on several factors including:

- Full or partially edentulous ridge
- Neighboring crown restorations
- Amount of keratinized gingiva
- Shape and volume of the maxillary sinus
- Simultaneous or delayed implant placement
- The need to combine a lateral and/or vertical bone augmentation

The incision line is designed to avoid the planned location of the lateral window. Most commonly, the initial incision is midcrestal extending well beyond the planned extension of the osteotomy (Fig. 5.2).

Sometimes, this incision is made slightly palatal to the crest (2–4 mm) to preserve a wider band of keratinized attached gingiva for a more solid wound closure and to

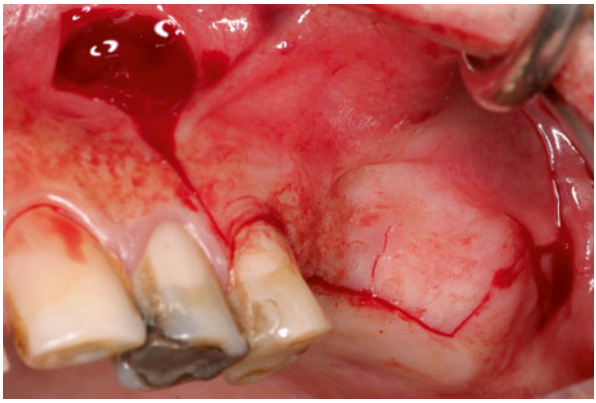


Fig. 5.2 Typical midcrestal, mesial, and distal releasing incisions: note the wider base of the flap to respect the blood supply

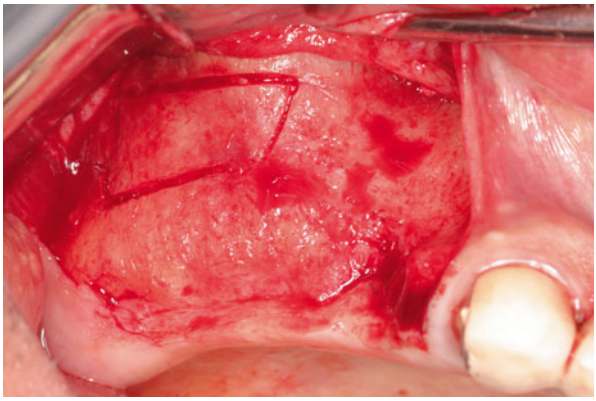


Fig. 5.3 Slightly buccally displaced midcrestal incision; releasing incision immediately posterior to the canine avoiding the infraorbitary plexus

avoid wound dehiscence. However, an incision made too far palatally may result in soft tissue dehiscence due to compromised blood supply (Kleinheinz et al. 2005).

When a staged approach is indicated, it would be recommended to place the incision line slightly on the buccal aspect (within the keratinized gingiva) of the crest as this may offer easier and quicker access for window opening. Moreover, the incision line should not cross the planned area of the lateral window. Wound edges lacking bone support may give rise to soft tissue collapse or major dehiscences in the absence of blood supply.

- The incision is carried on forward beyond the anterior border of the maxillary sinus. In case of the presence of neighboring teeth, the incision starts from the mesial area of the anterior tooth and extends intrasulcular until the distal portion of the posterior tooth.
- Releasing incisions are made anteriorly extending into the buccal vestibulum to facilitate reflection of a full-thickness mucoperiosteal flap; very often, the releasing incision is made immediately posterior to the canine tooth, which in most dentated cases was the posterior remaining tooth to avoid the infraorbitary plexus (Fig. 5.3).

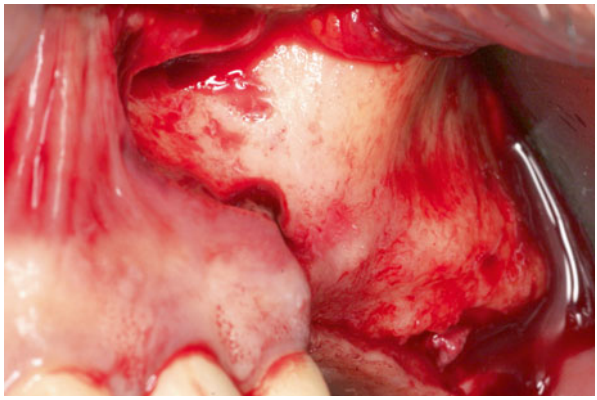


Fig. 5.4 Flap reflection (difficult) in case of a prominent zygoma buttress

However, we try to avoid vertical incisions whenever possible, as they tend to increase the discomfort in the postoperative phase.

5.3.4.2 Mucoperiosteal Elevation (Fig. 5.4)

A mucoperiosteal full-thickness flap is raised slightly superior to the anticipated height of the lateral window (antral wall). The flap reflection should reach the zygoma buttress in order to clearly visualize the lateral side of the maxilla. The reflection should be extended beyond the borders of the future osteotomy (window).

Once the flap has been raised to a desired level, the osteotomy step could start.

PS: In case of recently extracted teeth, showing a localized perforation of the bone, the flap reflection should be done through a careful split flap dissection in order to avoid a tearing of the Schneiderian membrane.

5.3.4.3 Sinus Window Osteotomy

Different surgical techniques to access the sinus cavity were described by clinicians.

The window size and position of the lateral maxillary wall are designed according to the planned location(s) of the implant(s) and anatomic conditions.

The sinus cavity is identified due to the lack of blood supply compared to the surrounding cortical, and is often bluish in case of a thin cortical bony wall (Fig. 5.5).

The bony window is either completely removed while the sinus membrane is carefully elevated to create a space for the grafting material or mobilized together with the attached bone window and rotated medially while preserving the sinus membrane intact.

The original modified Caldwell-Luc technique (top-hinge-trapdoor technique) (Tatum 1977), commonly referred to as the lateral window or lateral approach, describes a method of opening a bony window inward using a top hinge in the lateral maxillary sinus wall; the osteotomy is prepared in a superior position just anterior to the zygomatic buttress.

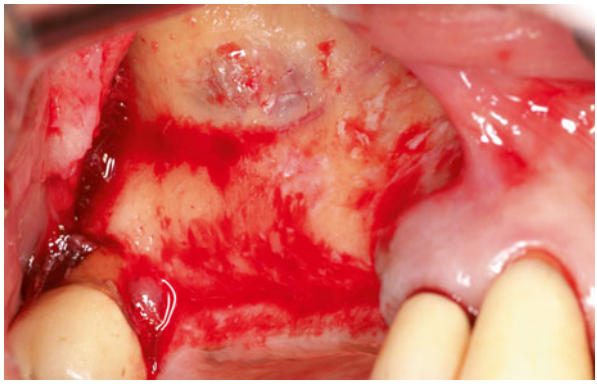


Fig. 5.5 Thin cortical bony wall showing bluish sinus membrane

Two other positions have also been described: a mid-maxillary position between the alveolar crest and zygomatic buttress area, and a low anterior position near the level of the existing alveolar ridge (Lazzara 1996; Zitzmann and Schärer 1998).

Important

- The crestal part of the window (osteotomy) should be higher than the sinus floor in order to contain the bone substitute.
- The shape of the window is generally pyramidal (the top of the pyramid is crestal), with rounded angles in order to avoid membrane tearing.
  This shape could be modified depending on several factors including:
- The presence of septa: a W shape is suggested in case of a short septum; if not, two windows surrounding the septum should be performed.
- The position of the PSAA (posterior superior alveolar artery) (detected on the CBCT) should be also considered to draw the osteotomy margins in order to avoid uncontrolled bleeding.

The osteotomy borders will then be shifted and leveled accordingly.

Lateral SFE approach today involve numerous antrostomy designs: below, a description of three different methods for handling the buccal cortical bone plate in order to introduce the selected bone substitutes.

Top-Hinge Trapdoor Technique (Figs. 5.6 and 5.7)

The originally described technique was the "trapdoor technique" similar to the Caldwell-Luc approach or in fracturing of the cortical bony plate like a trapdoor and using it as the superior border of the sinus compartment leaving it attached to the underlying Schneiderian membrane.

- After the lateral sinus wall has been exposed, round carbide burs (or piezoelectric surgery tips) are used to mark the outline of the osteotomy.
- A rectangular osteotomy is trimmed with round carbide burs (# 6 and 8) to create a U-shaped trapdoor into the lateral antral wall (lateral buttress of the maxilla).

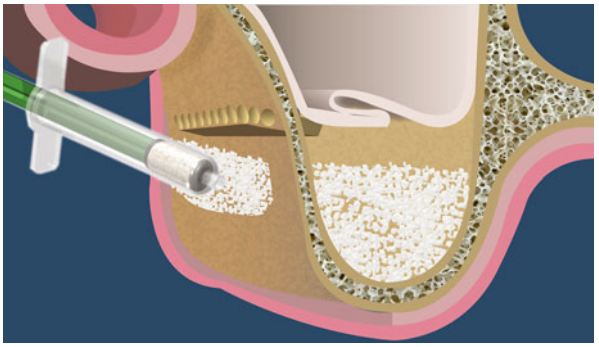


Fig. 5.6 Schematic drawing of the top-hinge-trapdoor SFE

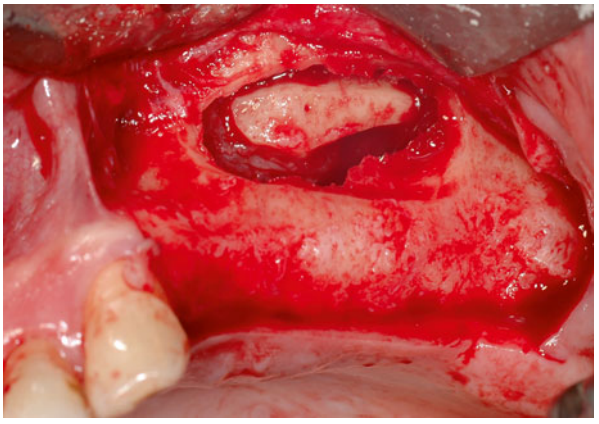


Fig. 5.7 Clinical view showing the reflected membrane and the trapdoor hinged toward the future sinus floor

- Osteotomy procedure must be done with a light touch and a brushing stroke so not to tear the Schneiderian membrane.
- The osteotomy runs from the area of the first or second molar posteriorly to the anterior extent of the maxillary sinus.

The first to be done is the inferior horizontal segment of the rectangle, which is made as close as possible to the floor of the sinus and no more than 2–3 mm above the floor.

This helps keeping the graft material in place in the floor of the sinus.

The superior horizontal segment of the rectangle is performed by drilling closely positioned holes.

This creates a trapdoor, which will be fractured inward and displaced medially while hinging on its superior margin (along the superior aspect of the rectangle).

- The height of this trapdoor should not exceed the width of the sinus (it can be measured in computerized tomography) to allow for a final horizontal position of the new floor.

The infracturing is done carefully to prevent tearing of the Schneiderian membrane during its elevation from the floor of the antrum.

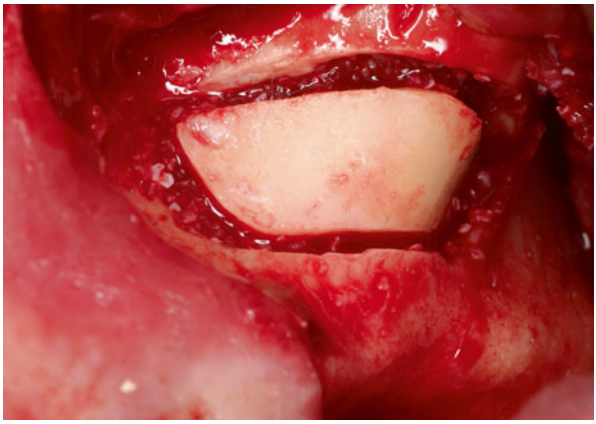


Fig. 5.8 Thick bony plate repositioned over the grafting material

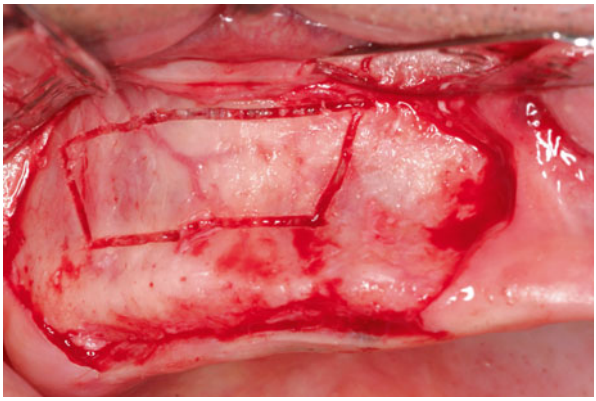


Fig. 5.9 Piezoelectric bony window preparation: note the PSAA artery showing by transparency via the thin buccal plate

It is important to free up the sinus membrane in all directions (anteriorly, posteriorly, and medially) before attempting to intrude the trapdoor medially.

Once the window is created and the membrane exposed, the bone that is adherent is rotated in medially.

It then becomes the new floor of the maxillary sinus.

Since the cortical bony plate is resistant to bone resorption, this may protect the graft.

The space created after the sinus membrane has been elevated by the intruded trapdoor is now ready to receive the bone grafting material in the next stage.

Repositioned Bony Window Trapdoor (Video 5.1) (Figs. 5.8, 5.9, 5.10, and 5.11)
Other methods propose the removal and preservation of the buccal plate.

In this situation, following the preparation of a rectangular osteotomy using a mechanical (burs or microsaw) or piezoelectric tips, lateral window is gently

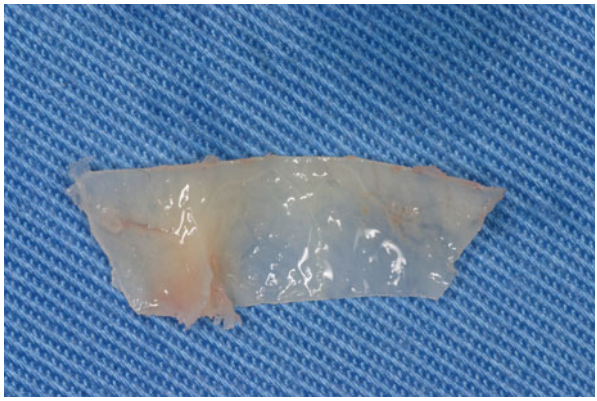


Fig. 5.10 Thin bony plate removed, before its repositioning following the grafting procedure

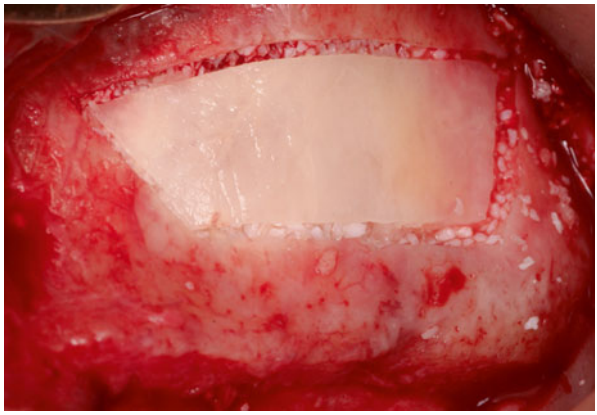


Fig. 5.11 Thin bony plate repositioned in place containing the particulate bone substitutes

mobilized, a small periosteal elevator or a Freer elevator is carefully inserted into the osteotomy line, and via an elevating motion that set the fulcrum on the intact maxillary wall, the bony window is easily detached from the underlying sinus membrane and stored in saline.

The sinus membrane is dissected around the margins of the window and extended inferiorly to expose the floor of the sinus in the edentulous area.

The bony plate will then be repositioned in place on the lateral aspect of the graft material without rigid fixation.

Lundgren et al. (2008) demonstrated the key role of replaceable bone window technique (using an oscillating saw with a thin blade) in a successful SFE procedure.

Bone cutting should be ideally performed in an oblique direction (thick buccal plate), resulting in a flanged bone window capable of being replaced in a stable position.

The rationale for this method was the notion that the lateral window would not completely heal without replacement of its cortical plate that could also stabilize the grafting material (Kim et al. 2014).

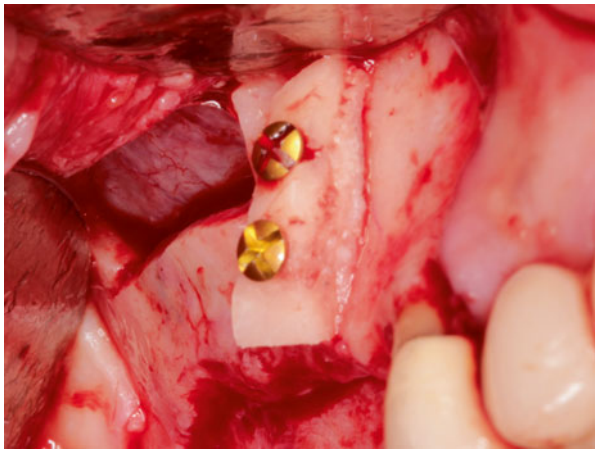


Fig. 5.12 Thick bony plate reclined and positioned anteriorly for an onlay 2D ridge augmentation in the premolar region

Some advantages of using a repositioned bony window:

- Soft tissue from the overlaying oral mucosa does not penetrate to the sinus cavity.
- The fact that air cannot pass through the bony window reduces the risk of disturbing the sinus membrane and the underlying blood clot; the bone window replacement technique may help to reestablish proper pneumatic conditions (Timmenga et al. 1997).
- It is possible that the surface of the bony window contributes to a prolonged period of healing, passively by serving as a stabilizing surface for the blood clot and actively by promoting bone formation beneath the elevated sinus membrane.
- Replaceable bony window acts as an osteoinductive autologous barrier membrane over various bone graft materials and accelerates new bone formation (Kim et al. 2014).

However, healing of the lateral window by bone apposition has been demonstrated to occur without replacing the cortical bony plate (Boyne 1993).

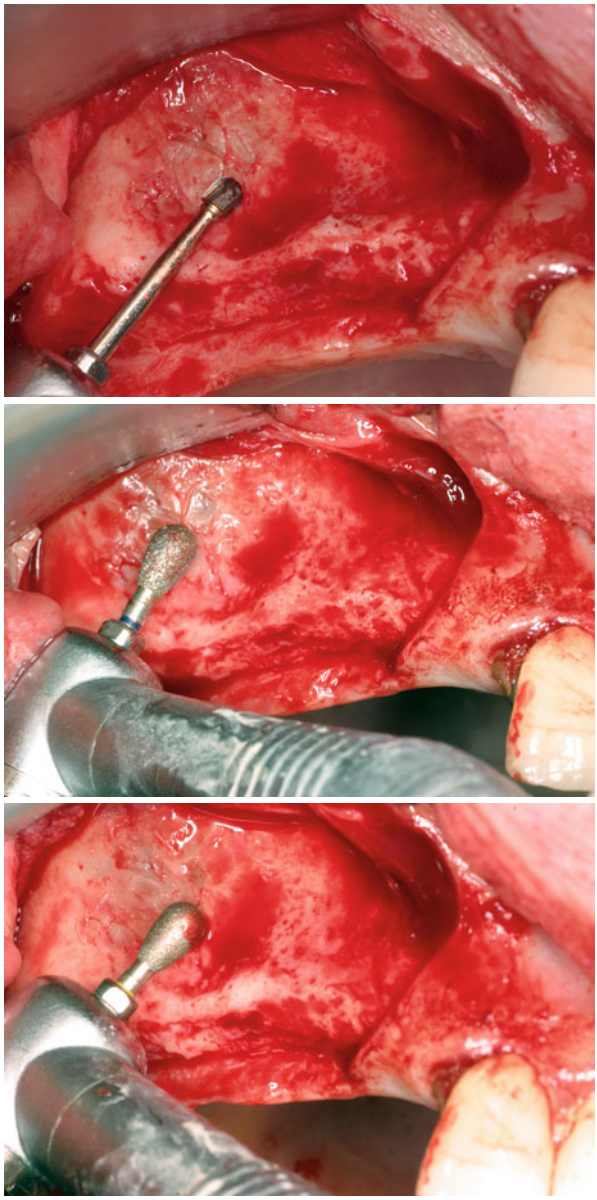
This bony plate could be also positioned in another sites for lateral ridge augmentation (2D or 3D) (Fig. 5.12).

The main indication for this technique is the presence of a thick lateral sinus wall since:

- In case of a complete osteotomy procedure, a thick bony wall may be a time-consuming problematic barrier requiring additional efforts to reach the Schneiderian membrane.
- In case of a classical "trapdoor hinge technique," a thick lateral maxillary wall that often resists inward movement is better removed and repositioned later.

Complete osteotomy (Video 5.2) (Figs. 5.13, 5.14, and 5.15)**.**

The third surgical technique and the most commonly reported is the preparation of an access hole by removing the entire buccal bone plate (thinning of the buccal bone to a paper-thin bone lamella prior to the elevation of the sinus membrane).



Figs. 5.13, 5.14, and 5.15 Complete osteotomy: using carbide round bur followed by large grit diamond bur then fine grit diamond bur

- In case of a thick bony window, it is less time-consuming to first reduce the thickness of the wall: the bone is trimmed down to a thin bony plate with a round carbide bur, a piezoelectric tip, or a bone scraper (Figs. 5.16, 5.17, and 5.18).
- Upon confirmation that the sinus membrane is visible through the window, the round carbide bur is switched with a round bur or a diamond-coated smoothing piezoelectric insert (see Fig. 5.16) to refine the window and minimize the risk of

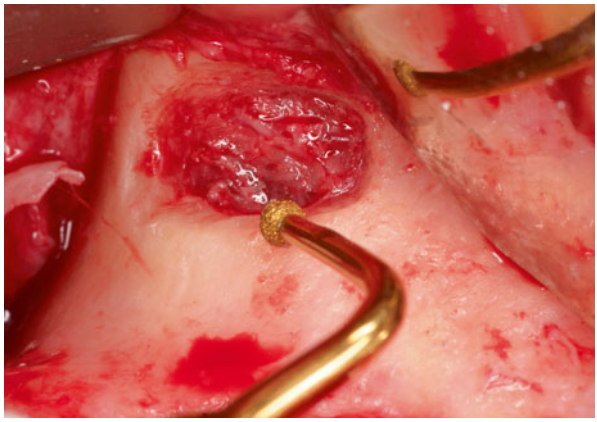


Fig. 5.16 Complete osteotomy using a piezoelectric round tip, minimizing the risk of membrane perforation

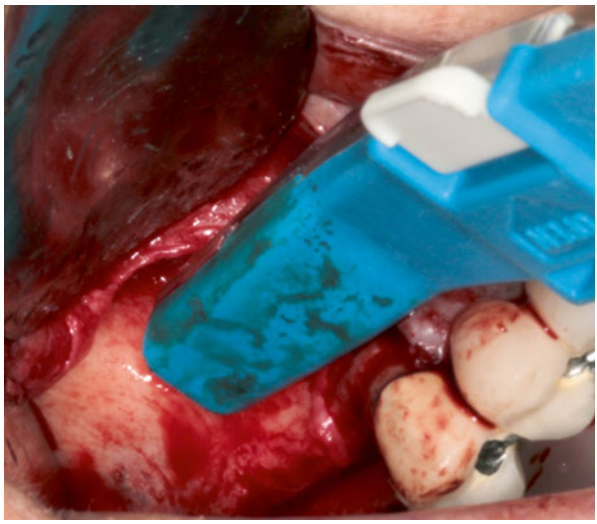


Fig. 5.17 Bone scraper trimming the buccal plate in order to reduce the thickness of the wall

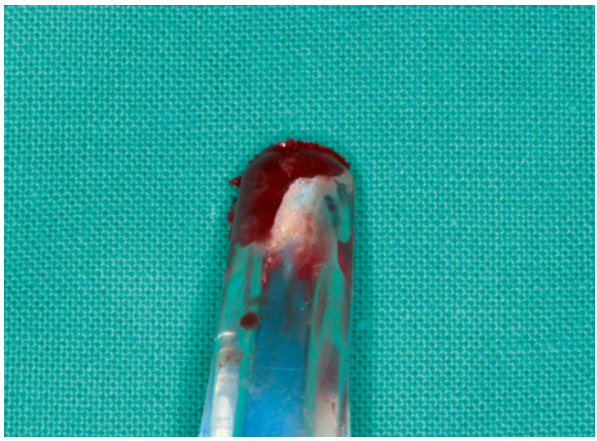


Fig. 5.18 Particulate autogenous bone collected using a bone scraper ready to be mixed with bone substitutes

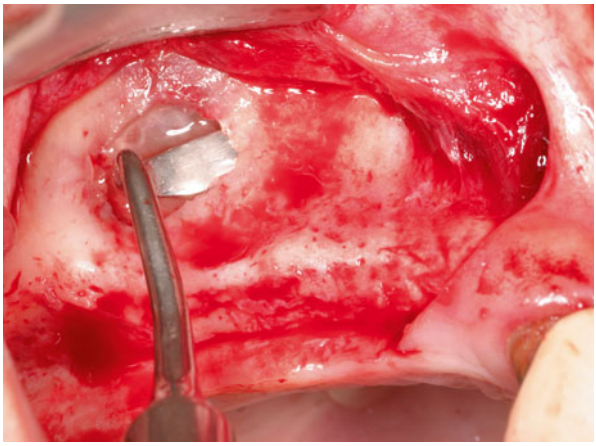


Fig. 5.19 Short and smooth sinus curette initiating the membrane lifting

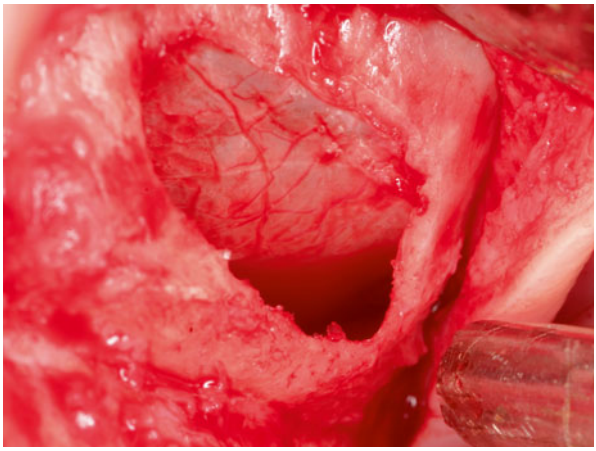


Fig. 5.20 Schneiderian membrane lifted in all directions: anteriorly, posteriorly, and medially

unintended perforation of the sinus membrane. The bone removed by osteoplasty could be harvested and incorporated within the sinus graft.

- The preparation is continued until a bluish hue of the sinus membrane is observed.
- The osteotomy border should be as smooth as possible, avoiding cutting edge in order to reduce the risk of membrane tearing.

Window preparation is a critical step. Perforations of the membrane occur frequently during this step and are the main reason of aborting the SFE procedure. The use of piezoelectric devices is recommended to increase safety and reduce complications related to Schneiderian membrane tearing.

5.3.4.4 Lifting the Schneiderian Membrane (Figs. 5.19, 5.20, and 5.21)

Care must be taken to perform a 3D membrane elevation: it is important to free up the sinus membrane in all directions (mesially, distally, and medially).

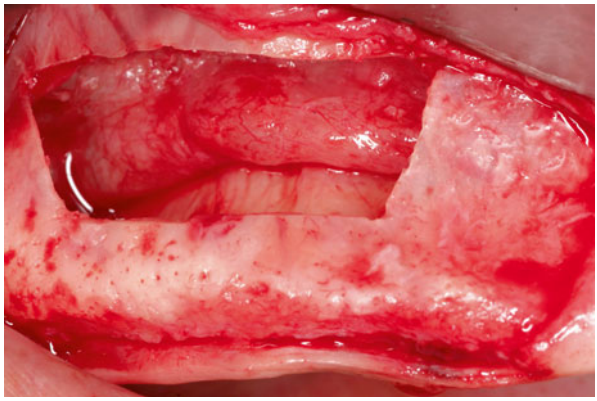


Fig. 5.21 Membrane elevation should reach the medial wall in order to optimize a tension-free grafting material introduction for a 3D regeneration (filling)

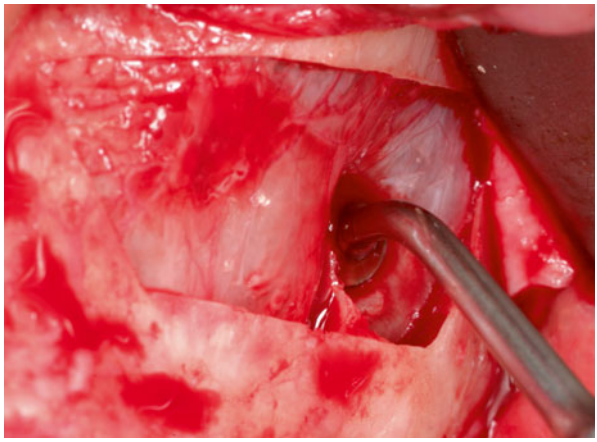


Fig. 5.22 "Bell-shaped" tip facilitating the lifting procedure toward the knife-edge septum

The membrane at the inferior aspect of the osteotomy is dissected from the floor of the maxillary sinus and elevated upward to create a space in the floor of the sinus for the bone-graft material. This procedure will be performed according to the technique used.

If the buccal wall is eliminated (complete antrostomy), the sinus membrane is elevated directly with blunt instruments, broad-based freers, and curettes with different angulations to access the different walls of the sinus. It is recommended to use smooth and large end curettes in order to reduce the trauma. Dedicated piezoelectric inserts are also available. They are particularly useful to start the lifting procedure especially in the presence of a septum (Figs. 5.22 and 5.23).

Usually, membrane elevation starts at the edges, using a short curette, increasing gradually the amount of membrane elevation from the superior border of the osteotomy, proceeding approximately 2–3 mm mesially, toward the mesio-superior line angle and along the mesial part of the window, and effecting detachment of a portion of the sinus membrane from the alveolar bone.

We proceed to the next step only once we have released the membrane at least 2 mm along the superior, mesial, and distal borders of the bony window, allowing

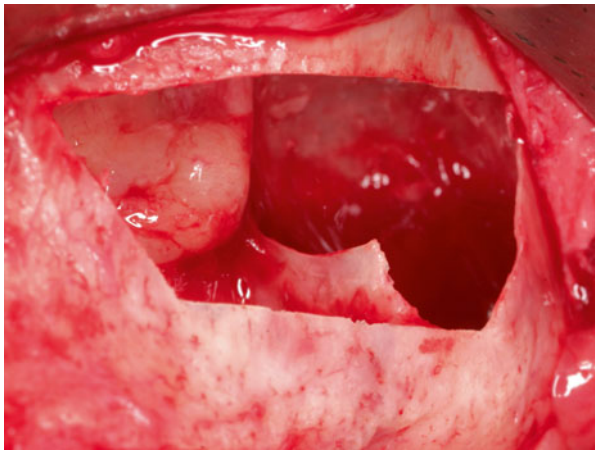


Fig. 5.23 The presence of a septum with a sharp edge jeopardizing the integrity of the Schneiderian membrane

the passive insertion of longer curettes into the created space. Surgical curettes should be permanently in tight contact with the underlying bony walls in order to minimize membrane tearing.

Care should be taken to perform 3-dimensional membrane lifting in order to decrease incidence of sinus membrane perforation.

Excessive pressure in a specific area while reflecting the membrane may lead to a perforation.

Moreover, the membrane must be elevated higher than the superior osteotomy to prevent excessive pressure on the bone-graft material.

It is also important to reflect the membrane up to the medial (palatal) wall (see Fig. 5.21) of the maxillary sinus in order to avoid membrane overlapping, thus resulting in incomplete bone regeneration at the palatal wall of the implant.

The limits of the reflected area are strongly related to the desired area to be grafted and the positions of the future implants (delayed or simultaneous).

- In case of "complete osteotomy" or "repositioned bony window") procedures, the reflected membrane becomes the superior (and distal) wall of the compartment that will receive the osseous graft.
- In the trapdoor hinge technique, gentle tapping is continued until complete movement of the bony plate is observed. The bone trap that was fractured inward in combination with the elevation of the sinus membrane and rotated upward will create the roof and provide adequate space for grafting material. Care should be taken not to perforate the sinus membrane at this step.

Septa Incidence on SFE (Figs. 5.24 and 5.25)

These septa were first described by the anatomist Underwood13 in 1910 and are thus also referred to as Underwood's septa.

The presence of septa in the region of the sinus floor (bucco-palatal or mesio-distal) can cause complications during SFE procedures; while they can limit

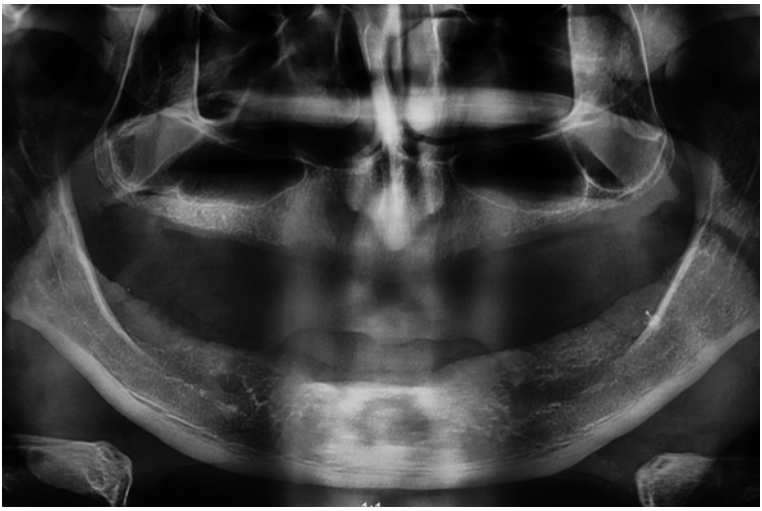


Fig. 5.24 Panoramic radiograph showing a vertical septum protruded in the sinus cavity

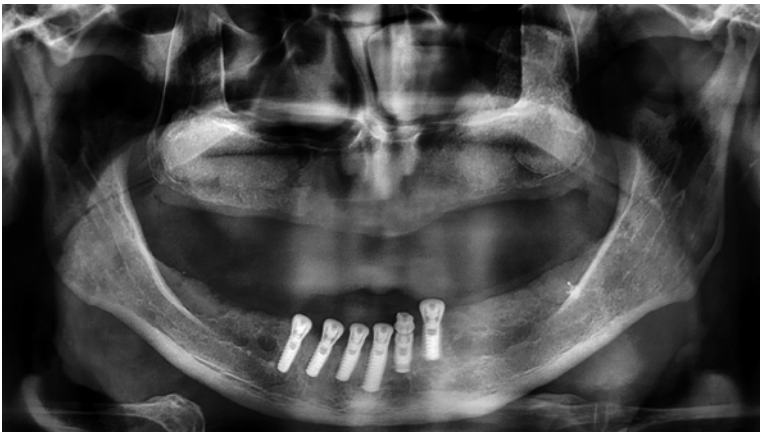


Fig. 5.25 One-month postoperative radiography after sinus grafting

creation of a window in the lateral antral wall and elevation of a hinge door, there is a risk of tearing the Schneiderian membrane of the maxillary sinus when elevating it from an alveolar recess containing several septa.

If septa are encountered in the antral floor during SFE procedures, Boyne and James (1980) recommended cutting them with a narrow chisel (or a piezoelectric device nowadays) and removing them with a hemostat so that the bone graft can be placed completely across the antral floor without interruption. If septa are left in situ during SFE, the Schneiderian membrane is at risk of being torn, particularly at the cranial edge of the septum, when being elevated. Moreover, septa can impede the view of the sinus floor and may limit placement of grafting material, thus preventing adequate filling of the sinus floor.

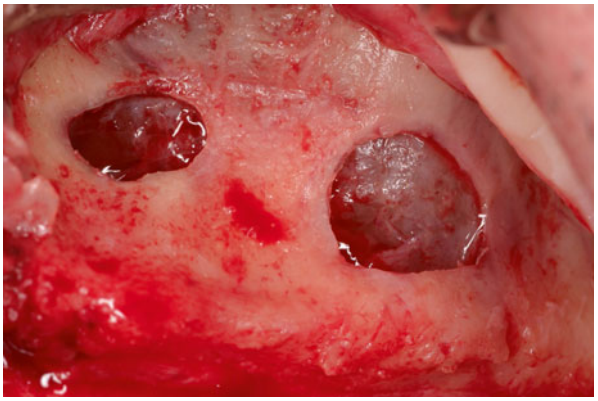


Fig. 5.26 Two distinct entries to reach the sinus from each side of the septum

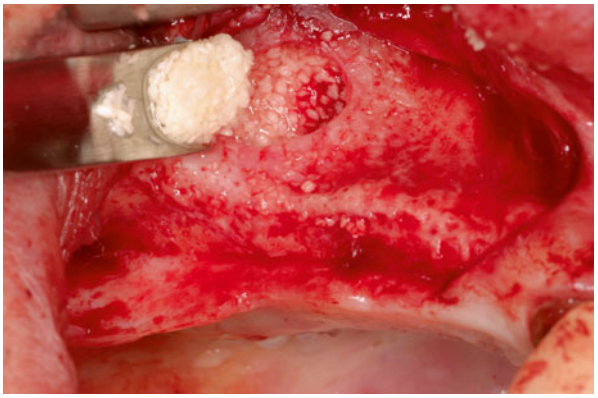


Fig. 5.27 Packing the grafting material in the created space under the membrane

An interesting alternative would be to perform two different osteotomies from each side of the septum, as if we are in the presence of two side-by-side sinuses (Fig. 5.26).

While rotary instruments are commonly used for window preparation, surgical curettes for membrane elevation, the recent development of piezoelectric ultrasonic devices may contribute to reduce intraoperative complications such as membrane perforation (Wallace et al. 2007).

5.3.4.5 Introduction of the Grafting Material into the Sinus (Fig. 5.27)

The resulting space created after membrane-lifting inward is packed with bone-graft material that is placed under the membrane. The grafting material should be pushed through the window in all directions: mesially and distally with the help of instruments such as pluggers, periosteal elevators, or even osteotomes. Most importantly, it must reach the medial wall of the maxillary sinus. It should be placed in the cavity loosely, avoiding overpacking.

The surgeon should add an additional 20 % of bone-grafting material to counteract the loss of originally grafted volume. After the grafting material is placed into the sinus, the mucoperiosteal flap is repositioned combined or not to membrane placement over the lateral window (Figs. 5.28 and 5.29).

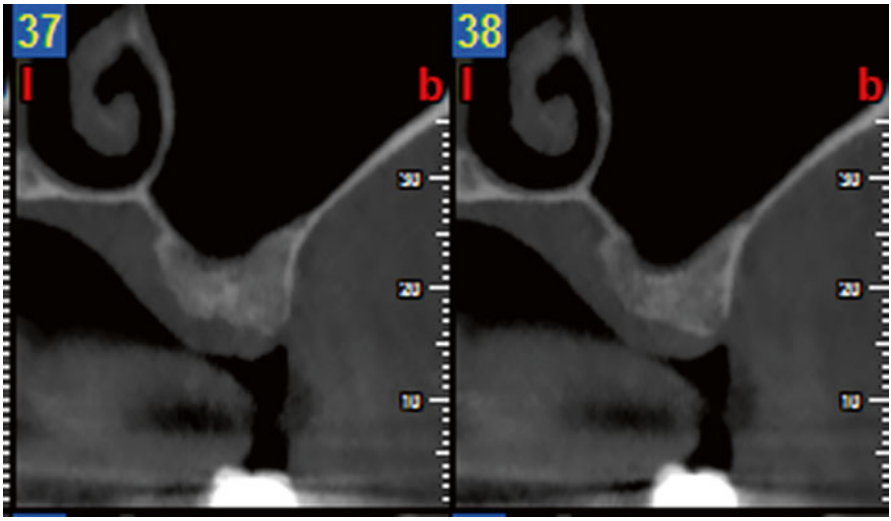


Fig. 5.28 Preoperative CBCT prior to lateral SFE

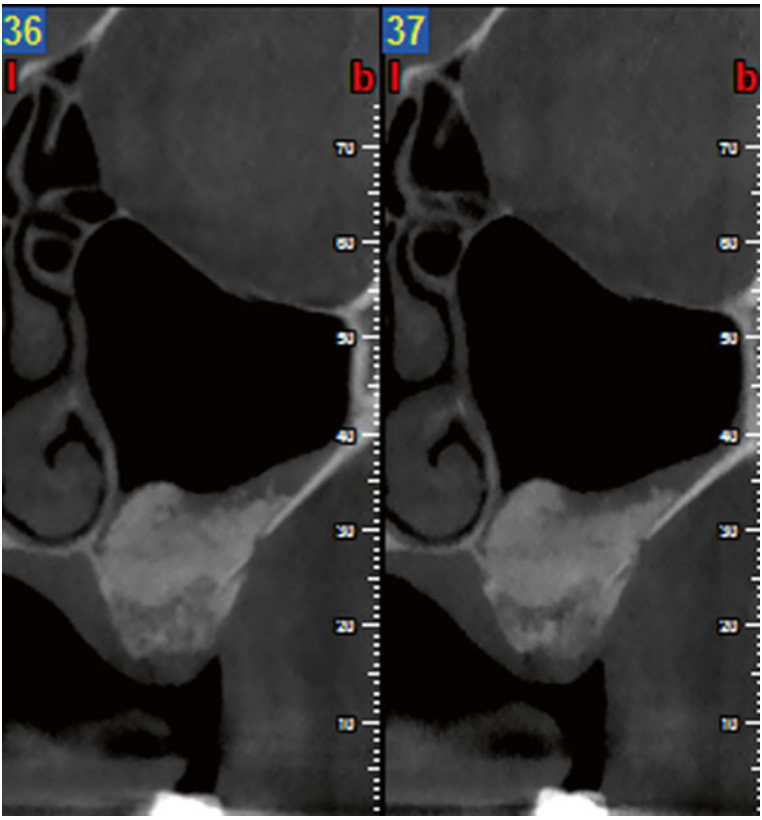


Fig. 5.29 Postoperative CBCT at 8 weeks showing the graft remodeling

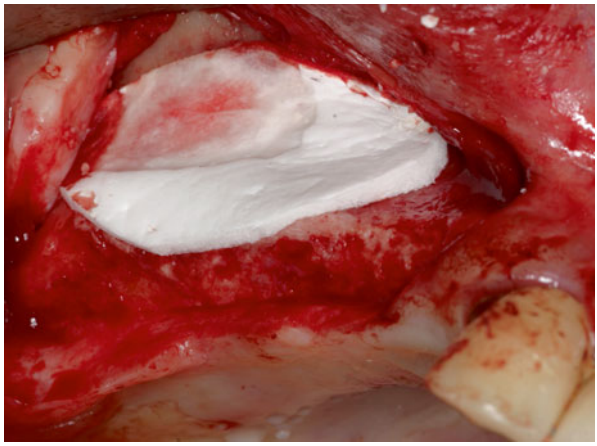


Fig. 5.30 Absorbable collagen membrane protecting the grafting material

5.3.4.6 Membrane Placement (Fig. 5.30)

Conflicting results concerning the benefits of placing a membrane over the lateral window have been reported.

Many investigators claimed positive results with barrier membrane placement over the lateral wall in SFE (Wallace et al. 2005; Small et al. 1993; Hürzeler et al. 1996; Peleg et al. 1999; Lorenzoni et al. 2000) and revealed a tendency for better bone formation and less implant failures (Tawil and Mawla 2001; Pjetursson et al. 2008). On the opposite, a recent review (Klijn et al. 2012) with histomorphometric data following SFE with autografts alone did not confirm any effect of a barrier membrane on bone formation.

The membrane barrier is used to cover the osteotomy site extending 2–3 mm beyond its borders, promoting hemostasis, and preventing graft disruption at the time of suturing (Avila et al. 2010).

Depending on the authors, the membrane is stabilized (with tacks or screw) or not. As in a GBR procedure, the membrane appears to exclude non-osteogenic soft tissue invasion from the grafted sinus, with a resultant increase in vital bone formation and an increased rate of implant survival.

Fewer studies have compared the results achieved with and without barrier membranes (Froum et al. 1998; Tarnow et al. 2000; Tawil and Mawla 2001).

Note

- It appears that covering the lateral window with a membrane may have a beneficial effect. Previous studies reported that:
  1. Vital bone formation in SFE is improved when a membrane is placed over the window.
  2. Vital bone formation is similar with nonabsorbable and absorbable membranes.
  3. Implant survival rate is similar with nonabsorbable and absorbable membranes.

Overall, it is recommended to use a membrane over the lateral window in clinical situations characterized by a limited osteogenic potential of the patient or the bone substitute used.

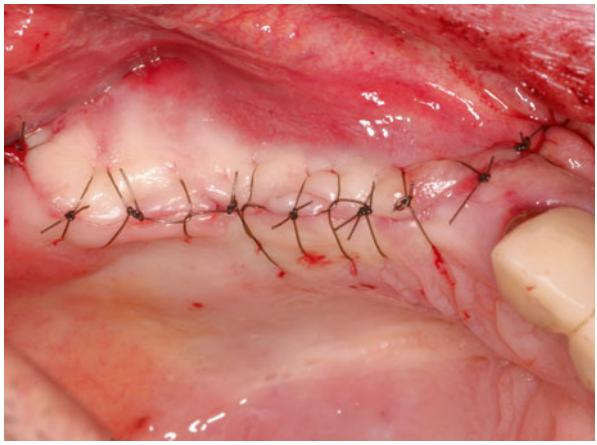


Fig. 5.31 Proper flap closure using uninterrupted sutures on the top of the crest and single sutures for the releasing incisions

5.3.4.7 Suturing Technique (Fig. 5.31)

Suturing technique should insure proper flap closure without tension in order to maintain hemostasis and to prevent bone exposure through healing by primary intention.

Single interrupted sutures (5/0 or 4/0) are mainly used for the releasing incisions.

Uninterrupted sutures are used specifically on the top of the ridge in case of delayed or submerged implant placement; the stitch is commenced at one extremity of the wound (generally at the posterior extremity) and after the needle is passed through the two lips. It is then carried under the slack of the thread, so that the loop of each stitch after being tightened shall be at right angles to the edge of the wound, while the portion intervening between the stitches is parallel to it. This kind of suturing technique provides adequate tension for wound closure, but loose enough to prevent tissue ischemia and necrosis.

Sutures should be removed 10 days to 2 weeks following the SFE procedure.

5.3.5 Contribution of Piezoelectric Surgery in SFE

Piezoelectric surgery is a hard tissue surgical application using multipurpose high-end ultrasonic device that was originally developed for the atraumatic cutting of bone by way of ultrasonic vibrations and as an alternative to the mechanical instruments that are used in conventional oral surgery.

A critical feature of a piezosurgery unit is the ability to vary the oscillation frequency and the cutting energy resulting in the selective cutting of bone without damaging the adjacent soft tissue (e.g., vessels, nerves or specifically sinus membrane in SFE), providing a clear visibility in the operating field due to pressurized irrigation and cavitation effect, and cutting with micron sensitivity without the generation of heat. Specific inserts are some three times more powerful than conventional ultrasonic units, which allow them to cut highly mineralized cortical bone. The reduced range and the linearity of the vibrations allow for precise control of cutting. The cutting characteristics of piezosurgery are mainly depending upon the

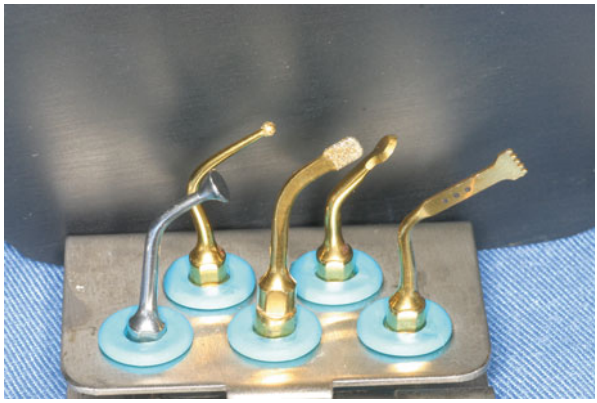


Fig. 5.32 Piezoelectric kit including various tips used in the different steps of SFE

degree of bone mineralization, the design of the insert, the applied pressure on the handpiece and the speed of movement during usage.

All of the surgical techniques to elevate the maxillary sinus present the possibility of perforating the Schneiderian membrane. This complication can occur during the osteotomy, which is performed with burs, or during the elevation of the membrane when using surgical manual curettes. The piezoelectric osteotomy of the bony window easily cuts mineralized tissue without damaging the soft tissue; moreover, sinus membrane elevation from the sinus floor is performed using both piezoelectric elevators and the force of a physiologic solution subjected to piezoelectric cavitation without causing perforations.

Over the past two decades, an increasing amount of literature has shown that piezoelectric devices are innovative tools in oral surgery (Fig. 5.32). Numerous publications have also shown the benefits of their use in SFE (Vercellotti et al. 2001, 2005; Wallace et al. 2007).

Piezosurgery can be particularly useful for the preparation of the bony window (diamond-coated square or bell-shaped tips) (see Fig. 5.16) and in atraumatic dissection of the thin and delicate sinus membrane with specially designed tips (rounded, dull, bell-shaped, or curette-shaped tips) (Fig. 5.33).

Piezoelectric SFE surgery has been described by Vercellotti et al. (2001) (Vercellotti et al. 2005) who demonstrated its clinical effectiveness and a better tissue response based on histologic and histomorphometric evidence of wound healing and bone formation; the tissue response is more favorable to piezosurgery than to diamond or carbide rotary instrumentation (Vercellotti et al. 2005).

When the lateral wall is thin, it is advised to use the diamond ball smoothing insert or the diamond scalpel to outline the window.

If the wall is thick, it is less time-consuming to first reduce the thickness of the wall with the osteoplasty insert and then refine the window with the diamond-coated smoothing insert.

The bone removed by osteoplasty can be harvested and incorporated within the sinus graft.

The initial release of the membrane from the antrostomy edges is performed with a dull, rounded, noncutting elevator that works with saline cavitation to safely create

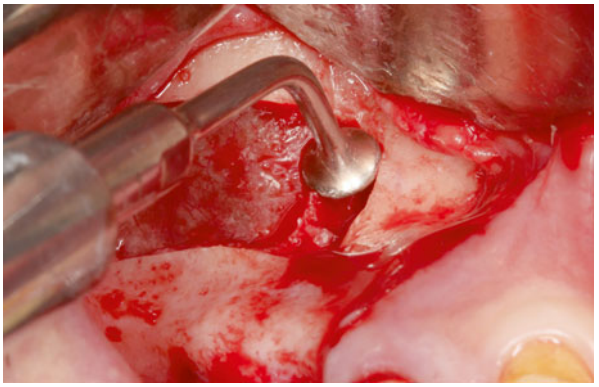


Fig. 5.33 "Bell-shaped" piezoelectric tip initiating the dissection of the Schneiderian membrane

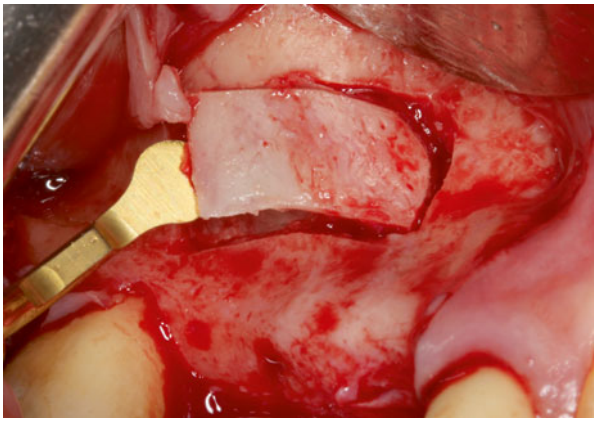


Fig. 5.34 "Osteoplasty" insert used toward the internal side of the bony trap in order to detach it from the sinus membrane

a small internal elevation (Vercellotti et al. 2001). The procedure is often completed with conventional sinus membrane curettes.

While perforation of the sinus membrane is the most common complication (14–56 %) in SFE when using rotary instruments (Testori et al. 2008), Wallace et al. (2007) reported that piezosurgery could significantly minimize sinus perforation rates (3–7 %). Consequently, piezosurgery offers a 75 % reduction in the expected perforation rate.

Further, the occurrence of perforations appears to be equally attributable to rotary instrumentation, initial release of the membrane at the antrostomy margin with hand instruments, and the continued elevation of the membrane from the internal sinus walls.

Various tips are specifically designed for SFE. Light handpiece pressure and an integrated saline coolant spray keep the temperature low and the visibility of the surgical site high. It is claimed that inadvertent perforations of the sinus membrane are unlikely when piezosurgical techniques are appropriately applied.

Both hinge and complete antrostomies can be performed. Repositioned bony window is a particularly interesting application of piezoelectric surgery (Fig. 5.34).

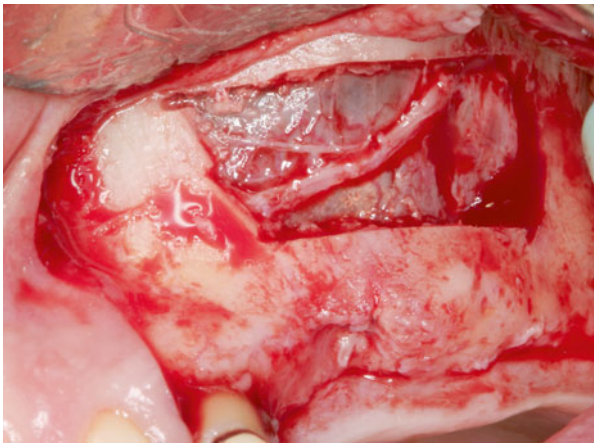


Fig. 5.35 Intact PSAA (posterior superior alveolar artery) showing within the sinus membrane due to the atraumatic use of piezoelectric surgery

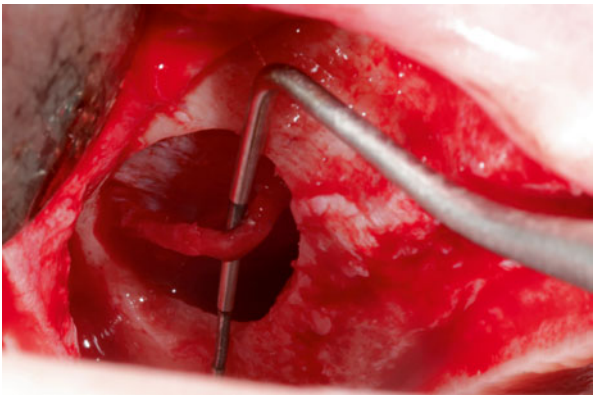


Fig. 5.36 Atraumatic bone osteotomy using piezoelectric device leaving undamaged the PSAA artery due to the selective cutting piezosurgery feature

On the other hand, the use of piezoelectric inserts allows for antrostomy preparation without injury to the vessels in the lateral wall as the inserts do not cut soft tissue, thus avoiding intraoperative complication such profuse bleeding (Fig. 5.35 and 5.36). Bleeding is the second most frequent complication in SFE when performing the antrostomy with rotary cutting instruments. This occurs when the anastomosis of the lower branch of the posterior superior alveolar artery and the infraorbital artery is severed, usually with the vertical osteotomy cuts (Elian et al. 2005). Bleeding from this artery is usually minimal, but may become sometimes uncontrolled, increasing the operative time, postoperative edema, and ecchymosis.

While piezoelectric surgery is relatively new, it has been used with excellent results in Europe for more than 10 years. The following advantages have been shown in SFE using piezoelectric techniques:

1. Reduced membrane perforation rate
2. Improved intraoperative visibility
3. Reduced intraoperative bleeding
4. Reduced surgical trauma

5.4 Graftless Approach

Recently, the relevance of placing a grafting material in SFE procedures has been questioned (Summers 1994a; Cosci and Luccioli 2000; Vercellotti et al. 2001; Galindo-Moreno et al. 2007).

Researchers have hypothesized that sinus membrane elevation without insertion of any BS is a suitable technique for SFE (Lundgren et al. 2003; 2004; Palma et al. 2006; Hatano et al. 2007; Thor et al. 2007; Sul et al. 2008; Jeong et al. 2009; Jung et al. 2007).

Clinical studies have confirmed that an isolated coagulum space created by the elevated membrane and a simultaneous protruding implant placement resulted in new bone formation (and a new sinus floor), as indicated by the concept of guided tissue regeneration (Lundgren et al. 2004).

Several studies (Lundgren et al. 2004; Palma et al. 2006; Hatano et al. 2007; Thor et al. 2007; Sul et al. 2008; Jeong et al. 2009) have confirmed the key role of dental implants as a space-maintaining device in graftless technique: a prerequisite as these implants serve as tent poles for the sinus membrane. However, achieving implant primary stability is often difficult in many patients in the presence of an unfavorable bone volume.

Cricchio et al. (2011) have shown that the use of a stable space-making device between the sinus membrane and the secluded space is able to induce bone formation. Lundgren et al. (2008) used a space-making device of about 8 mm, made of a bioresorbable polymer, and introduced into the maxillary sinus floor in order to keep up the elevated membrane.

Although the new bone was insufficient to allow implant placement with full bone coverage, the 3–4 mm of new bone made it possible to place implants with sufficient primary stability to perform a second sinus membrane-elevation procedure to gain additional bone (Lundgren et al. 2004).

Long-term human studies using blood as grafting material in SFE and with a minimum of 1-year follow-up revealed the presence of bone gain. In a rabbit experiment, Xu et al. (2005) observed newly formed woven bone in the augmented space after SFE and grafting of blood clot.

Hatano et al. (2007) performed SFE with simultaneous implant placement using venous blood as filler. They described a mean gain in bone height of 10 mm after 6 months of healing in a human study.

In contrast, Sul et al. (2008) and Kim et al. (2014) showed only about 3.5 mm of new bone gain beyond the sinus floor in histologic sections from experimental dogs.

Though the short-term human studies demonstrated new bone formation, it requires long-term follow-up to confirm these results.

There has been controversy concerning the potential osteogenic role of the sinus membrane. While Kirker-Head et al. (1997) reported that the maxillary SFE procedure with absorbable collagen sponges failed to mineralize by 4 weeks in an animal study, later studies strongly indicated an osteogenic potential for the sinus membrane (Lundgren et al. 2003, 2004; Palma et al. 2006; Hatano et al. 2007;

Thor et al. 2007; Sul et al. 2008; Jeong et al. 2009; Jung et al. 2007; Gruber et al. 2004; Xu et al. 2005; Srouji et al. 2009). Gruber et al. (2004) revealed that the sinus mucosa contains mesenchymal progenitor cells and cells committed to the osteogenic lineage, which may constitute another source of bone-forming cells with sinus membrane elevation.

To summarize:

- If a substantial amount of new bone is required, SFE should be performed in conjunction with grafting material and delayed implant placement.
- In more favorable cases with more residual bone, SFE could be performed simultaneously with implant placement to maintain the closed coagulum space for new bone formation without grafting material: approximately 3 mm gain of new bone can be expected (Hatano et al. 2007; Sul et al. 2008; Leblebicioglu et al. 2005; Nedir et al. 2009; Pjetursson et al. 2009).
- Surface-modified implants showed a stronger bone response than machined implants in maxillary sites particularly in graftless SFE (Lundgren et al. 2008).

5.5 Technical Guidelines of One-Stage SFE (with Simultaneous Implant Placement) (Figs. 5.37, 5.38, and 5.39)

- A relatively small buccal window is created in the lateral wall of the maxillary sinus to preserve the residual bone for a better implant osseointegration.
- The osteotomy at the inferior aspect of the window should be sufficiently away from the top of the residual alveolar ridge to prevent an uneventful fracture of the residual lateral wall during implant stabilization.

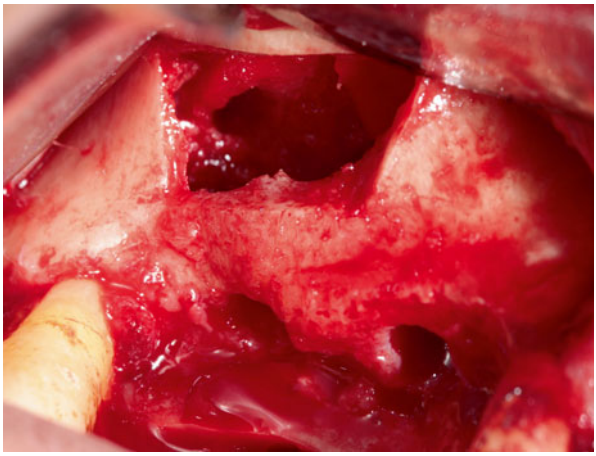


Fig. 5.37 SFE combined to simultaneous preparation of the implant sites

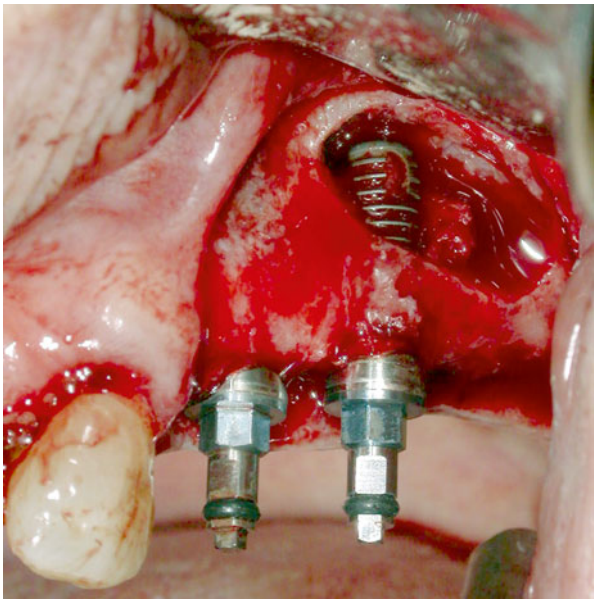


Fig. 5.38 After grafting the medial part of the sinus, simultaneous implants are placed with a particular care to achieve a proper primary stability

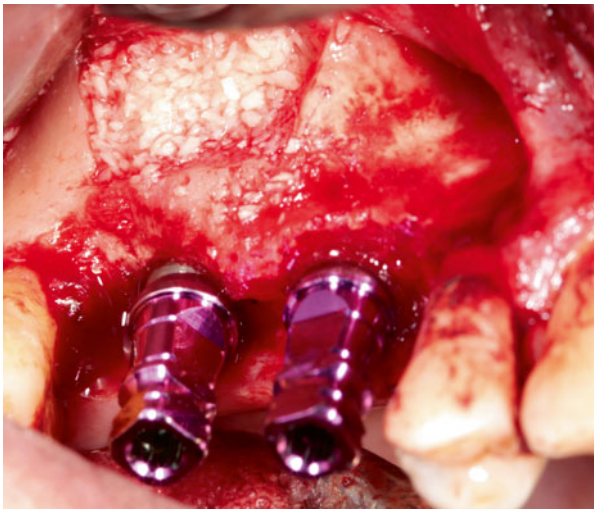


Fig. 5.39 Accomplishing bone grafting on the outer part of the sinus cavity after implant placement

- Knowing that primary stability is an important factor in implant survival rate, implant site preparation is performed according to manufacturers' recommendations in soft bone protocol (undersizing).
- In patients with low bone density, bone condensing may enhance the quality of loosely structured trabecular bone in the maxilla. This is achieved by using only the small diameter pilot drill (2 mm generally), followed by application of osteotomes or the implant itself, thus condensing the bone in a lateral direction to enhance primary stability.

- Care is taken not to penetrate the sinus membrane during implant site preparation.
- Graft material placement in the created cavity should be initiated before inserting the implant to insure meticulous condensation toward the medial bony wall of the sinus cavity and then completed after implant stabilization.
- Implants are then placed in their final position. Graft condensation and mesio-distal parallelism of the implants are controlled visually and by periapical X-rays.
- Achieving primary stability relies on both bone quality and quantity.
- Implant design being another factor that influence implant stability: Tapered implants with high insertion torque may favor primary stability in resorbed maxilla.
- Rough-surface implants are favored since they lead to higher survival rates than machined surface implants when placed in grafted sinuses (Wallace and Froum 2003; Del Fabbro et al. 2004).

5.6 Comparison of One-Stage Versus Two-Stage SFE

Two general procedures could be considered in SFE techniques regarding the timing of dental implant placement: a "two-stage" technique using a lateral window approach, followed by implant placement after a healing period of 4–10 months (depending on augmentation volume, sinus anatomy, and grafting material), and a "one-stage" technique with a simultaneous implant placement; this technique was first suggested by Tatum (1986) who performed a SFE procedure with simultaneous placement of submerged implants.

The decision to apply a one- or two-stage technique is made based on the amount and the quality of residual bone available, thus the possibility of achieving implant primary stability (Pjetursson et al. 2008).

It used to be a general rule that a residual bone height (RBH) ≥ 5 mm is considered sufficient to achieve initial implant stability (Misch 1987; van den Bergh et al. 2000; Ulm et al. 1995).

Despite numerous studies (Peleg et al. 1998; Winter et al. 2002) have demonstrated the successful outcome of a one-stage approach when RBH is as little as 1 mm, from an experimental point of view, it seems that simultaneous implant placement and SFE should be performed in the presence of a RBH of at least 4 mm to achieve implant stability; less than 4 mm of RBH would jeopardize the technique's success (Felice et al. 2014); then a 2-stage lateral SFE should be carried out (Zitzmann and Schärer 1998; Ioannidou and Dean 2000).

Controlled clinical and experimental trials have compared the effect of different RBH on clinical outcome following simultaneous implant placement.

Experimental animal trials (Fenner et al. 2009) evidenced a significant association of RBH with implant stability.

In one study, Geurs et al. (2001) indicated a greater implant loss when less initial native bone is noted. So the amount of RBH significantly influenced the implant survival rate (ISR) after SFE.

Aghaloo and Moy's (2007) systematic review attempted to address the important question of ISR based on the residual bone height (RBH) beneath the maxillary sinus, but few studies comparing this aspect met the inclusion criteria. They demonstrated an ISR varying from 81 to 96 %, which is comparable to those reported in previously systematic reviews. A study showed a 96.8 % ISR with less than 5 mm and 89.3 % ISR with greater than 5 mm RBH (Valentini and Abensur 1997), while other studies showed the opposite result, with 73.3 % success with less than 4 mm and 94.6 % success with greater than 4 mm (Toffler 2004) and 85.3 % success with less than 5 mm and 93.6 % with greater than 5 mm (Kaptein et al. 1998).

In one-stage SFE approach, primary stability is influenced by several other factors in addition to RBH such as bone quality (Chiapasco et al. 2006).

In the "sinus consensus conference," the ISR of implants placed simultaneously with SFE was compared to the ISR of those placed 6–9 months after SFE; a better success rate was found with a delayed approach (Jensen et al. 1994). A histological analysis demonstrated that a one-stage SFE approach apparently resulted in a low proportion of "bone to implant" contact after 6–14 months irrespective of graft type (Jensen and Sennerby 1998).

Experimental research has also shown the advantages of a two-stage technique in the osseointegration process (Rasmusson et al. 1999).

However, a more recent systematic review (Del Fabbro et al. 2013) demonstrated controversial results with a significantly better ISR for simultaneous implant placement (95.95 % for simultaneous procedure versus 93.34 % for delayed procedure).

In fact, numerous clinical studies reported that the ISR is similar for implants placed at the time of lateral SFE or 6 months later (91.8–100.0 % and 91.9–100.0 %, respectively) (Khoury 1999; Peleg et al. 2006; Hatano et al. 2004; Strietzel 2004; Becktor et al. 2004).

Wallace and Froum (2003) published in their systematic review a similar ISR for implants placed in a one-step or a two-step procedure with 89.7 and 89.6 %, respectively.

Del Fabbro et al. (2004) came to a similar conclusion. The ISR obtained from his systematic review were 92.93 % for a simultaneous and 92.17 % for a staged implant placement. A more recent literature review has suggested that both approaches may involve similar ISR (Del Fabbro et al. 2008).

Supporters of the one-stage SFE mention the following benefits:

- The treatment period: a 1-stage procedure is less time-consuming for both the clinician and the patient (Smiler and Holmes 1987; Zinner and Small 1996; Khoury 1999; Chiapasco and Ronchi 1994), and the morbidity is lowered (Khoury 1999) because there is no need for a second surgery.
- The risk of a graft resorption is minimized (Chiapasco and Ronchi 1994).

The main disadvantage of one-stage SFE remains in the less predictable initial stability (Chiapasco and Ronchi 1994; Felice et al. 2014).

To summarize, one-stage SFE is more technique sensitive, and its success relies mostly on the amount of RBH.

In a staged approach, the initial stability is achieved easily since the grafted site is well mineralized (Chiapasco and Ronchi 1994). However, the time required for graft healing (at least 5 months) before implant placement extends the treatment time (Rodoni et al. 2005) and displeases the patients.

5.6.1 Classifications and Criteria for Selection of One-Stage Versus Two-Stage Approach in SFE

Numerous authors attempted to propose classifications that may help the practitioner in selecting the most appropriate technique for a given clinical situation. These classifications were based on several parameters such as the RBH, the ridge width, the distance between the top of the bone crest, and the cementoenamel junction.

Jensen (1994) and Misch and Judy (1987) were the first to describe the first classifications according to bone resorption patterns in edentulous ridges (RBH). At that time, crestal SFE approach was not published yet. Therefore, lateral SFE was the only treatment option. Moreover, short implants were not available and scientifically proven. Consequently, lateral SFE was still performed in the presence of an RBH of 10 mm, which is nowadays unacceptable.

Zitzmann and Schärer (1998) were the first authors to introduce the crestal approach in their classification. They proposed guidelines also based on the RBH, distinguishing between three clinical situations: ≤4 mm (two-stage), 4–6 mm (one-stage lateral SFE), and ≥ 6 mm (one-stage crestal SFE).

Misch (1999) modified his 1987 classification to include the lateral dimension of the sinus cavity in addition to RBH. This is based on the fact that the healing period protocol in smaller-width sinuses (0–10 mm) allows reduced healing periods (than larger-width (>15 mm) sinuses, resulting in faster bone formation.

Simion (2004) introduced the distance between the top of the crest and the CEJ (of the adjacent teeth) as a new parameter.

Similar criteria have also been proposed by Misch (1987), Summers (1994b), and Summers (1995) (see the CLASSIFICATIONS in Table 9.1).

Fugazzotto (2003) proposed a hierarchy of treatment selection (simultaneous vs. delayed) associated to SFE after a critical analysis of the literature.

Some formulas were addressed to facilitate the clinician's decisions (see the Table 6.2 Chap. 6):

- In the case of a RBH of 2X-2 (X represent the RBH coronal to the sinus floor at the time of therapy) is sufficient to support implant, the SFE with osteotomes and immediate implant placement can be done.
- If 2X-2 is insufficient to support implant but 4X-6 is adequate, the SFE using osteotomes can be performed without implant placement. After 12 months the area can be reentered with a new osteotome approach and simultaneous implant placement.
- If 2X-2 and 4X-6 are both insufficient to retain the implant, a lateral SFE is carried out with delayed implant placement.

Numerous authors attempted to propose classifications and guidelines for a suitable technique selection. These classifications were based on various parameters, which were progressively updated through the time. Despite their relative success, the constant development of implants' length (shorter implants), designs (tapered and screw design for a better initial stability), and surfaces will require the need for newer classifications based on these continuous improvements.

Conclusion

Today, there is strong evidence that lateral SFE is a highly predictable procedure to rehabilitate the atrophic posterior maxilla, using either a simultaneous or a staged implant approach (Jensen and Terheyden 2009; Chiapasco et al. 2009).

SFE may be influenced by many variables, such as grafting material, implant surface, timing of implant placement, RBH (and volume) in the posterior maxilla, and use of a covering membrane.

Nevertheless, there are still uncontrolled parameters leading to uneventful complications (Pjetursson et al. 2009) such as:

- Perforation of the sinus membrane, which was the most frequent complication in SFE: 19.5 %.
- Postoperative graft infection: mean incidence 2.9 %.
- Graft loss resulting in inability of implant placement: 1.9 % of cases.
- Failure of the implant placed in the augmented sites: 3.5 % per year.

The predictability of SFE has been extensively reported and frequently measured through implant survival rate (ISR) criteria in order to evaluate the bone augmentation success. Ten systematic evidence-based reviews from 2003 to 2013 were published relative to implant outcomes following SFE (Aghaloo and Moy 2007; Wallace and Froum 2003; Del Fabbro et al. 2004, 2008, 2013; Graziani et al. 2004; Pjetursson et al. 2008; Nkenke and Stelzle 2009; Jensen and Terheyden 2009; Esposito et al. 2010) and demonstrated a mean ISR beyond 90 % (Wallace and Froum 2003; Del Fabbro et al. 2004, 2008, 2013; Graziani et al. 2004; Pjetursson et al. 2008; Nkenke and Stelzle 2009; Jensen and Terheyden 2009; Esposito et al. 2010).

The minimum follow-up period of these reviews was 1 year of loading time.

The authors of these systematic reviews have drawn the following conclusions:

- *Implant survival rate*: The ISR of implants placed in conjunction with a lateral SFE approach varied between 61.7 and 100 %, with an average of 91.8 %, while Pjetursson et al. (2009) reported a 3-year ISR of 90.1 % based on implant level (implant failure: 3.5 % per year). However, when failure rate was analyzed based on subject level, the estimated annual failure was 6.04 % per year.
- *Simultaneous versus delayed implant placement*: Controversial results were reported regarding the ISR when comparing simultaneous and delayed implant approaches. Numerous studies found quite similar ISR for both techniques. Nevertheless, no long-term randomized controlled clinical trials have

been performed to compare the simultaneous and the staged SFE approaches in identical clinical situations.

- *Grafted versus non-grafted sites*: Similar ISR following lateral SFE for both implants placed in grafted and non-grafted sites (Tong et al. 1998).
- *Implant surface texture*: Rough surface implants demonstrated less annual failure rate (1.2 %) than did machined surface (6.9 %) (Pjetursson et al. 2008). A more recent systematic review (Del Fabbro et al. 2013) stated that implants with a machined surface displayed an overall ISR of 81.0 %, while implants with a rough surface displayed an overall ISR of 96.57 %.
- *Particulate versus block grafts*: ISR was higher when using particulate AB grafts compared with block grafts. The 3-year ISR ranged between 96.3 and 99.8 % depending on the grafting material used (Pjetursson et al. 2008).
- *Autogenous bone* (*AB*) *versus bone substitutes* (*BS*): The inclusion of AB as a component of composite grafts (with BS) did not improved ISR. The overall ISR using 100 % AB was significantly lower than that using 100 % BS Wallace and Froum (2003). The annual failure rates of rough surface implants were similar using BS (1.1 %) and combinations of AB and BS (1.1 %) (Pjetursson et al. 2008).
- *Use of a barrier membrane*: ISR was higher when barrier membranes were placed over the lateral window (Tawil and Mawla 2001; Pjetursson et al. 2008). The overall ISR was 97.12 % when a membrane was used versus 93.29 % when it was not used (Del Fabbro et al. 2013).
- *Residual bone height*: Statistical analysis showed that there is a significant correlation between a RBH of less than 4 mm and increased implant failure, independent of other confounding variables (Testori et al. 2012; Geurs et al. 2001; Rios et al. 2009; Chao et al. 2010). On the contrary, other studies (Urban and Lozada 2010; Del Fabbro et al. 2013) did not found any statistically difference between ISR of implants placed in minimal (≤3.5 mm) RBH and those placed in moderate (>3.5 mm) RBH.

SFE is a predictable procedure performed achieving high ISR. The technique's success is based on an accurate radiographical and clinical analysis in order to select the following:

- The design and the dimension of the bony window trap achieving the better access to the sinus cavity (top-hinge-trapdoor, complete osteotomy, repositioned bony trap) depending on the ridge anatomy (lateral bone thickness, zygomatic buttress, etc.).
- The use of conventional (mechanical) or piezoelectric surgery, lately extensively used, mainly in the presence of a thin lateral bony plate, a thin sinus membrane, and/or a large PSAA.
- The decision to perform a simultaneous or delayed implant placement depending on the bone quantity and quality. Two-stage SFE appears safe and predictable with minimal complications that can be managed successfully without a negative effect on clinical outcomes.

Numerous other issues remain unclear regarding the long-term prognosis of SFE. It is still unclear when SFE are really needed. Would the use of successful short implants (4–6 mm) loaded in maxillary bone with a RBH of 4–6 mm replace SFE in many cases although their long-term prognosis is unknown? (Esposito et al. 2014). Would a graftless approach in the presence of a RBH of 3–4 mm be a sustainable alternative to the augmentation via a grafting material, sufficient to regenerate new bone to allow a proper rehabilitation? Would the BS be able to mimic the physiology and the function of AB? If the RBH is 3–6 mm, would a crestal SFE approach in conjunction of a short implant (4–6 mm) lead to fewer complications than a lateral SFE combined to a longer implant placement (10–12 mm)? (Cannizzaro et al. 2013). Future long-term RCT trials are still needed to clarify these relevant questions.

References

Aghaloo TL, Moy PK (2007) Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 22 Suppl:49–70

Avila G, Wang H-L, Galindo-Moreno P, Misch CE, Bagramian RA, Rudek I, Benavides E, Moreno-Riestra I, Braun T, Neiva R (2010) The influence of the bucco-palatal distance on sinus augmentation outcomes. J Periodontol 81:1041–1050. doi:10.1902/jop.2010.090686

Becktor JP, Isaksson S, Sennerby L (2004) Survival analysis of endosseous implants in grafted and nongrafted edentulous maxillae. Int J Oral Maxillofac Implants 19:107–115

Boyne PJ (1969) Restoration of osseous defects in maxillofacial casualties. J Am Dent Assoc 78:767–776

Boyne PJ (1993) Analysis of performance of root-form endosseous implants placed in the maxillary sinus. J Long Term Eff Med Implants 3:143–159

Boyne PJ, James RA (1980) Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 38:613–616

Chao Y-L, Chen H-H, Mei C-C, Tu Y-K, Lu H-K (2010) Meta-regression analysis of the initial bone height for predicting implant survival rates of two sinus elevation procedures. J Clin Periodontol 37:456–465. doi:10.1111/j.1600-051X.2010.01555.x

Cannizzaro G, Felice P, Minciarelli AF, Leone M, Viola P, Esposito M (2013) Early implant loading in the artrophic posterior maxilla: 1-stage lateral versus crestal sinus lift and 8 mm Hydroxyapatite-Coated implants. A 5-year randomised controlled trial. Eur J Oral Implant 6(1):13–25

Chiapasco M, Casentini P, Zaniboni M (2009) Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants 24 Suppl:237–259

Chiapasco M, Ronchi P (1994) Sinus lift and endosseous implants–preliminary surgical and prosthetic results. Eur J Prosthodont Restor Dent 3:15–21

Chiapasco M, Zaniboni M, Boisco M (2006) Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res 17(Suppl 2):136–159. doi:10.1111/j.1600-0501.2006.01357.x

Cosci F, Luccioli M (2000) A new sinus lift technique in conjunction with placement of 265 implants: a 6-year retrospective study. Implant Dent 9:363–368

Cote MT, Segelnick SL, Rastogi A, Schoor R (2011) New York state ear, nose, and throat specialists' views on pre-sinus lift referral. J Periodontol 82:227–233. doi:10.1902/jop.2010.100344

Cricchio G, Palma VC, Faria PEP, de Olivera JA, Lundgren S, Sennerby L, Salata LA (2011) Histological outcomes on the development of new space-making devices for maxillary

sinus floor augmentation. Clin Implant Dent Relat Res 13:224–230. doi:10.1111/j.1708-8208.2009.00208.x

Del Fabbro M, Testori T, Francetti L, Weinstein R (2004) Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 24:565–577

Del Fabbro M, Rosano G, Taschieri S (2008) Implant survival rates after maxillary sinus augmentation. Eur J Oral Sci 116:497–506. doi:10.1111/j.1600-0722.2008.00571.x

Del Fabbro M, Wallace SS, Testori T (2013) Long-term implant survival in the grafted maxillary sinus: a systematic review. Int J Periodontics Restorative Dent 33:773–783

Elian N, Wallace S, Cho S-C, Jalbout ZN, Froum S (2005) Distribution of the maxillary artery as it relates to sinus floor augmentation. Int J Oral Maxillofac Implants 20:784–787

Esposito M, Felice P, Worthington HV (2014) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev 13(5):CD008397. doi:10.1002/14651858.CD008397

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington HV, Coulthard P (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev (3):CD008397. doi:10.1002/14651858.CD008397

Felice P, Pistilli R, Piattelli M, Soardi E, Barausse C, Esposito M (2014) 1-Stage versus 2-Stage lateral sinus lift procedures: 1-Year post-loading results of a multicentre randomised controlled trail. Eur J Oral Implant 7(1):65–75

Fenner M, Vairaktaris E, Stockmann P, Schlegel KA, Neukam FW, Nkenke E (2009) Influence of residual alveolar bone height on implant stability in the maxilla: an experimental animal study. Clin Oral Implants Res 20:751–755. doi:10.1111/j.1600-0501.2008.01570.x

Froum SJ, Tarnow DP, Wallace SS, Rohrer MD, Cho SC (1998) Sinus floor elevation using anorganic bovine bone matrix (OsteoGraf/N) with and without autogenous bone: a clinical, histologic, radiographic, and histomorphometric analysis–Part 2 of an ongoing prospective study. Int J Periodontics Restorative Dent 18:528–543

Fugazzotto PA (2003) Augmentation of the posterior maxilla: a proposed hierarchy of treatment selection. J Periodontol 74:1682–1691. doi:10.1902/jop.2003.74.11.1682

Galindo-Moreno P, Avila G, Fernández-Barbero JE, Aguilar M, Sánchez-Fernández E, Cutando A, Wang H-L (2007) Evaluation of sinus floor elevation using a composite bone graft mixture. Clin Oral Implants Res 18:376–382. doi:10.1111/j.1600-0501.2007.01337.x

Geurs NC, Wang IC, Shulman LB, Jeffcoat MK (2001) Retrospective radiographic analysis of sinus graft and implant placement procedures from the Academy of Osseointegration Consensus Conference on Sinus Grafts. Int J Periodontics Restorative Dent 21:517–523

Graziani F, Donos N, Needleman I, Gabriele M, Tonetti M (2004) Comparison of implant survival following sinus floor augmentation procedures with implants placed in pristine posterior maxillary bone: a systematic review. Clin Oral Implants Res 15:677–682. doi:10.1111/j.1600-0501.2004.01116.x

Gruber R, Kandler B, Fuerst G, Fischer MB, Watzek G (2004) Porcine sinus mucosa holds cells that respond to bone morphogenetic protein (BMP)-6 and BMP-7 with increased osteogenic differentiation in vitro. Clin Oral Implants Res 15:575–580. doi:10.1111/j.1600-0501.2004.01062.x

Hatano N, Shimizu Y, Ooya K (2004) A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 15:339–345. doi:10.1111/j.1600-0501.2004.00996.x

Hatano N, Sennerby L, Lundgren S (2007) Maxillary sinus augmentation using sinus membrane elevation and peripheral venous blood for implant-supported rehabilitation of the atrophic posterior maxilla: case series. Clin Implant Dent Relat Res 9:150–155. doi:10.1111/j.1708-8208.2007.00043.x

Hürzeler MB, Kirsch A, Ackermann KL, Quiñones CR (1996) Reconstruction of the severely resorbed maxilla with dental implants in the augmented maxillary sinus: a 5-year clinical investigation. Int J Oral Maxillofac Implants 11:466–475

Ioannidou E, Dean JW (2000) Osteotome sinus floor elevation and simultaneous, non-submerged implant placement: case report and literature review. J Periodontol 71:1613–1619. doi:10.1902/jop.2000.71.10.1613

Jensen OT, Sennerby L (1998) Histologic analysis of clinically retrieved titanium microimplants placed in conjunction with maxillary sinus floor augmentation. Int J Oral Maxillofac Implants 13:513–521

Jensen SS, Terheyden H (2009) Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. Int J Oral Maxillofac Implants 24 Suppl:218–236

Jensen OT, Shulman LB, Block MS, Iacono VJ (1998) Report of the Sinus Consensus Conference of 1996. Int J Oral Maxillofac Implants 13 Suppl:11–45

Jensen, OT (1994) Guided bone graft augmentation. In: Buser D, Dahlin C, Schenk RK (eds). Guided bone regeneration in implant dentistry. First edition. Quintessence, Chicago, pp235-264

Jeong S-M, Choi B-H, Li J, Xuan F (2009) A retrospective study of the effects of sinus membrane elevation on bone formation around implants placed in the maxillary sinus cavity. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 107:364–368. doi:10.1016/j.tripleo.2008.05.032

Jung Y-S, Chung S-W, Nam W, Cho I-H, Cha I-H, Park H-S (2007) Spontaneous bone formation on the maxillary sinus floor in association with an extraction socket. Int J Oral Maxillofac Surg 36:656–657. doi:10.1016/j.ijom.2007.01.013

Kan JY, Rungcharassaeng K, Lozada JL, Goodacre CJ (1999) Effects of smoking on implant success in grafted maxillary sinuses. J Prosthet Dent 82:307–311

Kaptein ML, de Putter C, de Lange GL, Blijdorp PA (1998) Survival of cylindrical implants in composite grafted maxillary sinuses. J Oral Maxillofac Surg 56:1376–1380; discussion 1380–1381

Khoury F (1999) Augmentation of the sinus floor with mandibular bone block and simultaneous implantation: a 6-year clinical investigation. Int J Oral Maxillofac Implants 14:557–564

Kim J-M, Sohn D-S, Heo J-U, Moon J-W, Lee J-H, Park I-S (2014) Benefit of the replaceable bony window in lateral maxillary sinus augmentation: clinical and histologic study. Implant Dent 23:277–282. doi:10.1097/ID.0000000000000070

Kirker-Head CA, Nevins M, Palmer R, Nevins ML, Schelling SH (1997) A new animal model for maxillary sinus floor augmentation: evaluation parameters. Int J Oral Maxillofac Implants 12:403–411

Kleinheinz J, Büchter A, Kruse-Lösler B, Weingart D, Joos U (2005) Incision design in implant dentistry based on vascularization of the mucosa. Clin Oral Implants Res 16:518–523. doi:10.1111/j.1600-0501.2005.01158.x

Klijn RJ, van den Beucken JJJP, Bronkhorst EM, Berge SJ, Meijer GJ, Jansen JA (2012) Predictive value of ridge dimensions on autologous bone graft resorption in staged maxillary sinus augmentation surgery using Cone-Beam CT. Clin Oral Implants Res 23:409–415. doi:10.1111/j.1600-0501.2011.02342.x

Lazzara RJ (1996) The sinus elevation procedure in endosseous implant therapy. Curr Opin Periodontol 3:178–183

Leblebicioglu B, Ersanli S, Karabuda C, Tosun T, Gokdeniz H (2005) Radiographic evaluation of dental implants placed using an osteotome technique. J Periodontol 76:385–390. doi:10.1902/jop.2005.76.3.385

Levin L, Herzberg R, Dolev E, Schwartz-Arad D (2004) Smoking and complications of onlay bone grafts and sinus lift operations. Int J Oral Maxillofac Implants 19:369–373

Lorenzoni M, Pertl C, Wegscheider W, Keil C, Penkner K, Polansky R, Bratschko RO (2000) Retrospective analysis of Frialit-2 implants in the augmented sinus. Int J Periodontics Restorative Dent 20:255–267

Lundgren S, Andersson S, Sennerby L (2003) Spontaneous bone formation in the maxillary sinus after removal of a cyst: coincidence or consequence? Clin Implant Dent Relat Res 5:78–81

Lundgren S, Andersson S, Gualini F, Sennerby L (2004) Bone reformation with sinus membrane elevation: a new surgical technique for maxillary sinus floor augmentation. Clin Implant Dent Relat Res 6:165–173

Lundgren S, Cricchio G, Palma VC, Salata LA, Sennerby L (2008) Sinus membrane elevation and simultaneous insertion of dental implants: a new surgical technique in maxillary sinus floor augmentation. Periodontol 2000 47:193–205. doi:10.1111/j.1600-0757.2008.00264.x

Misch, Carl E (1999) Contemporary Implant Dentistry. 2nd ed. St. Louis: Mosby. pp. xviii, p. 684

Misch CE (1987) Maxillary sinus augmentation for endosteal implants: organized alternative treatment plans. Int J Oral Implantol 4:49–58

Misch CE, Judy KW (1987) Classification of partially edentulous arches for implant dentistry. Int J Oral Implantol 4:7–13

Nedir R, Nurdin N, Szmukler-Moncler S, Bischof M (2009) Placement of tapered implants using an osteotome sinus floor elevation technique without bone grafting: 1-year results. Int J Oral Maxillofac Implants 24:727–733

Nkenke E, Stelzle F (2009) Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. Clin Oral Implants Res 20(Suppl 4):124–133. doi:10.1111/j.1600-0501.2009.01776.x

Palma VC, Magro-Filho O, de Oliveria JA, Lundgren S, Salata LA, Sennerby L (2006) Bone reformation and implant integration following maxillary sinus membrane elevation: an experimental study in primates. Clin Implant Dent Relat Res 8:11–24. doi:10.2310/j.6480.2005.00026.x

Peleg M, Mazor Z, Chaushu G, Garg AK (1998) Sinus floor augmentation with simultaneous implant placement in the severely atrophic maxilla. J Periodontol 69:1397–1403. doi:10.1902/jop.1998.69.12.1397

Peleg M, Mazor Z, Garg AK (1999) Augmentation grafting of the maxillary sinus and simultaneous implant placement in patients with 3 to 5 mm of residual alveolar bone height. Int J Oral Maxillofac Implants 14:549–556

Peleg M, Garg AK, Mazor Z (2006) Predictability of simultaneous implant placement in the severely atrophic posterior maxilla: a 9-year longitudinal experience study of 2132 implants placed into 731 human sinus grafts. Int J Oral Maxillofac Implants 21:94–102

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35:216–240. doi:10.1111/j.1600-051X.2008.01272.x

Pjetursson BE, Ignjatovic D, Matuliene G, Brägger U, Schmidlin K, Lang NP (2009) Transalveolar maxillary sinus floor elevation using osteotomes with or without grafting material. Part II: Radiographic tissue remodeling. Clin Oral Implants Res 20:677–683. doi:10.1111/j.1600-0501.2009.01721.x

Rasmusson L, Meredith N, Cho IH, Sennerby L (1999) The influence of simultaneous versus delayed placement on the stability of titanium implants in onlay bone grafts. A histologic and biomechanic study in the rabbit. Int J Oral Maxillofac Surg 28:224–231

Rios HF, Avila G, Galindo P, Bratu E, Wang H-L (2009) The influence of remaining alveolar bone upon lateral window sinus augmentation implant survival. Implant Dent 18:402–412. doi:10.1097/ID.0b013e3181b4af93

Rodoni LR, Glauser R, Feloutzis A, Hämmerle CHF (2005) Implants in the posterior maxilla: a comparative clinical and radiologic study. Int J Oral Maxillofac Implants 20:231–237

Simion M, Fontana F, Rasperini G, Maiorana C (2004) Long-term evaluation of osseointegrated implants placed in sites augmented with sinus floor elevation associated with vertical ridge augmentation: a retrospective study of 38 consecutive implants with 1- to 7-year follow-up. Int J Periodontics Res Dent. 24(3):208–21

Small SA, Zinner ID, Panno FV, Shapiro HJ, Stein JI (1993) Augmenting the maxillary sinus for implants: report of 27 patients. Int J Oral Maxillofac Implants 8:523–528

Smiler DG, Holmes RE (1987) Sinus lift procedure using porous hydroxyapatite: a preliminary clinical report. J Oral Implantol 13:239–253

Srouji S, Kizhner T, Ben David D, Riminucci M, Bianco P, Livne E (2009) The Schneiderian membrane contains osteoprogenitor cells: in vivo and in vitro study. Calcif Tissue Int 84: 138–145. doi:10.1007/s00223-008-9202-x

Strietzel FP (2004) Sinus floor elevation and augmentation. Evidence-based analysis of prognosis and risk factors. Mund Kiefer Gesichtschir 8:93–105. doi:10.1007/s10006-004-0530-3

Sul S-H, Choi B-H, Li J, Jeong S-M, Xuan F (2008) Effects of sinus membrane elevation on bone formation around implants placed in the maxillary sinus cavity: an experimental study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105:684–687. doi:10.1016/j.tripleo.2007.09.024

Summers RB (1994a) A new concept in maxillary implant surgery: the osteotome technique. Compendium (Newtown Pa) 15:152, 154–156, 158 passim; quiz 162

Summers RB (1994b) The osteotome technique: Part 3 – less invasive methods of elevating the sinus floor. Compendium (Newtown Pa) 15:698, 700, 702–704 passim; quiz 710

Summers RB (1995) The osteotome technique: Part 4 – future site development. Compend Contin Educ Dent 16:1090, 1092 passim; 1094–1096, 1098, quiz 1099

Tarnow DP, Wallace SS, Froum SJ, Rohrer MD, Cho SC (2000) Histologic and clinical comparison of bilateral sinus floor elevations with and without barrier membrane placement in 12 patients: Part 3 of an ongoing prospective study. Int J Periodontics Restorative Dent 20:117–125

Tatum OH (1977) Maxillary sinus grafting for endosseous implants. Lecture presented at the annual meeting of the Alabama Implant Study Group, Birmingham

Tatum H Jr (1986) Maxillary and sinus implant reconstructions. Dent Clin North Am 30:207–229

Tawil G, Mawla M (2001) Sinus floor elevation using a bovine bone mineral (Bio-Oss) with or without the concomitant use of a bilayered collagen barrier (Bio-Gide): a clinical report of immediate and delayed implant placement. Int J Oral Maxillofac Implants 16:713–721

Testori T, Wallace SS, Del Fabbro M, Taschieri S, Trisi P, Capelli M, Weinstein RL (2008) Repair of large sinus membrane perforations using stabilized collagen barrier membranes: surgical techniques with histologic and radiographic evidence of success. Int J Periodontics Restorative Dent 28:9–17

Testori T, Weinstein RL, Taschieri S, Del Fabbro M (2012) Risk factor analysis following maxillary sinus augmentation: a retrospective multicenter study. Int J Oral Maxillofac Implants 27:1170–1176

Thor A, Sennerby L, Hirsch JM, Rasmusson L (2007) Bone formation at the maxillary sinus floor following simultaneous elevation of the mucosal lining and implant installation without graft material: an evaluation of 20 patients treated with 44 Astra Tech implants. J Oral Maxillofac Surg 65:64–72. doi:10.1016/j.joms.2006.10.047

Timmenga NM, Raghoebar GM, Boering G, van Weissenbruch R (1997) Maxillary sinus function after sinus lifts for the insertion of dental implants. J Oral Maxillofac Surg 55:936–939; discussion 940

Toffler M (2004) Osteotome-mediated sinus floor elevation: a clinical report. Int J Oral Maxillofac Implants 19:266–273

Tong DC, Rioux K, Drangsholt M, Beirne OR (1998) A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 13:175–182

Ulm CW, Solar P, Krennmair G, Matejka M, Watzek G (1995) Incidence and suggested surgical management of septa in sinus-lift procedures. Int J Oral Maxillofac Implants 10:462–465

Urban IA, Lozada JL (2010) A prospective study of implants placed in augmented sinuses with minimal and moderate residual crestal bone: results after 1 to 5 years. Int J Oral Maxillofac Implants 25:1203–1212

Valentini P, Abensur D (1997) Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): a clinical study of 20 patients. Int J Periodontics Restorative Dent 17:232–241

Van den Bergh JP, ten Bruggenkate CM, Disch FJ, Tuinzing DB (2000) Anatomical aspects of sinus floor elevations. Clin Oral Implants Res 11:256–265

Vercellotti T, De Paoli S, Nevins M (2001) The piezoelectric bony window osteotomy and sinus membrane elevation: introduction of a new technique for simplification of the sinus augmentation procedure. Int J Periodontics Restorative Dent 21:561–567

Vercellotti T, Nevins ML, Kim DM, Nevins M, Wada K, Schenk RK, Fiorellini JP (2005) Osseous response following resective therapy with piezosurgery. Int J Periodontics Restorative Dent 25:543–549

Wallace SS, Froum SJ (2003) Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol 8:328–343. doi:10.1902/annals.2003.8.1.328

Wallace SS, Froum SJ, Cho S-C, Elian N, Monteiro D, Kim BS, Tarnow DP (2005) Sinus augmentation utilizing anorganic bovine bone (Bio-Oss) with absorbable and nonabsorbable membranes placed over the lateral window: histomorphometric and clinical analyses. Int J Periodontics Restorative Dent 25:551–559

Wallace SS, Mazor Z, Froum SJ, Cho S-C, Tarnow DP (2007) Schneiderian membrane perforation rate during sinus elevation using piezosurgery: clinical results of 100 consecutive cases. Int J Periodontics Restorative Dent 27:413–419

Winter AA, Pollack AS, Odrich RB (2002) Placement of implants in the severely atrophic posterior maxilla using localized management of the sinus floor: a preliminary study. Int J Oral Maxillofac Implants 17:687–695

Wood RM, Moore DL (1988) Grafting of the maxillary sinus with intraorally harvested autogenous bone prior to implant placement. Int J Oral Maxillofac Implants 3:209–214

Xu H, Shimizu Y, Ooya K (2005) Histomorphometric study of the stability of newly formed bone after elevation of the floor of the maxillary sinus. Br J Oral Maxillofac Surg 43:493–499. doi:10.1016/j.bjoms.2005.02.001

Zinner ID, Small SA (1996) Sinus-lift graft: using the maxillary sinuses to support implants. J Am Dent Assoc 127:51–57

Zitzmann NU, Schärer P (1998) Sinus elevation procedures in the resorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:8–17

6 Crestal Sinus Floor Elevation (SFE) Approach: Overview and Recent Developments

Nabih Nader, Maissa Aboul Hosn, and Ronald Younes

Contents

N. Nader, DDS (✉) • M. Aboul Hosn
Department of Oral and Maxillofacial Surgery, Lebanese University, School of Dentistry, Beirut, Lebanon
e-mail: nabih.nader@gmail.com; maissahosn@hotmail.com

R. Younes, DDS, PhD
Department of Oral Surgery, Faculty of Dentistry, St Joseph University, Beirut, Lebanon
e-mail: ronald.younes@usj.edu.lb, ronald.younes@hotmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_6

6.1 Scientific Background of Minimally Invasive SFE

Osteotome-mediated transcrestal SFE approach was first proposed by Tatum in the 1970s. His results using this transalveolar technique for SFE with simultaneous placement of implants were later published in 1986 (Tatum 1986). In his original publication, a special instrument known as "socket former" (for a selected implant size) was used to prepare the implant site leading to a controlled "greenstick fracture" of the sinus floor, moving it in a more apical direction. Root-formed implants were then placed and allowed to heal in a submerged manner. At the time, the author did not use any grafting material to increase and maintain the volume of the elevated area.

Later, Summers (1994a) described a modification of this technique and codified another transalveolar approach, namely, the "osteotome technique" (OSFE: osteotome sinus floor elevation), as a simpler and less invasive approach using a set of osteotomes of varying diameters. It leads to an increase of bone quantity at the sinus floor combined to a simultaneous implant placement. The use of conical osteotomes is intended to increase the density of the maxillary soft bone (type III and IV), through lateral condensation resulting in bone compression and stiffness achieving a better primary stability of simultaneously inserted dental implants (Summers 1994a). The author stated that these maneuvers preserve bone and increase the lateral bone density since drilling is avoided. This surgical technique was originally indicated where the sub-sinus residual bone height (RBH) is 5–6 mm and the bone is of low density.

The main difference with the lateral window technique is that the sinus membrane is lifted through the crestal bone using osteotomes, and implants are inserted directly in the sites prepared with these codified instruments (Fig. 6.1).

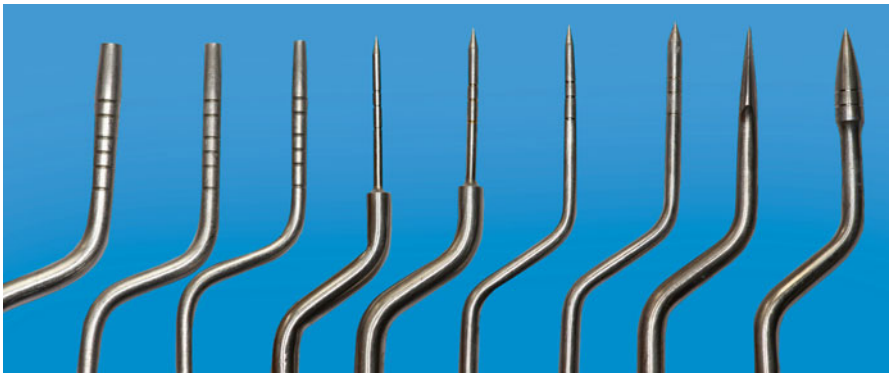


Fig. 6.1 Different shapes of osteotomes used during crestal SFE

Osteotomes are surgical instruments that can be used effectively to enhance the placement of dental implants. The term "osteotome" means a bone-cutting or bone-deforming instrument.

They are generally wedge-shaped instruments with varied steepness of taper, designed to compress, cut, or deform bone. They are available with flat blades, pointed tips, concave (cupped) and convex (round shape) end:

- The round (convex) osteotomes are mainly used for bone compression, especially at the beginning of the crestal SFE in presence of narrow ridges or soft bone.
- Bladed osteotomes can be used to cut into the cortex of bone to split the cortices apart or segment a portion of narrow crest.
- A pointed-end osteotome can be used to advance and widen the osteotomy in less dense bone. The cortex must be drilled wide enough to accommodate the osteotome so the instrument does not meet resistance.
- Concave osteotomes are used to collect and compress bone into the apical end of the osteotomy. They are mostly used during crestal OSFE procedures.
- Flat-ended osteotomes can compress (but not collect) bone fragments for increased density and are generally used in the anterior maxilla.

Osteotomes can be lubricated with saline or sterile water to facilitate movement through tissue. Round osteotomes should be used with straight, in-and-out movements to prevent the osteotomies from assuming an oval shape. This shape would jeopardize implant healing and/or osseointegration.

Osteotomes are optimally used by pressing the instrument into the bone and malleting only when there is slight resistance. Firmer resistance requires the use of a drill to widen the cortex: most resistance is caused by a too small cortical opening that prevents the osteotome to easily pass through (Flanagan 2006).

P.S.: An inappropriate use of the osteotomes (excessive malleting force) may lead to a labyrinthine concussion that lasts 1–3 weeks. However, some patients may require specific treatment in the form of head maneuvers to reposition the otoliths (Fig. 6.2a–c).

In brief, the Summers technique is performed in the following way:

- A midcrestal incision where buccal and palatal mucoperiostal flaps are reflected in a full-thickness approach exposing the crestal part of alveolar ridge.
- The implant sites are marked with a 2.0 mm round drill and then prepared with a drill to a depth of 0.5–1.5 mm from the sinus floor.
- The osteotomes are then selected to expand the preparation area both horizontally and vertically, achieving the initial sinus up-fracture. The osteotome itself should never penetrate the maxillary sinus.
- The expansion of the osteotomy sites is performed with a number of Concave tipped tapered osteotomes with increasing diameters that are applied through the edentulous alveolar crest at the inferior border of the maxillary sinus floor. With each insertion of a larger osteotome, bone is compressed, pushed laterally and apically while pushing the garnered bone apically beneath the tented membrane.

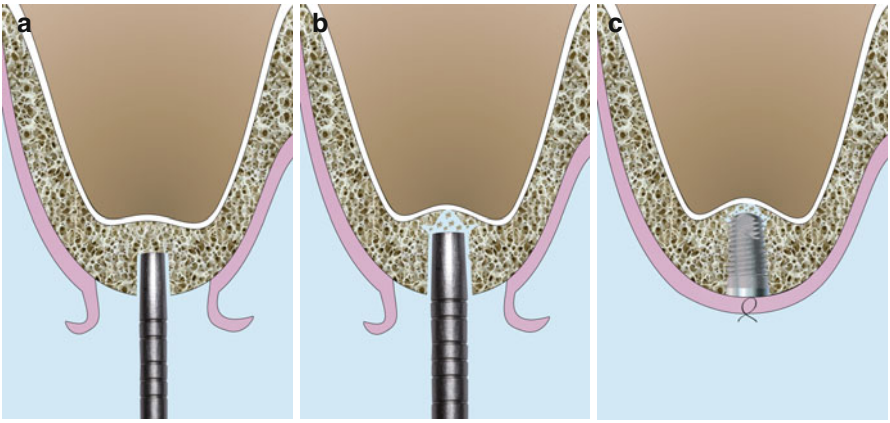


Fig. 6.2 Schematic drawings illustrating the original's Summers technique (OSFE). (**a**) Concave osteotome introduced 2 mm beneath the sinus floor. (**b**) Larger osteotome pushing up the sinus floor via the residual bone. (**c**) Implant placement showing the bone apically to the implant lifting the sinus floor

Clinically, the tenting effect provides a space leading the advance of a bone mass (bone substitute or blood clot formation) beyond the level of the original sinus floor.

- Osteotomes are marked at the corresponding implant lengths and with progressively larger diameters (0.5 mm increments).

This is similar to the green stick fracture method, which adds 2–3 mm of bone height beneath the elevated but unsullied sinus membrane.

A mallet is used, when needed, on the osteotome to expand the bone. The instrument is turned after each push of the mallet to prevent the tip from binding in the bone; the osteotome is maintained in a precise axial position as it is turned; a controlled pressure is needed to prevent the osteotomes from advancing more than 1 mm with each impact of the mallet avoiding the sinus floor perforation. (Some osteotome kits are proposed with stoppers for this purpose.) (Summers 1998).

The sinus elevation is delayed until the osteotome with the final apical diameter is used at the desired working depth. Once the largest osteotome has expanded the implant site. The sinus floor fracture is obtained with the final osteotome, punching out the cortical plate of sinus floor with the adherent sinus membrane (Checchi et al. 2010).

If after several mallet strikes and the osteotome do not progress, the surgeon should go back to a smaller-sized osteotome or use a drill.

This intrusion procedure produces a fracture in the least traumatic way possible. The osteotome technique is superior to drilling for many applications in soft maxillary bone. Furthermore, it allows more implants to be inserted in a greater variety of sites during a routine office procedure.

In the first three articles (Summers 1994a, b, c), Summers described the use of osteotome hand instruments to lift the sinus. The osteotome procedures that were introduced compressed soft maxillary bone, widened narrow ridge segments (ridge expansion osteotomy REO technique), and elevated the sinus floor for immediate implant insertion (osteotome sinus floor elevation OSFE and bone-added osteotome sinus floor elevation BAOSFE surgery).

In 1995, Summers (1995) also introduced a new means of intruding the ridge crest with larger osteotomes to create broader areas of sinus floor elevation, known as the future site development (FSD procedure). A bone plug is defined with a trephine and displaced superiorly with the use of a broad osteotome.

6.2 Modifications of the "Original" Technique (OSFE Summers 1994c)

6.2.1 Bone-Added Osteotome Sinus Floor Elevation (BAOSFE) (Fig. 6.3a–c)

Summers (1994b) combined the original OSFE procedure with the addition of a bone graft material, called the BAOSFE, as he considered it to be more conservative and less invasive than the lateral approach. It should be noted that in this technique, the bone substitutes are blindly introduced into the space below the sinus membrane.

Pressure on the graft material and trapped fluids exert hydraulic pressure on the sinus membrane, creating a blunt force over an expanded area that is larger than the osteotome tip (Chen et al. 2007). The sinus membrane is then less exposed to tearing with such a fluid consistent pressure, avoiding direct application of a hard surgical instrument (Summers 1994b).

Many reports have proposed modifications to Summers' original BAOSFE (bone-added osteotome sinus floor) protocol to expedite the procedure, minimize malleting force, and simplify sinus floor infracture. Other authors have suggested modifications to the BAOSFE procedure in terms of instrumentation, grafting materials, and implant surface and design (Figs. 6.4, 6.5, 6.6, 6.7, and 6.8).

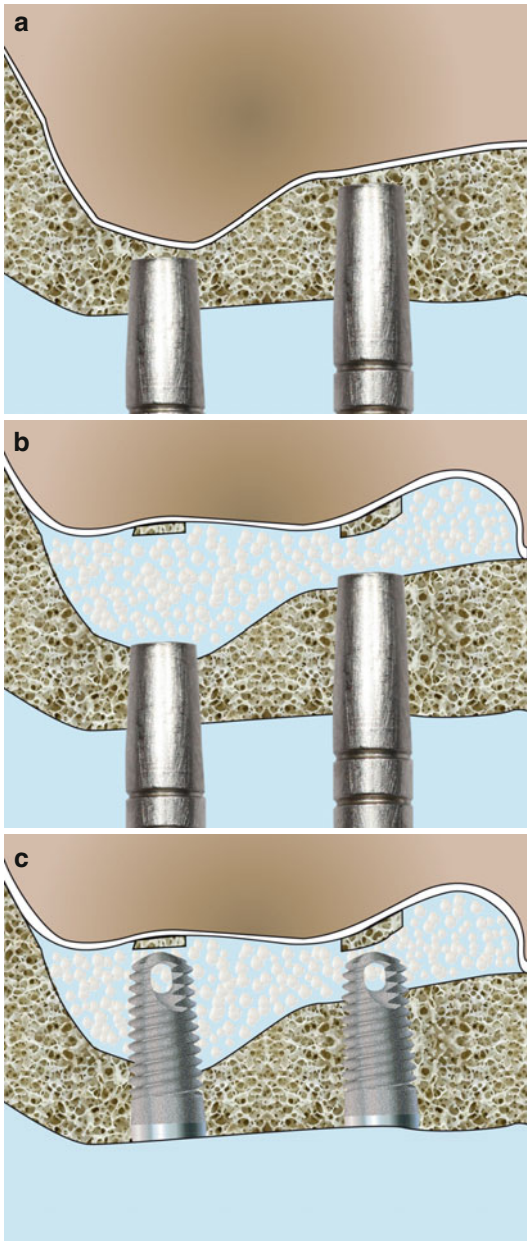


Fig. 6.3 Schematic drawings illustrating the BAOSFE technique. (**a**) Concave osteotome introduced 1–2 mm beneath the sinus floor. (**b**) Bone particles filling the created space beneath the sinus membrane. (**c**) Implants stabilized in the residual bone with their apical part surrounded by bone chips

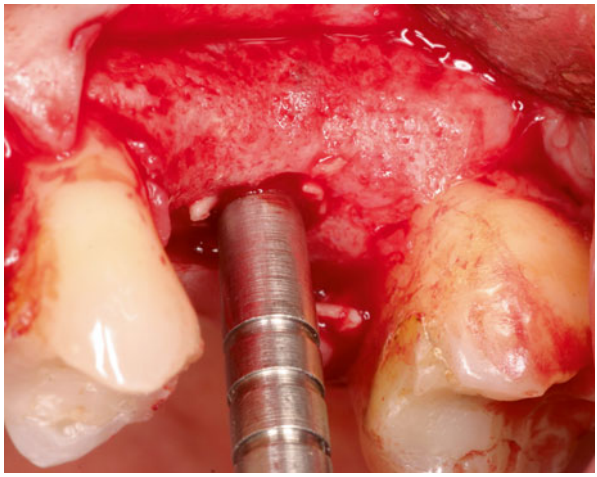


Fig. 6.4 Grafting material introduced upward with controlled osteotome pressure

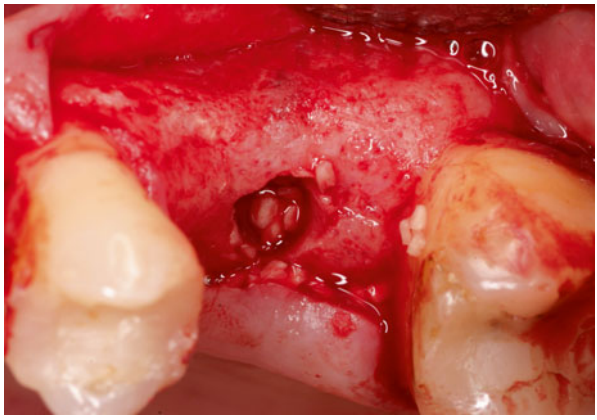


Fig. 6.5 Bone chips progressively filled into the site prepared by the osteotome

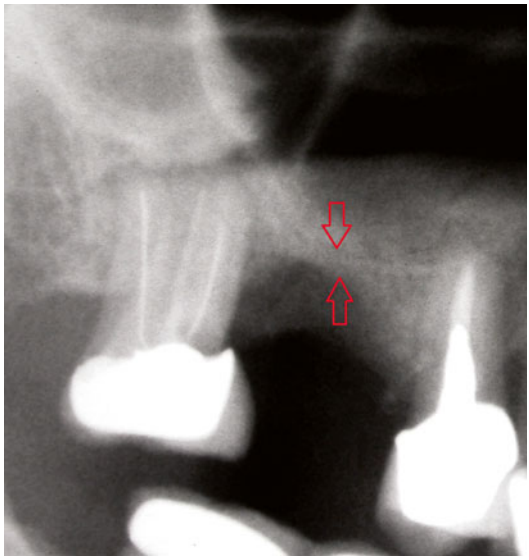


Fig. 6.6 Preoperative X-ray showing the initial residual bone height (3 mm). The *red arrows* indicate the RBH between the top of the crest and the sinus floor

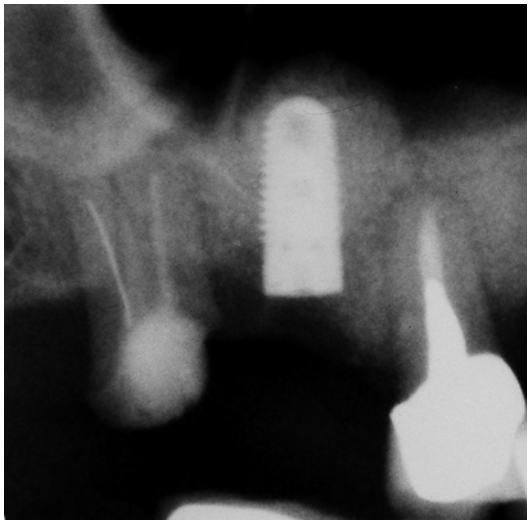


Fig. 6.7 Postoperative X-ray showing a tapered implant placed into the augmented sinus

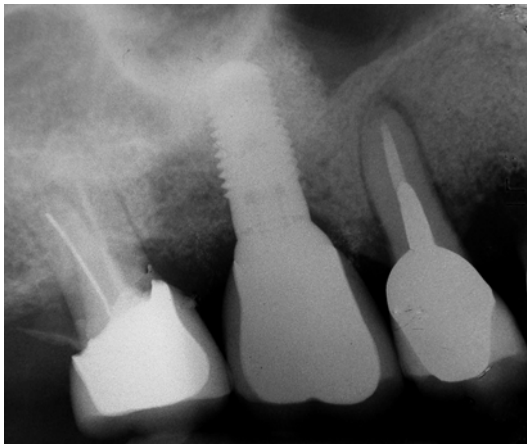


Fig. 6.8 1-year postoperative radiograph showing the final bone level after loading

6.2.2 Modified Osteotome Technique (Drills + Osteotomes + BS) (Fig. 6.9a–c)

In the presence of a dense sub-sinus bone quality, with no need to improve it further, the use of the osteotomes following Summers technique would be considered harmful for the patient. The use of 2 and 3 mm twist drills might be used initially to reach just 1–2 mm below the hard cortical plate of the sinus floor. Because further condensation of osseous tissue is deemed unnecessary in such cases, drilling alone would be more efficient and timesaving. The sinus floor is then "fractured" with #2 and #3 osteotomes by malleting.

For this purpose, in 1996, a new sequence of surgery based on the combined use of osteotomes, drills, and screw-type implants with a rough surface texture was proposed (Davarpanah et al. 2001).

This technique is indicated where the RBH ≥5 mm. The authors detailed the operative protocol as follows:

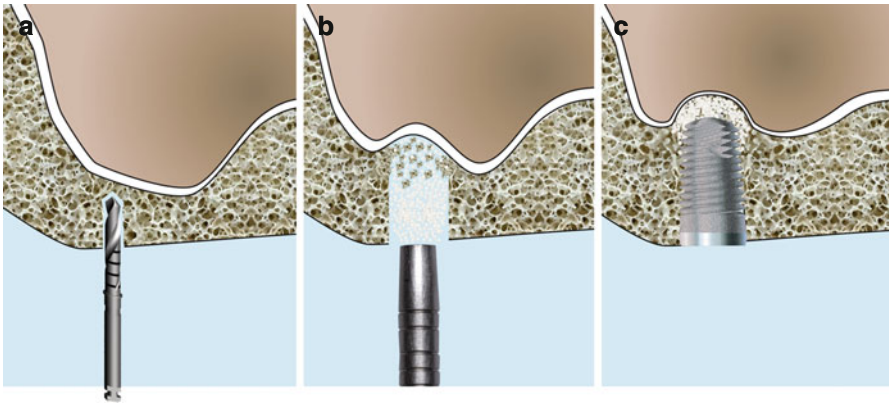


Fig. 6.9 Schematic drawings illustrating the modified osteotome technique. (**a**) Pilot drill initiating the SFE preparation avoiding the sinus floor. (**b**) Concave osteotome kept beneath the sinus floor while pushing up added bone substitutes mixed with the residual fragmented autogenous bone. (**c**) Implant surrounded by particulate bone substitute mixed with autogenous bone; note the intact lifted sinus membrane apically

No instrument (osteotome, drill) should penetrate the sinus cavity during any part of the procedure.

- The positioning of the implants is carried out with a round bur, and the preparation of the site begins with a 2 mm twist drill (pilot drill) and maintained to a distance of only 2–3 mm,
- The 3 mm twist drill completes the preparation of the implant site for a standard-diameter implant.
- The drilling must remain 1 mm below the floor of the sinus.
- Radiographic control helps to confirm the integrity of the sub-sinus floor.
- Grafting material is introduced into the surgical site before using the first osteotome (Summers No. 3 osteotome). This material will serve as a shock absorber to gently fracture the sinus floor.

The fracture is performed at the end with the largest instrument that corresponds to the size of the implant to be placed. Direct contact of the instruments with the sinus membrane is avoided since bone particles or a combination of autogenous bone and bone substitutes are immediately added after the sinus floor infracture on the top of the instruments into the developing space (Diserens et al. 2006).

At this stage, the integrity of the sinus membrane is confirmed by asking the patient to blow through the nose (after pinching the nostrils) and looking for mist on the mirror (Valsalva maneuver). If the sinus membrane has been perforated, two options can be considered: stop the operation and wait 4 weeks of healing prior to resuming the procedure or continue using a lateral approach.

- The bone is progressively condensed using an osteotome.
- With each use of the osteotome to condense the material, the sinus membrane is lifted approximately 1 mm.

The "modified osteotome technique" eliminated unnecessary hammering in the presence of a dense sub-sinus residual bone and therefore proved to be more tolerable to patients.

6.2.3 Modified Trephine/Osteotome Approach (Simultaneous Implant Placement) (Fig.6.10a–c)

Fugazzotto (2002) presented a technique in which a trephine with a 3.0 mm external diameter is utilized instead of a drill (or an osteotome) as a first step, followed by an osteotome to implode a core of residual alveolar bone prior to simultaneous implant placement.

- This technique could be utilized either following a flap reflection or using a flapless approach.
- A calibrated trephine bur with 3.0 mm external diameter is used to prepare the site to within approximately 1–2 mm of the sinus membrane at a reduced cutting speed.
- Following removal of the trephine bur, if the bone core is found to be inside the trephine, it's gently removed from the trephine and replaced in the alveolar bone preparation.
- A calibrated osteotome corresponding to the diameter of the trephine preparation is used under gentle malleting forces, to implode the trephine bone core to a depth approximately 1 mm less than that of the prepared site.
- The widest osteotome utilized will be one drill size narrower than the normal implant site preparation.
- Implant placement induces a lateral dispersion of the imploded alveolar core with gentle and controlled displacement.

This technique both lessen the patient's trauma and preserve a maximum amount of alveolar bone at the precise site of anticipated implant placement.

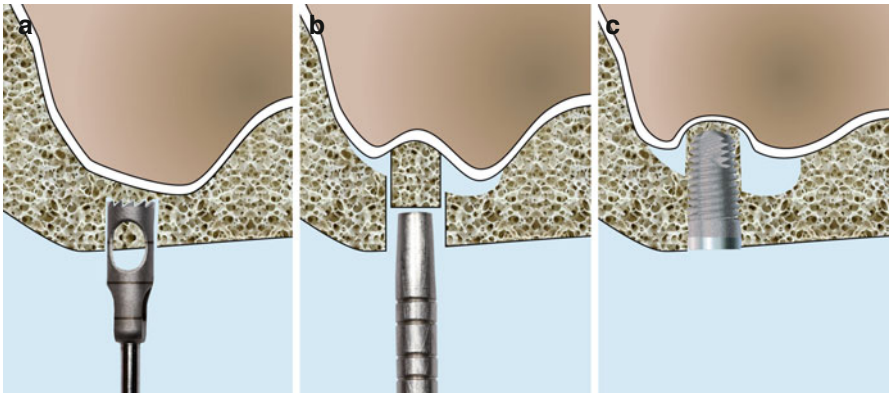


Fig. 6.10 Schematic drawings of modified trephine/osteotome approach. (**a**) Trephine preparing a crestal bone core. (**b**) Concave osteotome pushing the resulting crestal bone core. (**c**) Implant placement lifting the bone core and the overlying sinus membrane upwards

This technique is indicated in the presence of 4–5 mm of RBH in order to avoid repeated traumatic malleting of the osteotomes and is always combined to simultaneous implant placement (Figs. 6.11,.6.12, 6.13, and 6.14).

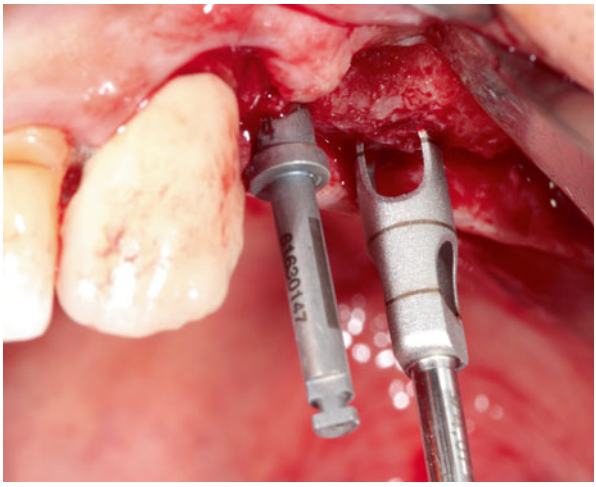


Fig. 6.11 Graduated trephine drill preparing the bone core at the selected implant site

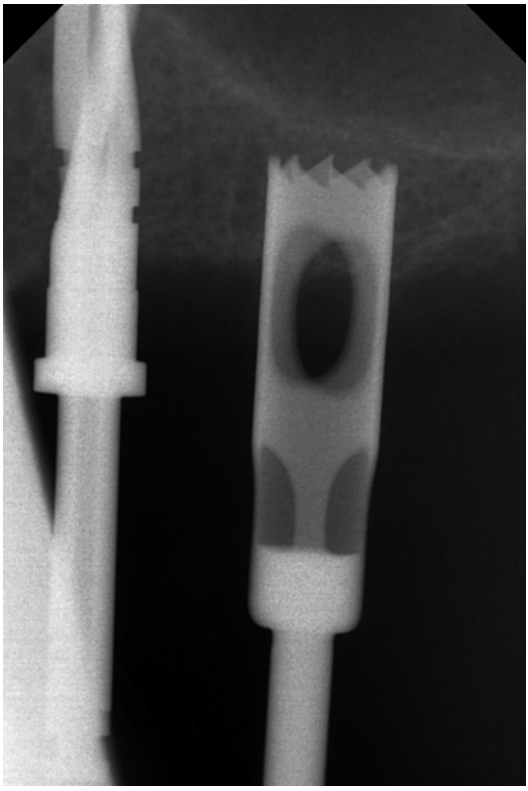


Fig. 6.12 X-ray showing the trephine drill remaining 1 mm below the sinus floor

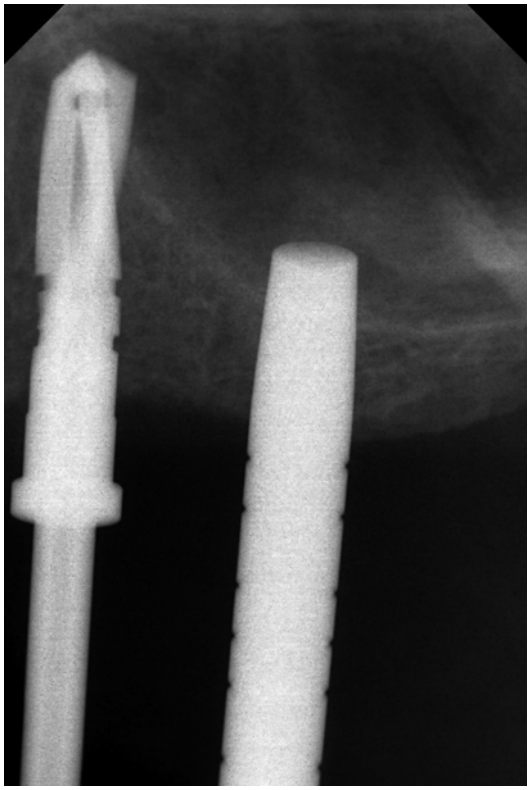


Fig. 6.13 X-ray of the osteotome imploding the trephine bone core into the sinus cavity

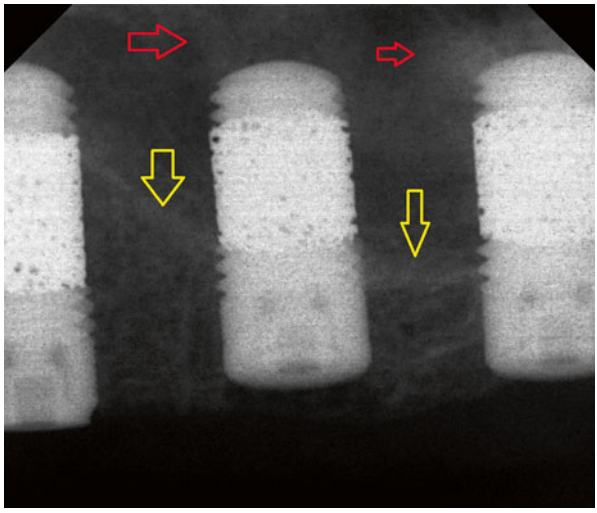


Fig. 6.14 Postoperative X-ray showing the original sinus floor (*yellow arrows*) and the imploded bone core apical to the implant (*red arrows*). Note the use of "trabecular metal technology" to optimize the bone ingrowth

6.2.4 Cosci Technique

The crestal approach technique has been also modified by Cosci and Luccioli (2000). Cosci technique is a one-stage crestal SFE approach using a specific sequence of atraumatic drills of varying lengths.

The shape of the drill tip prevents perforation of the sinus membrane and permits gentle abrasive removal of the cortical bone of the sinus floor without fracture.

Description of Cosci technique:

- If the RBH is 6–7 mm:
  - A dedicated trephine drill of 3 mm diameter is initially used for the first 2–4 mm.
  - The dedicated 3 mm long and 2 mm diameter pilot drill is then used.
  - Followed by the 3 mm long intermediate and 3.1 mm diameter drill and by one or more atraumatic lifting drills of the actual height of the ridge as measured on the radiograph.
- If the residual bone height is 4–5 mm: the trephine drill is not used, and the site is initially prepared with the dedicated 3 mm long and 2 mm diameter pilot drill, the rest of the preparation procedure being identical.

After using the first atraumatic lifting drill, the site is probed with a blunt instrument to feel the presence of the Schneiderian membrane. If the presence of bone is felt, a 1 mm longer atraumatic lifting drill is used, and so on, until the sinus lining is felt.

With a special rounded probe, a check of the alveolar bone is made to determine the integrity of the sinus membrane as well as the Valsalva maneuver (nose-blowing test).

Then, the graft is gently pushed into the site using a particular instrument called "body lifting"; this step is repeated until the site is filled with the graft (Bernardello et al. 2011).

Referring to the author (Cosci), the Cosci technique required, on average, almost 10 min less to be completed than the Summers technique; knowing that "harmful" osteotomes are not used, this technique might be preferred by the patients and the operators.

Drills used to prepare the implants site and lift the sinus lining according to the Cosci technique. Eight atraumatic SFE drills are available in the kit with incremental lengths of 1 mm starting from 5 and up to 12 mm (Fig. 6.15).

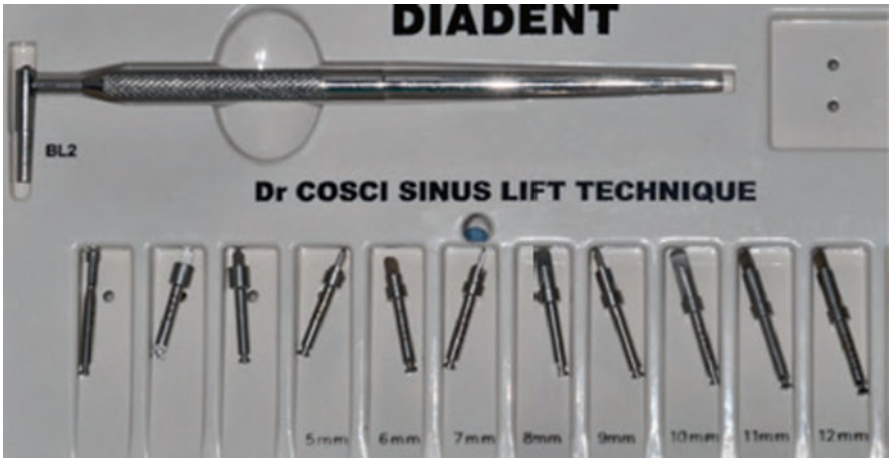


Fig. 6.15 Dr Cosci's "noninvasive" sinus lift kit

6.3 Modifications of Summers Technique (OSFE) with Delayed Implant Placement

The prerequisite to simultaneous implant placement is to achieve a primary stability, depending on bone quantity and quality.

Crestal approach (Summers) could be applied without implant placement in two situations:

1. By first intention when we consider that the bone volume is insufficient to insure primary implant stability.
2. By second intention when we fail to ensure a primary stability while placing the implant.

6.3.1 Future Site Development (FSD) Technique

This technique, described by Summers (1994c) is indicated where the RBH is less than 5 mm. The placement of the implant is deferred until 7–9 months (Summers) after the SFE. The operative protocol is as follows.

- A 2 mm diameter drill is used with the aid of a surgical guide.
- A trephine with a 5 mm internal diameter is used to produce a cylinder of bone, which is displaced with a Summers No. 5 osteotome.
- The sinus membrane is then elevated with this cylinder of bone, which acts as a shock absorber. The integrity of the sinus membrane must be confirmed. If it is perforated, the procedure should be discontinued.

Autogenous bone (with or without bone substitute) is progressively inserted until the necessary volume of sub-sinus bone has been achieved.

The FSD technique could also be used without trephine, especially when we have a reduced RBH (<4 mm) (Figs. 6.16, 6.17, 6.18, 6.19, and 6.20).

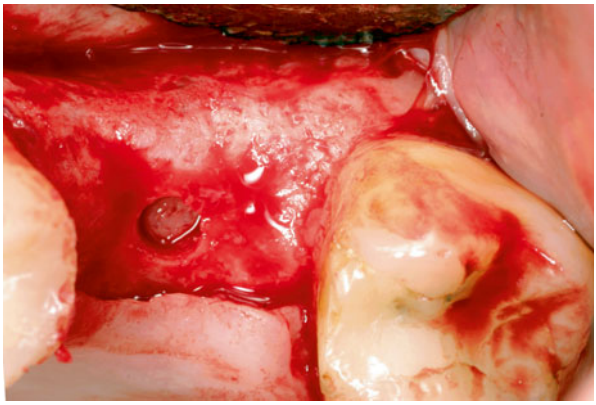


Fig. 6.16 Reduced residual bone height initiated with a concave osteotome

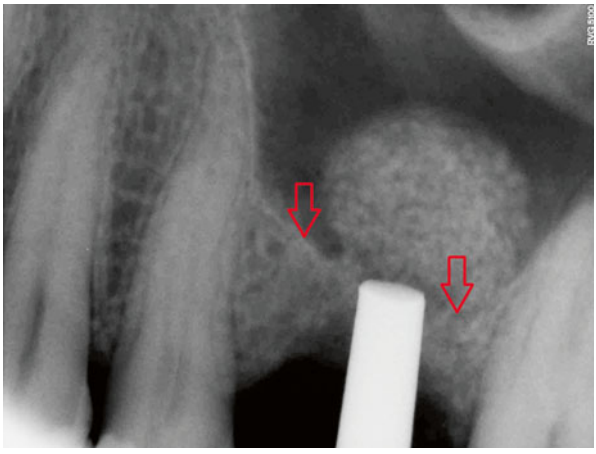


Fig. 6.17 Preoperative radiograph showing particulate bone substitute intruded incrementally through the osteotomy site. The *arrows* indicate the initial sinus floor

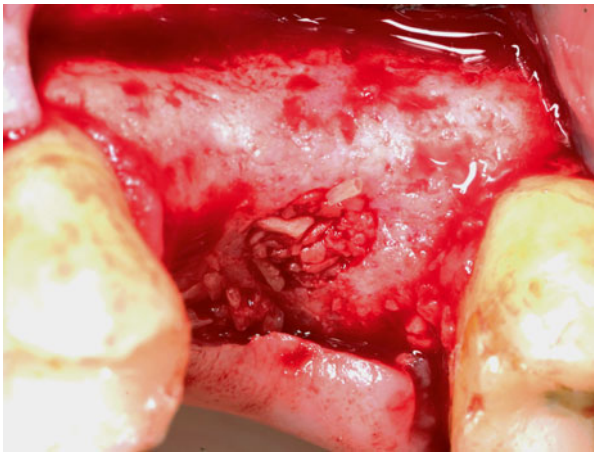


Fig. 6.18 Clinical view showing osteotomy site filled with particulate bone substitute

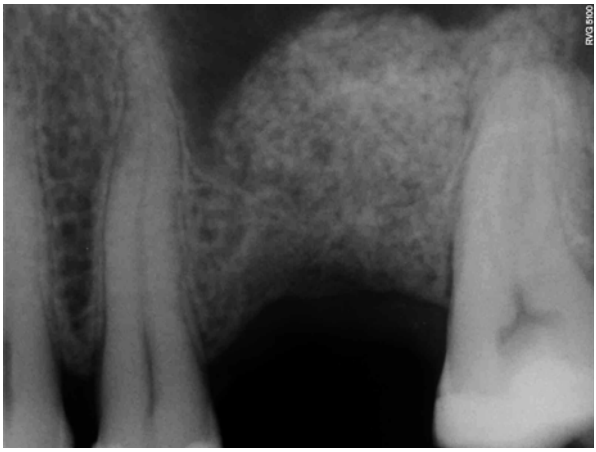


Fig. 6.19 Postoperative radiograph showing substantial sinus lifting gain

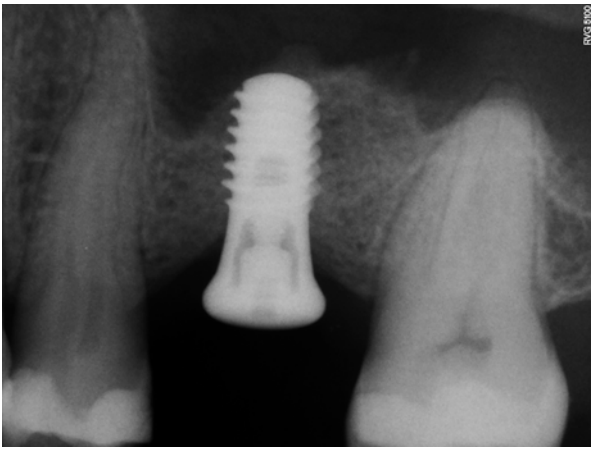


Fig. 6.20 5 months later, implant is placed in the regenerated sinus (allograft)

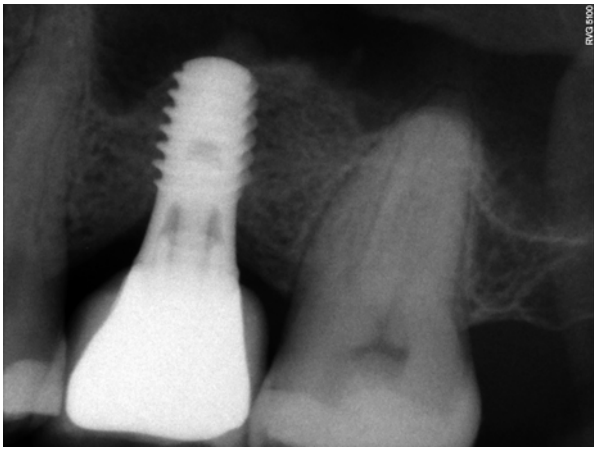


Fig. 6.21 1-year follow-up showing the minimal shrinkage of the regenerated bone

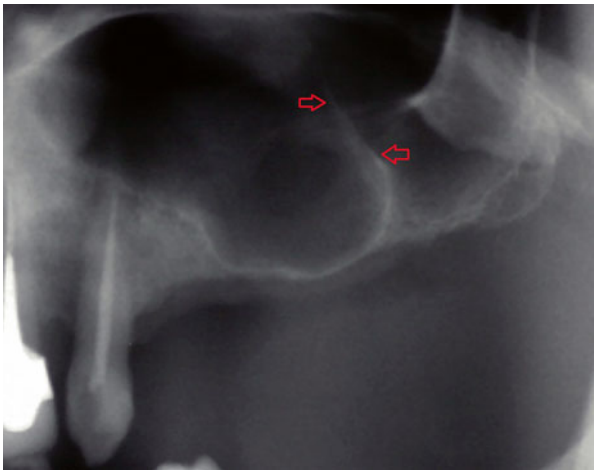


Fig. 6.22 Preoperative radiograph showing the presence of a "knife-edge" septum (*red arrows*)

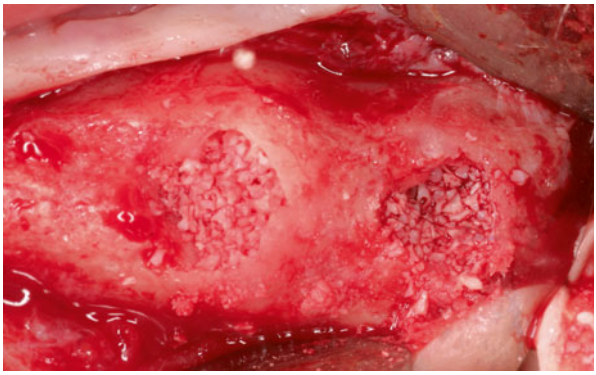


Fig. 6.23 Two crestal entries (anterior and posterior to the septum) prepared using a concave osteotome

In multiple edentulous sectors, with the presence of septa combined to a reduced RBH, we may perform two entries either of the septum in order to avoid membrane perforation that may happen when using a lateral approach (Figs. 6.22 and 6.23).

6.3.2 Modified Trephine/Osteotome Sinus Augmentation Technique (Post-extraction Molars and Premolars) (Fig. 6.24a-b)

Fugazzotto (1999) described a technique for accomplishing both localized SFE and guided bone regeneration at the time of maxillary molar extraction.

- After the atraumatic extraction of the molar in a manner so as to preserve interradicular bone, a calibrated trephine bur is placed over the interradicular bone,

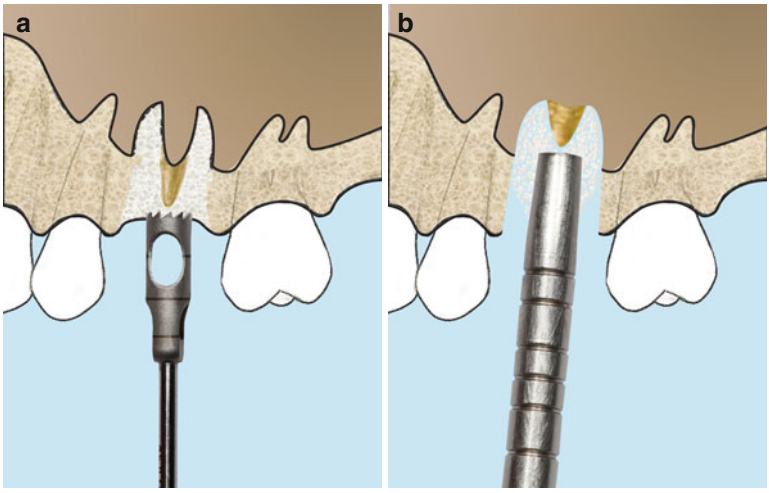


Fig. 6.24 Schematic drawings of the modified trephine/osteotome sinus augmentation technique. (**a**) Sinus floor is intruded by applying a trephine technique. (**b**) Intrusion of the interradicular bone using osteotomes

which is of sufficient dimension to encompass both the interradicular septum and approximately 50 % of the extraction sockets (each trephine bur is approximately 1 mm thick).

- Based on preoperative radiographs, measurement of removed roots and residual ridge morphology as guides, the clinician uses the trephine to prepare a site to within approximately 1–2 mm of the sinus membrane.
- If the bone core is retained inside the trephine after its removal, it is gently pulled out and replaced in the alveolar bone preparation.
- An osteotome is selected according to the diameter of the trephine preparation: gentle malletting forces implode both the trephined interradicular bone and the underlying sinus membrane to a depth at least equal to the apico-occlusal dimension of the trephined bone core.
- The residual extraction socket is filled with bone substitutes.
- An appropriate membrane is secured with fixation tacks.
- Flaps are sutured so as to achieve passive primary closure.

This technique combines SFE procedure with GBR at the time of molar extraction in order to regenerate bone both buccolingually and apico-occlusally for an optimal implant positioning (delayed).

6.3.3 Minimally Invasive Antral Membrane Balloon Elevation (MIAMBE)

The presence of septa in maxillary sinus requires modification of surgical technique and carries a higher complication rate. Minimally invasive antral membrane balloon

elevation (MIAMBE) is one of many modifications of the BAOSFE method, originally described by Soltan and Smiler (2005), in which antral membrane elevation is executed via the osteotomy site using a dedicated balloon.

After drilling depth is determined according to measurements obtained from the CT scan:

- A pilot drill pilot (2 mm diameter) is introduced in the center of the alveolar crest up to 1–2 mm below the sinus floor.
- The osteotomy is enlarged with the dedicated osteotomes.
- Bone substitute (BS) is injected into the site, and subsequently, the sinus floor is gently fractured.
- The membrane integrity is assessed. BS is injected again and a screw tap is tapped into the prepared site 2 mm beyond the sinus floor.
- After screw-tap removal and evaluation of sinus membrane integrity, the metal sleeve of the balloon-harboring device is inserted into the osteotomy 1 mm beyond the sinus floor.
- The balloon is inflated slowly with the barometric inflator up to 2 atm. Once the balloon emerged from the metal sleeve underneath the sinus membrane, the pressure dropped down to 0.5 atm.
- Subsequently, the balloon is inflated with progressively higher volume of contrast fluid.
- Sequential periapical X-rays evaluate the balloon inflation and membrane elevation. Once the desired elevation (usually 10 mm) is obtained, the balloon should be left inflated 5 min to reduce the sinus membrane recoil.
- Then, the balloon is deflated and removed. The membrane integrity is assessed by direct visualization and examination with the suction syringe and respiratory movement of blood within the osteotomy site.

Implant placement at the same sitting is optional if the RBH is sufficient (Figs. 6.25, 6.26, and 6.27).

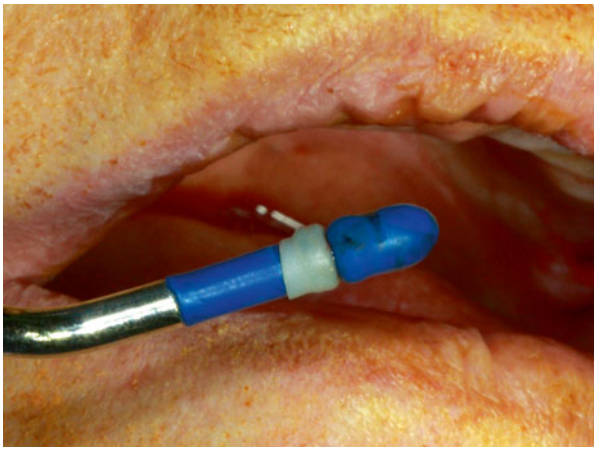


Fig. 6.25 Pneumatic device consisting of a syringe, tubing, and a metal shaft with a tip connected to a latex mini balloon with an inflation capacity

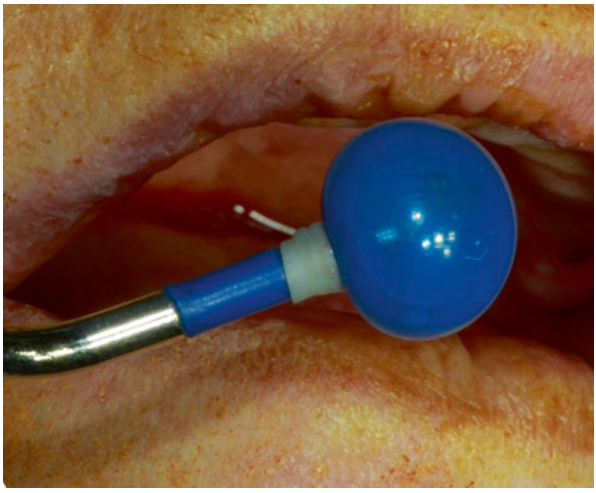


Fig. 6.26 Balloon is stretched by inflating it before initiating the membrane elevation

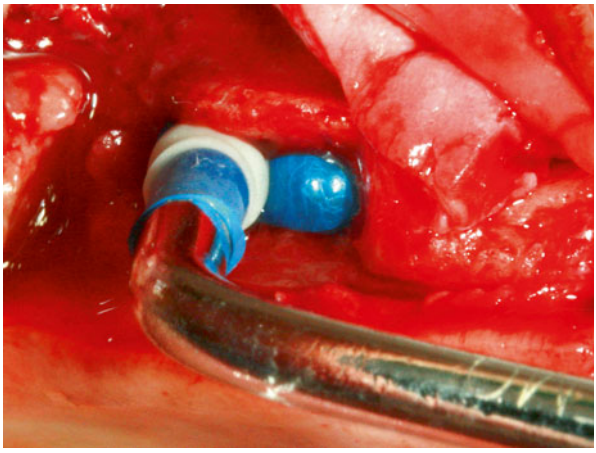


Fig. 6.27 Inflated sinus lift balloon gently elevates the Schneiderian membrane

Referring to the authors (Soltan and Smiler 2005), this procedure is highly successful and easy to perform. On the patient side, this procedure eliminates the complications, discomfort, and disfiguring associated with traditional hinge osteotomy and may abbreviate the time to implant exposure and functionality.

6.3.4 Hydraulic Pressure Technique

The same year Soltan and Smiler (2005) published their "MIAMBE" technique, Sotirakis and Gonshor (2005) developed a new modification of the original Summers technique. After the use of osteotomes, saline is injected beneath the membrane under hydraulic pressure with a suitably fitted syringe.

A so-called minimally invasive hydraulic sinus condensing technique has been described (Chen and Cha 2005). IT uses a sinus condensing kit consisting of round

diamond sinus burs 1, 2, and 3 mm diameters, developed especially for this procedure. Titanium-coated sinus graft condensers are also supplied in 2, 3, 5, and 6 mm diameters. Using these tools in combination with hydraulic pressure supplied by a surgical handpiece, clinicians can safely separate the Schneiderian membrane from the sinus floor and prepare the area for immediate implant placement, taking advantage of anatomical features normally viewed as restrictive. Hydraulic pressure and pliable bone graft mixture, used in tandem, can gently dissect soft tissue from bone in the sinus without danger of perforation.

Few years later, another innovative crestal technique based on high hydraulic pressure, considered as a minimally invasive sinus floor augmentation (MISFA), has also been studied recently by Jesch et al. (2013). This method consists of a drill, a pump, and a connecting tube set. After drilling into the RBH and staying 1–2 mm away from the sinus floor, a hydraulic pressure is created by the pump (1.5 bar); it pushes back the sinus membrane from the drill using physiological saline (NaCl). Saline is then set into hydraulic vibration to create a further separation of the membrane from the bone with a reduced risk of perforation. The cavity is then filled with BS preceding implant placement.

Based on the same principle, another system (physiolifter device) has been developed using a piezoelectric device with specially designed tips, considered to be safe and atraumatic during site preparation when compared to osteotomes and hammering. After site preparation, a specialized instrument (CS1 elevator), which is connected via a tube to a 3 ml saline syringe, is introduced into the cavity, leading to a controlled membrane elevation through a hydrodynamic pressure of the liquid. Simultaneous implant placement can be performed if indicated.

6.4 Transalveolar Sinus Elevation Combined with Ridge Expansion

Alveolar resorption often includes loss of both vertical and buccal dimension.

In case of horizontal bone loss where the sinus is prominent, ridge expansion is combined with simultaneous SFE.

In ridges as narrow as 3–4 mm and for a RBH ≥4 mm, ridge expansion combined to SFE and simultaneous implant placement is indicated.

Initial ridge expansion begins in the sectioned ridge below the sinus floor using either bone chisels or piezoelectric specialized tips toward the facial aspect in a manner to keep the facial cortical plate intact.

Localized management of sinus floor (LMSF) elevation up to 3 mm can be accomplished with gentle osteotome pressure at implant sites, with increased osteotome diameter leading to progressive ridge expansion. The implant is placed; the expansion cavity could be filled with a collagen sponge or a bone substitute.

In large edentulous sectors, SFE combined to ridge expansion requires to section the alveolar crest along the length of the posterior maxilla away from the sinus floor. Blunted monobevel chisels or "D"-shaped osteotomes (or bullet shape) are then used to expand the bone "flap" anteroposteriorly about 2 mm. The sinus floor is then sequentially fractured across the entire length by progressive malleting forces. The ridge is then expanded to its final width previous to implant placement (Cullum and Jensen).

6.5 Advanced Crestal Techniques

In large edentulous sectors, following the same concept of a crestal SFE approach with delayed implant placement, different advanced techniques have been developed.

6.5.1 Crestal Bone Impacted Trap (CBIT)

In 1998, Fugazzotto and Vlassis described a crestal approach using a rectangular-shaped osteotomy that was prepared on the crest of the alveolar ridge. The detached "window" was then elevated apically while the sinus membrane was simultaneously reflected. This approach was used when less than 2 mm of bone was evident between the floor of the sinus and the crest of the residual ridge. In 2003 Winter et al. (2003) described a graftless crestal SFE with delayed implant placement called the sinus/alveolar crest tenting (SACT) technique (91 % implant success rate) indicated where the RBH ≤4 mm (mean RBH in their study was 2.87 mm). Neither BS nor membranes were used. This technique combines SFE with immediate implant placement creating a tenting membrane effect. The most common complication when performing this technique is the inability to achieve implant stability.

Therefore, few years later, Nader et al. (2006) and Soardi and Wang (2012) described in details a SFE technique using a crestal window's approach to reach the sinus with delayed implant placement as a modification of the SACT (Winter et al. 2003).

The depth of the osteotomy is determined from the thickness of the bone.

- The bony window should be contained within the width of the alveolar crest and does not extend onto the buccal or palatal aspect.
- Once the crestal window is mobile, a piezoelectric tip is used to elevate the Schneiderian membrane away from the bony walls.
- This technique minimizes membrane perforation by facilitating tension-free rapid detachment of the Schneiderian membrane. Thus, it might be beneficial in the presence of septa in an attempt to minimize membrane perforation.
  - The alveolar bony window is moved apically (roof) using a wide osteotome, taping gently until the entire rectangle is free. The resultant contained defect is filled with BS as an ideal site for bone regeneration.
  - A collagen barrier membrane, extended beyond the borders of the crestal window, is placed over the bone graft.

Other variations exist within this crestal CBIT technique, such as:

- The use of "beaver blade," bone chisels, or preferably a piezoelectric device to outline the window in an attempt to minimize the risk of membrane perforation technique and to preserve a minimal bone width of 1.5 mm around the crestal window (Figs. 6.28, 6.29, 6.30, 6.31, 6.32, 6.33, 6.34 and 6.35).

This technique is indicated in case of:

- A large edentulous sector
- A large crestal width
- RBH $\leq$ 2 mm
- The presence of anatomical sinus difficulties (septa, developed PSAA artery)

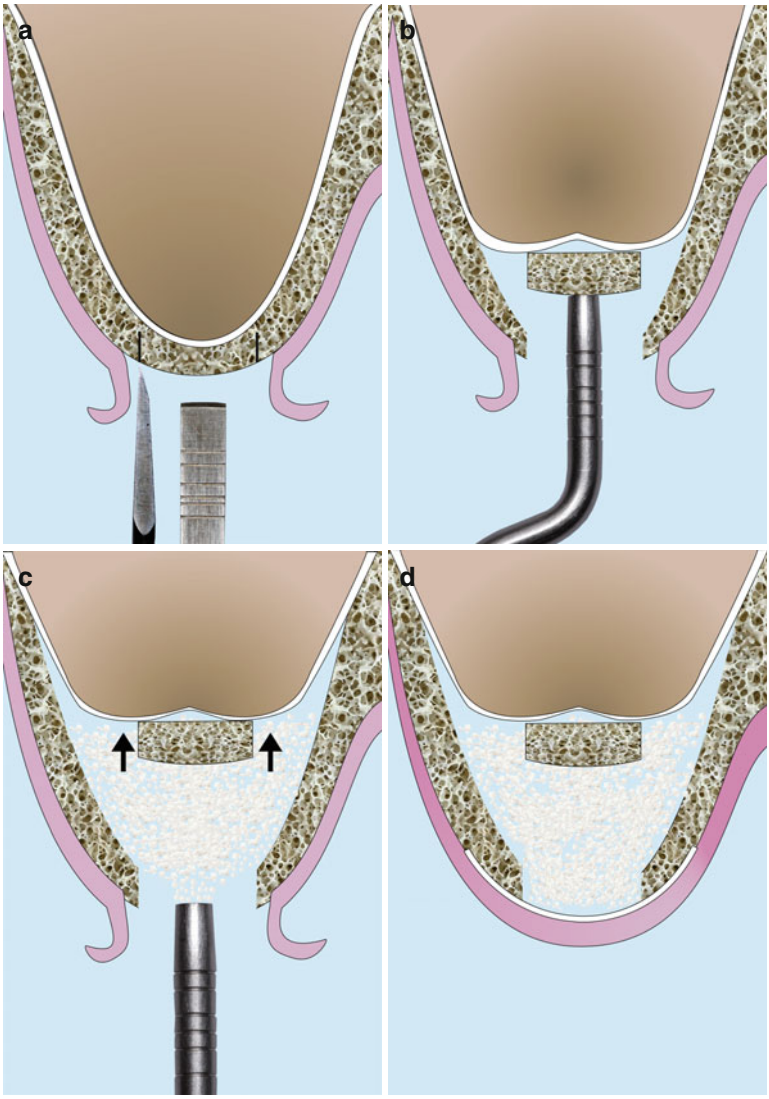


Fig. 6.28 Schematic drawings of CBIT technique. (**a**) Bone chisel preparing the bony window trap. (**b**) Osteotome pushing upward the detached bony trap. (**c**) Sinus cavity filled with BS; note the new position of the impacted bony trap. (**d**) Closure of the filled defect using an absorbable membrane

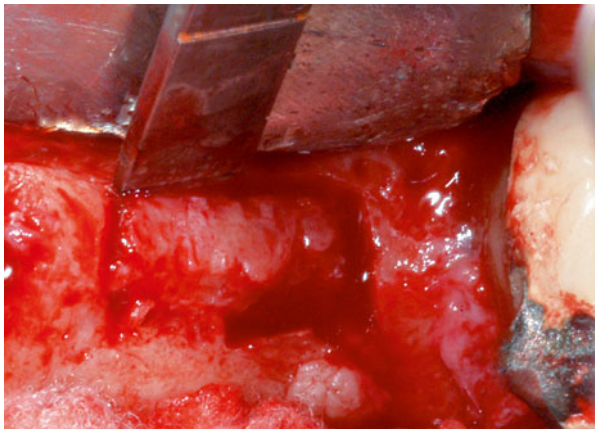


Fig. 6.29 Bone chisel outlining the bony window trap

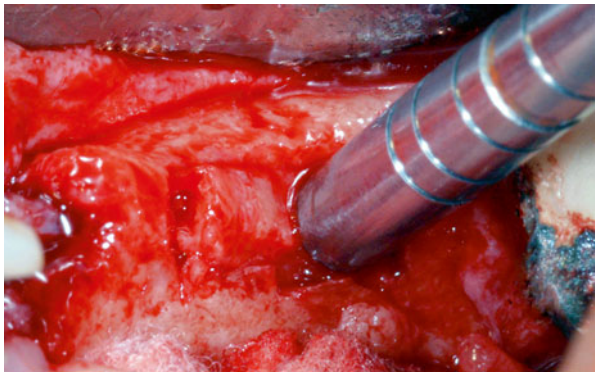


Fig. 6.30 Wide osteotome fracturing the bony window trap apically

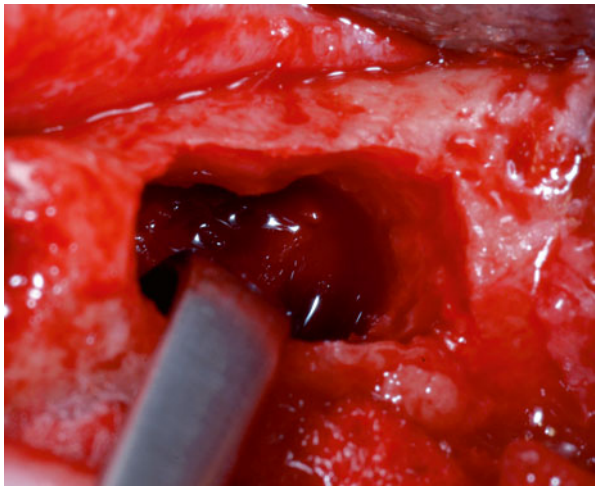


Fig. 6.31 Minimal sinus membrane elevation through the window using a sinus curette

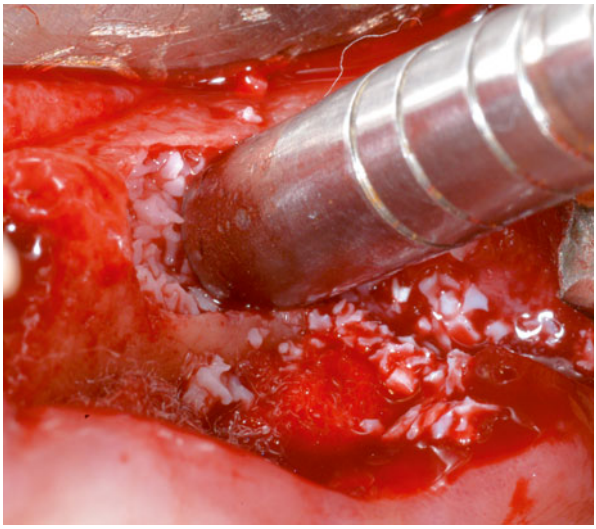


Fig. 6.32 Osteotome condensing upward particulate bone substitute

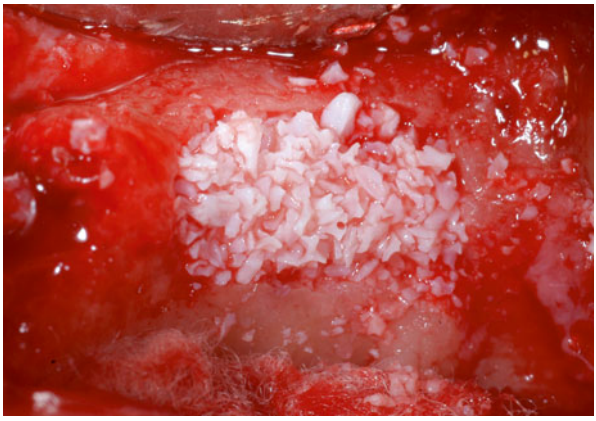


Fig. 6.33 Final crestal view of complete filling of the site

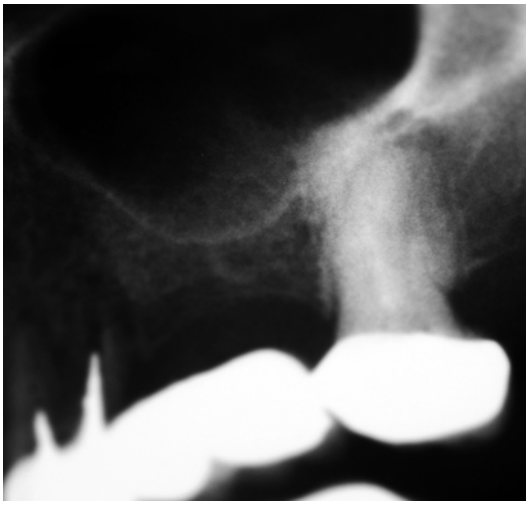


Fig. 6.34 Radiographic X-ray before CBIT technique

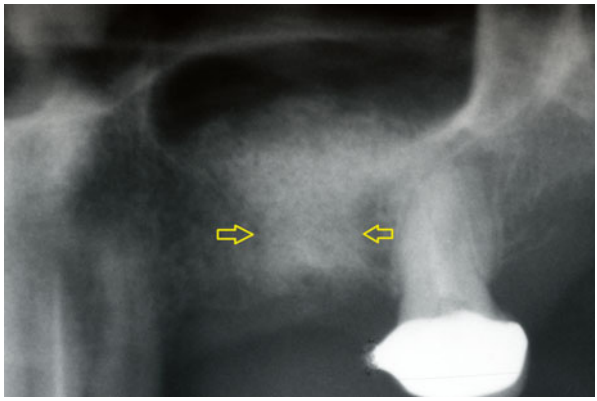


Fig. 6.35 Radiographic X-ray after CBIT technique. The *yellow arrows* indicate the filled defect

6.5.2 Crestal Bone Repositioned Trap (CBRT)

As an interesting evolution of the CBIT technique, Nader et al. (2006) introduced a surgical technique called the crestal bone repositioned trap (CBRT), by which the access to the maxillary sinus floor is obtained through the alveolar ridge, providing sufficient space for bone-substitute particulates and covered with the intact crestal bone repositioned window.

Detailed description:

- A bony window is marked with a bone chisel, preserving a minimum of 1.5 mm of bone thickness on the buccal and the palatal side of the osteotomy (in order to secure the trap repositioning, avoiding an uneventful postsurgical resorption).
- The window is then cut using a bone chisel, a reciprocating micro-saw or a piezzo device.
- The cutting should be performed in an oblique direction, resulting in a flanged bone window capable of being replaced in a stable position.
- The bone trap is reflected and separated from the residual cancellous bone and kept in saline.
- The remaining sub-sinus segments of bone should be tapped and fractured gently using osteotomes following Summers technique.
- After initiating the membrane elevation using a flare piezosurgery tip, to facilitate Schneiderian membrane detachment, a sinus membrane lifting instrument is then utilized within the osteotomy and manipulated gently in lateral and upward motion.
- After completion of bone grafting, the bone trap is then replaced covering the osteotomy and pushing additional BS toward the sinus.

There are several advantages using a repositioned bone trap.

- It is possible that the surface of the bone window passively contributes to healing by serving as a stabilizing surface for the BS and actively by bone formation into the space, at least after initial healing.

- The CBRT plays a role of a biologic autologous membrane, with osteogenic properties protecting the grafting material inside the sinus cavity with no need to use a synthetic barrier membrane.
- Moreover, the preservation of the residual crestal bone promotes bone and soft tissue healing (Figs. 6.36a–c, 6.37, 6.38, 6.39, 6.40, and 6.41).

This technique is indicated in case of:

- Large edentulous sector
- Large crestal width
- RBH ≥ 3 mm
- The presence of anatomical sinus obstacles (septa, developed PSAA artery)

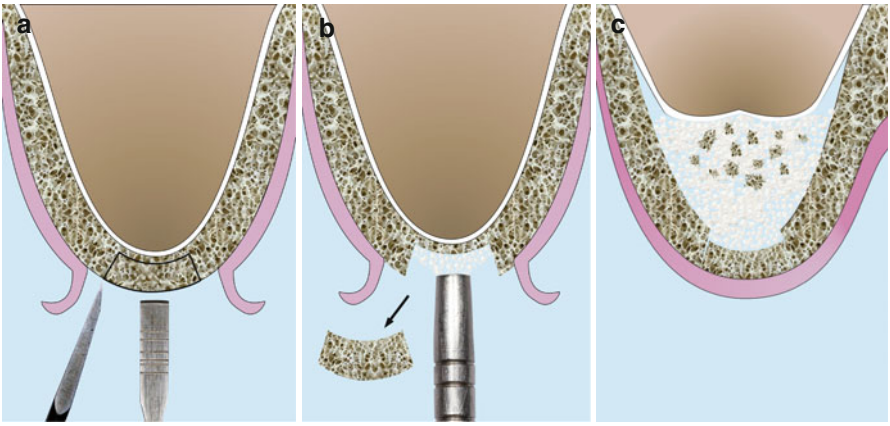


Fig. 6.36 Schematic drawings of CBRT technique. (**a**) Bone chisel outlining the bony window trap limited to the cortical. Note the inclined orientation of the bone chisels. (**b**) Reflecting the bony trap and fracturing the sinus floor using a wide osteotome. (**c**) Repositioning of the bony trap after grafting the sinus

Fig. 6.37 Clinical view showing the bone chisel outlining the bony window trap

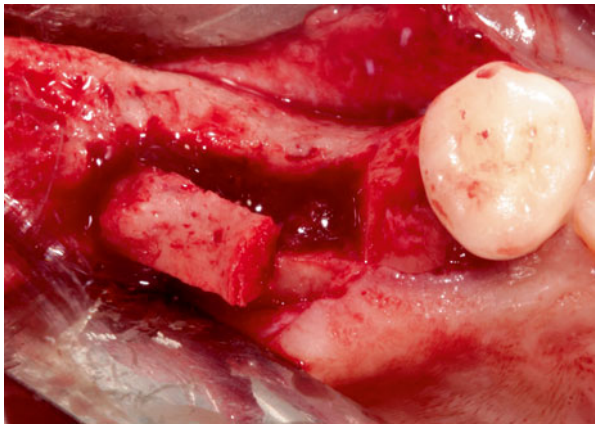


Fig. 6.38 Reflecting the bony trap following its complete release

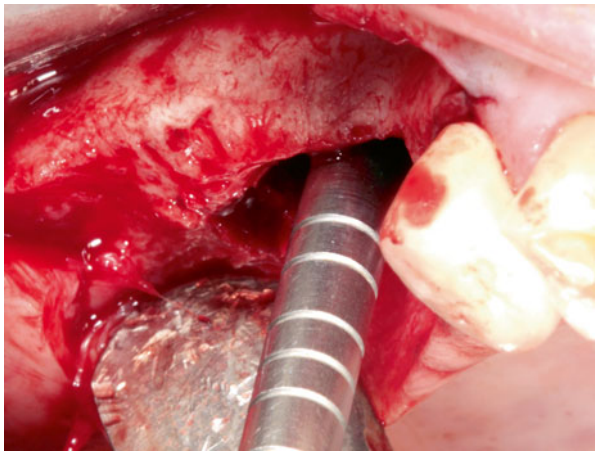


Fig. 6.39 Osteotome condensing particulate bone

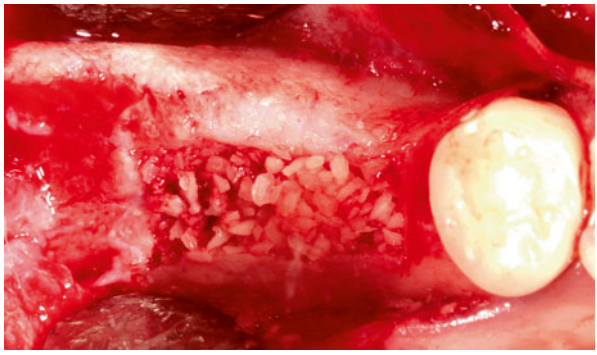


Fig. 6.40 Final crestal view showing a complete filling of the site

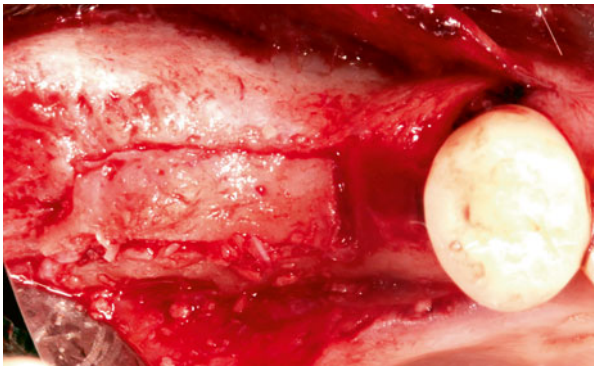


Fig. 6.41 Repositioned bony trap fitted in its original place

6.6 Graftless Approach

In 1984, Brånemark et al. (1984) used the technique of elevating nasal and sinus mucosa through the preparation of the implant site to gain height and newly formed bone when installing implants. Ten years later, Summers (1994c), with elevation of the sinus mucosal lining through the preparation site, also presented a further technique simplification in the vertically compromised implant site of the subantral maxillary area (OSFE).

In their original respective SFE techniques, neither Tatum nor Summers used any additional grafting material in the crestal SFE.

A modified osteotome technique without grafting insertion has been described by other authors (Schmidlin et al. 2008; Pjetursson et al. 2008).

Pjetursson et al. (2009a) evaluated the radiographic tissue remodeling of Summers SFE with or without grafting and concluded that crestal SFE should be performed in conjunction with the application of bone or bone-substitute grafting material for optimal outcome.

On the other hand, favorable results have been reported on Summers technique without any grafting materials (Leblebicioglu et al. 2005; Nedir et al. 2006, 2009; Fermergård and Astrand 2008; Schmidlin et al. 2008). A mean gain of alveolar bone height from 1.7 to 3.9 mm after transalveolar technique without grafting was also detected (Leblebicioglu et al. 2005; Schmidlin et al. 2008; Nedir et al. 2006; Ahn et al. 2011).

Other studies (Lai et al. 2008; Lai et al. 2010) reported no significant differences in implant survival rates between the two groups (with or without graft) after 5 years (Lai et al. 2008). In addition, the radiographic analysis also showed that the new bone gain in the elevated sinus was visible without grafting, but no comparison was conducted between the two groups. The randomized controlled clinical trials

(RCTs) are still needed to elucidate the necessity of grafting in case of OSFE (Tonetti et al. 2012).

Tan et al. (2008) also showed that the BAOSFE approach had no advantages after 3 years' observation, compared with OSFE (without grafting) showing at 6-month follow-up, that the bone gain of BAOSFE was significantly higher than OSFE. However, 2 years later, the yielded mean bone gain shrinks, reaching the same level of that without grafting (Tan et al. 2008). A more recent histological study (Si et al. 2013) evidenced spontaneous new bone formation and better bone-to-implant contact for OSFE. The grafting material application during BAOSFE procedure showed no advantages in histological results.

This same remodeling pattern resulting in graft volume reduction was also found by previous radiographic studies (Brägger et al. 2004; Hatano et al. 2004).

According to Boyne (1966), the implant's protrusion into the sinus without graft materials plays a major role in the amount of bone gain: complete regeneration was shown over the entire surface when implants protruded 2–3 mm into the sinus. In contrast, when protrusion was 5 mm and more, only partial growth of bone occurred at the lateral and apical aspects of the implant (Schmidlin et al. 2008). According to Lai et al. (2010), the technique's success benefits from "effective bone-to-implant surface" in the residual bone.

Nowadays, new tapered implant designs with microthreads (or microgrooves) clearly improved the primary stability with reduced RBH needed (≥4 mm); moreover, modified implant surfaces enable surgeons to reach higher success rates.

Some authors demonstrated the osteogenic potential of the Schneiderian membrane that is composed of a few layers including the epithelial lining, the lamina propria, and the maxillary bone interface. The Schneiderian membrane includes a richly vascularized lamina propria; a number of studies have suggested that osteoprogenitor cells may be associated with cells, pericytes, within the microvascular walls, or in the bone marrow, as adventitial subendothelial cells. Srouji et al. (2009) suggests that microvascular cells may represent one, or even the main, contributor to the osteogenic cell population present in the Schneiderian membrane.

Esposito et al. (2010, 2014) stated in a Cochran systematic review that the use of a rigid resorbable barrier in the elevated sinus area in the presence of 1–5 mm of RBH without the addition of a graft is sufficient to regenerate new bone to allow rehabilitation with implant-supported prosthese.

Nowadays, there is still controversy regarding the necessity of adding bone substitutes in crestal SFE.

Most of the clinicians prefer to apply grafting materials (autogenous, allogenic or xenogenic) while performing transalveolar sinus floor elevation to ensure the

space maintenance between the Schneiderian membrane and the floor of sinus cavity for new bone formation according to the Summers' BAOSFE publication (Summers 1994c) (Figs. 6.41, 6.42, and 6.43).

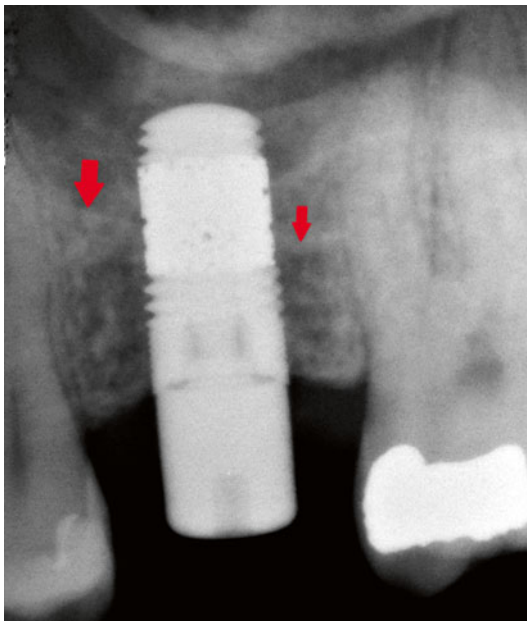


Fig. 6.42 Implant placed using a graftless approach. The *red arrows* showing the height of the pristine bone. The lifted membrane has been elevated further by seating the implant

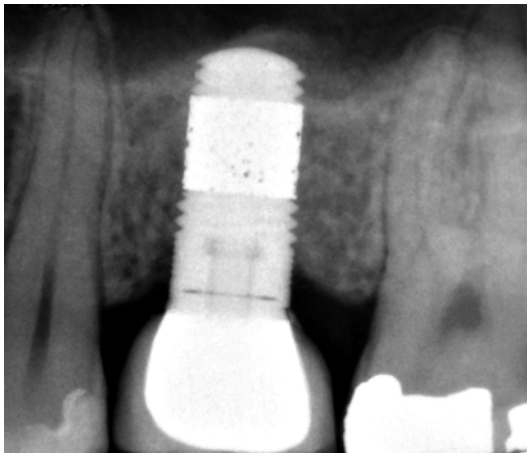


Fig. 6.43 6-month postoperative radiograph showing the bone growth apically to the implant

6.7 Implant Success Rate (ISR) Related to RBH Following Crestal Techniques

RBH has frequently been cited as a significant predictor of the success of crestal SFE and implant survival/success:

- Summers considered a requirement for at least 6 mm of RBH to ensure primary stability of the implant.
- The results of Zitzmann et al. indicate that the osteotome technique can be recommended when more than 6 mm of RBH is present and an increase of about 3–4 mm is expected. In cases of more advanced resorption, a one-step or two-step lateral SFE has to be performed (Zitzmann et al. 1997).

In a multicentric retrospective study, Rosen et al. (1999) evaluated the outcome of the Summers technique: a success rate of 96 % was obtained when the RBH was 5 mm or more but dropped dramatically to 85 % when the RBH was 4 mm or less. It may be due to the risk of tearing the membrane and the difficulty of obtaining primary implant stability in thin ridges.

Existing literature (Fugazzotto 1994; Rosen et al. 1999) suggests that RBH has a significant influence on the outcome of crestal procedures. Specifically, the technique's success decreases with reduced RBH.

- Sendyk and Sendyk (2002) also indicate that the osteotome technique has to be used when the SFE does not exceed 5 mm.
- However, in cases where the RBH is unable to achieve primary implant stability, crestal approach could still be used in two-stage technique; thus grafting material is introduced without implant placement for cases of less than 4 mm of RBH since Toffler et al. (2010) considered that RBH <4 mm is associated with reduced primary implant stability (73.3 %).
- On the other hand, a survival rate of 94.8 % was reported in patients with RBH between 6 and 9 mm (Ferrigno et al. 2006).
- In 2010, Esposito et al. (2010)stated that if the RBH is ≥4 mm (combined to a convenient crestal width ≥5), a crestal approach to lift the sinus lining and place 8 mm implants is recommended; it leads to fewer complications than a lateral window approach placing, at the same time, implants at least 10 mm long (Esposito et al. 2010).
- Several authors evaluated the implant success rate following SFE through crestal approach. Table. 6.1 illustrates the ISR following different crestal SFE procedures according to RBH using different grafting materials and implant surfaces.

Table 6.1 Summary of success rate data from crestal sinus floor elevation studies

Author	Year	RBH	Total patients	Total implants	Type of intervention	Grafting material	Success rate (%)	Membrane perforation (%)
Summers	1994	n.r	55	143	Osteotome		96	
Zitzmann and Sharer	1998	8.8	20	59	Osteotome	ABB	94.92 (2 years)	
Rosen et al.	1999	n.r	101	174	Osteotome	ABB, ABG, FDBA, OgN	97.03 (3 years)	
Cavicchia et al.	2001	2.9	43	97	Modified osteotome	None	88.65 (5 years)	
Fugazotto	2002	n.r	103	116	Trephine/osteotome	None	98.28 (3 years)	
Toffler	2004	7.1	167	276	Osteotome	ABB+ABG	93.48 (5 years)	4.7
Bragger et al.	2004	7	19		Osteotome	Deproteinized bovine bone, Bio-Oss, autologous	96	
Leblebicioglu et al.	2005	9.1	40	75	Osteotome	None	97.33 (2 years)	2.7
Ferrigno et al.	2006	n.r	323	588	Oteotome	ABB, ABG	98.6 (5 years)	2.2
Jurisic et al.	2008	n.r	33	40	Osteotome	None	100 (3 years)	
Diss et al.	2008	6.5	20	35	Osteotome	PRF	97.14 (2 years)	
Kermalli et al.	2008	7.2	45	57	Osteotome	ABB, ABG	96.49 (5 years)	
Schmidlin et al.	2008	3.6	24	24	Osteotome	None	100 (3 years)	
Gabbert et al.	2009	n.r	36	92	Osteotome	None	95.65 (5 years)	
Fermergard et al.	2009	6.3	36	53	Osteotome	None	94.30 (3 years)	
Pejtursson et al.	2009	7.5	181	252	Osteotome	ABB	97.14 (5 years)	10.4
Nedir et al.	2009	2.5	32	54	Osteotome	None	100 (2 years)	16
Calvo-Guirado et al.	2010	n.r	30	60	Threaded bone dilators	PB	96.67 (3 years)	
Crespi et al.	2010	6.62	20	30	Osteotome	MgHA	100 (3 years)	
Tetsch et al.	2010	8.2	522	983	Osteotome	None	96.84 (5 years)	
Bruschi et al.	2010	3	46	66	Osteotome	None	95.45 (5 years)	
Kfir et al.	2009	3.9 ± 2.1		1,615	MIAMBE		95.2	

RBH residual bone height, *ABB* anorganic bovine bone, *ABG* autogenous bone graft, *DFDBA* demineralized freeze-dried bone allograft, *FDBA* freeze-dried bone allograft, *MgHA* magnesium-enriched hydroxyapatite, *OgN* Osteograf-N (Ceramed, Lakewood, CO, USA), *PB* porcine bone, *PRF* platelet-rich fibrin, *Pro* prospective study, *Retro* retrospective study

6.8 Classifications Used for SFE Treatment Options

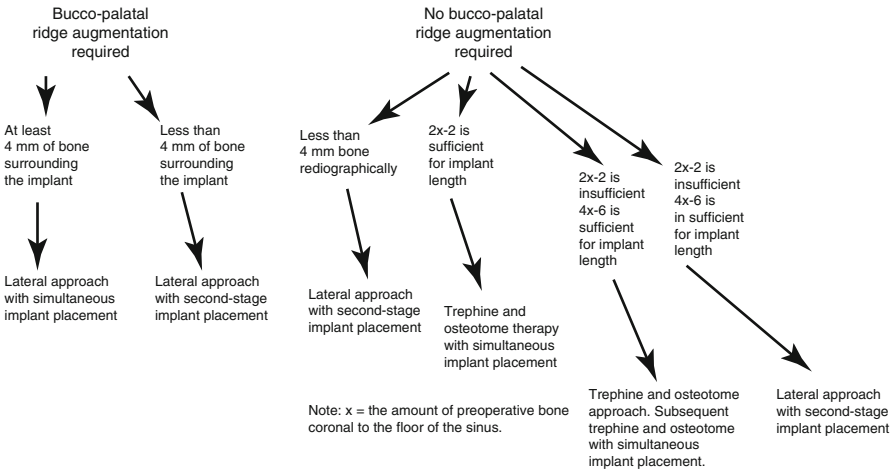
The data of the consensus conference of the Academy of Osseointegration, regarding SFE procedures, held on in 1996 was published in 1998 (Jensen et al. 1998). It was recommended to adjust the surgical procedure according to the RBH (Jensen 1994). When the RBH belongs to classes A and B (RBH 10 and 7–9 mm, respectively), the lateral SFE was recommended with simultaneous implant placement.

However, when the RBH belongs to class C (RBH 4–6 mm) or D (RBH 1–3 mm), the lateral approach is recommended; it involves the use of a grafting material in conjunction with immediate or delayed implant placement, for class C and class D, respectively. Note that at the time of this classification, it was recommended to place implants not shorter than 10 mm. Moreover, the crestal SFE was not prevalent yet. Later on, crestal SFE (and its modifications) became a technique of choice in cases when less RBH was available. Additionally, the standardization of the use of short implants with enhanced surfaces was also in favor of a crestal SFE approach.

Therefore, few years later, Zitzmann and Schärer classification (1998) recommended the osteotome technique when more than 6 mm of RBH is present, expecting an increase of about 3–4 mm. Then, lateral SFE was only recommended in cases of more advanced resorption using a one-step or two-step lateral SFE depending on RBH characteristics.

Furthermore, in order to simplify the appropriate use of each technique, Fugazzotto (2003) proposed a guide chart based on the RBH measurement in order to select the suitable technique. His findings led to the utilization of the formula 2×-2 when determining the maximum length of implants to be placed at the time of osteotome SFE, with x equaling the RBH.

He proposed the hierarchy of selection below:



Nowadays, these classifications should be modified since short implants (4–6 mm) have proved their effectiveness, thus excluding the absolute necessity for SFE in the presence of reduced RBH (6–8 mm).

Conclusion

The challenge facing clinicians today is not the ability to utilize each conventional SFE successfully. Rather, it is to select the most appropriate SFE technique depending on the initial clinical situation because the choice of treatment is influenced by the anatomy of the area as well as a number of other factors such as edentulous sector, RBH, etc. (Tan et al. 2008).

Evidence available today indicates that crestal techniques are predictable and safe with successful outcome in means of grafting technique and long-term ISR (Emmerich et al. 2005; Tan et al. 2008; Pjetursson et al. 2009a, b).

However, despite that the crestal SFE approach is considered to be more conservative than the lateral approach, the main drawback is that the crestal SFE is usually performed blindly due to the impossibility to visualize the sinus floor (Tan et al. 2008).

Endoscopic studies have demonstrated the risk of membrane perforation while performing transalveolar SFE (Nkenke et al. 2002; Berengo et al. 2004). Hence, the main disadvantage of this "blind" technique is the uncertainty of possible perforations of the Schneiderian membrane leading to anarchic spreading of bone particles within the sinus and failure of the SFE procedure.

In spite of this limitation, membrane perforation was reported to be less frequent in the osteotome-mediated procedure than in the lateral approach (Del Fabbro et al. 2012; Katranji et al. 2008; Chanavaz 1990). For this reason, an osteotome-staged approach with 6-month delayed implant insertion has been proposed with encouraging results (Kang 2008). Moreover, an endoscopic study revealed that the sinus floor might be elevated up to 5 mm without perforating the sinus membrane (Engelke and Deckwer 1997).

On the other hand, RBH should be carefully evaluated since it is considered as the most significant success factor of crestal SFE and implant survival/success rate.

In order to facilitate a proper selection of the various crestal techniques described in the present chapter, the authors suggest below a guide chart according to the RBH:

Crestal SFE	Single/multiple edentulism	Single/multiple edentulism	Single/multiple edentulism	Multiple edentulism	Multiple edentulism
RBH	5–7 mm	4–5 mm	<4 mm	3–4 mm	≤2 mm
OSFE (SI)	++				
BAOSFE (SI)		+			
Trephine (SI)		+			
FSD (DI)			+		
CBRT + DI				+	
CBIT + DI					+

OSFE osteotome sinus floor elevation, *BAOSFE* bone-added osteotome sinus floor elevation, *FSD* future site development, *DI* delayed implant placement

However, practically, the crestal approach cannot be extended to all cases since it necessitates a minimal ridge *width* of 5–6 mm, allowing the placement of a convenient implant diameter, particularly in multiple edentulous cases. Otherwise, a lateral approach should be performed, combined to an onlay graft or a GBR in order to widen the deficient ridge.

Nowadays, there is still a controversy regarding the appropriate indication of crestal SFE approach (versus lateral) and whether using a delayed or simultaneous implant placement. In fact, the delayed placement is either indicated in some situations as a primary objective when implant primary stability is difficult to achieve or in secondary intention when the surgeon failed to achieve primary implant stability the day of implant placement.

Further, crestal SFE approach is no more restricted by a minimal RBH (>5 mm), rather it is extended to more advanced cases with no prerequisite for simultaneous implant placement, as for the lateral SFE approach.

Finally, it is difficult to provide clear indications with respect to which crestal or lateral SFE procedures should be selected first. However, according to each clinical situation and to surgeon's experience, priority should be given to surgical interventions that are simpler, less invasive, with less risk of complications and especially with less patient morbidity.

References

Ahn J-J, Cho S-A, Byrne G, Kim J-H, Shin H-I (2011) New bone formation following sinus membrane elevation without bone grafting: histologic findings in humans. Int J Oral Maxillofac Implants 26:83–90

Berengo M, Sivolella S, Majzoub Z, Cordioli G (2004) Endoscopic evaluation of the bone-added osteotome sinus floor elevation procedure. Int J Oral Maxillofac Surg 33:189–194. doi:10.1054/ijom.2002.0459

Bernardello F, Righi D, Cosci F, Bozzoli P, Soardi CM, Carlo MS, Spinato S (2011) Crestal sinus lift with sequential drills and simultaneous implant placement in sites with <5 mm of native bone: a multicenter retrospective study. Implant Dent 20:439–444. doi:10.1097/ID.0b013e3182342052

Boyne PJ (1966) Osseous repair of the postextraction alveolus in man. Oral Surg Oral Med Oral Pathol 21:805–813

Brägger U, Gerber C, Joss A, Haenni S, Meier A, Hashorva E, Lang NP (2004) Patterns of tissue remodeling after placement of ITI dental implants using an osteotome technique: a longitudinal radiographic case cohort study. Clin Oral Implants Res 15:158–166

Brånemark PI, Adell R, Albrektsson T, Lekholm U, Lindström J, Rockler B (1984) An experimental and clinical study of osseointegrated implants penetrating the nasal cavity and maxillary sinus. J Oral Maxillofac Surg 42:497–505

Chanavaz M (1990) Maxillary sinus: anatomy, physiology, surgery, and bone grafting related to implantology–eleven years of surgical experience (1979–1990). J Oral Implantol 16:199–209

Checchi L, Felice P, Antonini ES, Cosci F, Pellegrino G, Esposito M (2010) Crestal sinus lift for implant rehabilitation: a randomised clinical trial comparing the Cosci and the Summers techniques. A preliminary report on complications and patient preference. Eur J Oral Implantol 3:221–232

Chen L, Cha J (2005) An 8-year retrospective study: 1,100 patients receiving 1,557 implants using the minimally invasive hydraulic sinus condensing technique. J Periodontol 76:482–491. doi:10.1902/jop.2005.76.3.482

Chen T-W, Chang H-S, Leung K-W, Lai Y-L, Kao S-Y (2007) Implant placement immediately after the lateral approach of the trap door window procedure to create a maxillary sinus lift without bone grafting: a 2-year retrospective evaluation of 47 implants in 33 patients. J Oral Maxillofac Surg 65:2324–2328. doi:10.1016/j.joms.2007.06.649

Cosci F, Luccioli M (2000) A new sinus lift technique in conjunction with placement of 265 implants: a 6-year retrospective study. Implant Dent 9:363–368

Cullum D, Jensen O (2006) Trans-alveolar sinus elevation combined with ridge expansion. In: Jensen OT (ed), The sinus bone graft. Second edition. Quintessence, Chicago, pp 251–262

Davarpanah M, Martinez H, Tecucianu JF, Hage G, Lazzara R (2001) The modified osteotome technique. Int J Periodontics Restorative Dent 21:599–607

Del Fabbro M, Corbella S, Weinstein T, Ceresoli V, Taschieri S (2012) Implant survival rates after osteotome-mediated maxillary sinus augmentation: a systematic review. Clin Implant Dent Relat Res 14(Suppl 1):e159–e168. doi:10.1111/j.1708-8208.2011.00399.x

Diserens V, Mericske E, Schäppi P, Mericske-Stern R (2006) Transcrestal sinus floor elevation: report of a case series. Int J Periodontics Restorative Dent 26:151–159

Emmerich D, Att W, Stappert C (2005) Sinus floor elevation using osteotomes: a systematic review and meta-analysis. J Periodontol 76:1237–1251. doi:10.1902/jop.2005.76.8.1237

Engelke W, Deckwer I (1997) Endoscopically controlled sinus floor augmentation. A preliminary report. Clin Oral Implants Res 8:527–531

Esposito M, Felice P, Worthington HV (2014) Interventions for replacing missing teeth: Augmentation procedures of the maxillary sinus (review). The cochrane library, 5: CD008397. doi:10.1002/14651858.CD008397.pub2

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington H, Coulthard P (2010) Effectiveness of sinus lift procedures for dental implant rehabilitation: a Cochrane systematic review. Eur J Oral Implantol 3:7–26

Fermergård R, Astrand P (2008) Osteotome sinus floor elevation and simultaneous placement of implants–a 1-year retrospective study with Astra Tech implants. Clin Implant Dent Relat Res 10:62–69. doi:10.1111/j.1708-8208.2007.00062.x

Ferrigno N, Laureti M, Fanali S (2006) Dental implants placement in conjunction with osteotome sinus floor elevation: a 12-year life-table analysis from a prospective study on 588 ITI implants. Clin Oral Implants Res 17:194–205. doi:10.1111/j.1600-0501.2005.01192.x

Flanagan D (2006) The use of osteotomes in dental implant surgery. Dent Today 25:68–72

Fugazzotto PA (1994) Maxillary sinus grafting with and without simultaneous implant placement: technical considerations and case reports. Int J Periodontics Restorative Dent 14:544–551

Fugazzotto PA (1999) Sinus floor augmentation at the time of maxillary molar extraction: technique and report of preliminary results. Int J Oral Maxillofac Implants 14:536–542

Fugazzotto PA (2002) Immediate implant placement following a modified trephine/osteotome approach: success rates of 116 implants to 4 years in function. Int J Oral Maxillofac Implants 17:113–120

Fugazzotto PA (2003) Augmentation of the posterior maxilla: a proposed hierarchy of treatment selection. J Periodontol 74:1682–1691. doi:10.1902/jop.2003.74.11.1682

Fugazzotto PA, Vlassis J (1998) Long-term success of sinus augmentation using various surgical approaches and grafting materials. Int J Oral Maxillofac Implants 13:52–58

Hatano N, Shimizu Y, Ooya K (2004) A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 15:339–345. doi:10.1111/j.1600-0501.2004.00996.x

Jensen OT, Shulman LB, Block MS, Iacono VJ (1998) Report of the Sinus Consensus Conference of 1996. Int J Oral Maxillofac Implants 13(Suppl):11–45

Jesch P, Bruckmoser E, Bayerle A, Eder K, Bayerle-Eder M, Watzinger F (2013) A pilot-study of a minimally invasive technique to elevate the sinus floor membrane and place graft for augmentation using high hydraulic pressure: 18-month follow-up of 20 cases. Oral Surg Oral Med Oral Pathol Oral Radiol 116:293–300. doi:10.1016/j.oooo.2013.05.014

Kang T (2008) Sinus elevation using a staged osteotome technique for site development prior to implant placement in sites with less than 5 mm of native bone: a case report. Int J Periodontics Restorative Dent 28:73–81

Katranji A, Fotek P, Wang H-L (2008) Sinus augmentation complications: etiology and treatment. Implant Dent 17:339–349. doi:10.1097/ID.0b013e3181815660

Lai H-C, Zhang Z-Y, Wang F, Zhuang L-F, Liu X (2008) Resonance frequency analysis of stability on ITI implants with osteotome sinus floor elevation technique without grafting: a 5-month prospective study. Clin Oral Implants Res 19:469–475. doi:10.1111/j.1600-0501.2007.01501.x

Lai H-C, Zhuang L-F, Lv X-F, Zhang Z-Y, Zhang Y-X, Zhang Z-Y (2010) Osteotome sinus floor elevation with or without grafting: a preliminary clinical trial. Clin Oral Implants Res 21: 520–526. doi:10.1111/j.1600-0501.2009.01889.x

Leblebicioglu B, Ersanli S, Karabuda C, Tosun T, Gokdeniz H (2005) Radiographic evaluation of dental implants placed using an osteotome technique. J Periodontol 76:385–390. doi:10.1902/jop.2005.76.3.385

Nader N, Younes R, Makari C, Jabbour G (2006) Prospective Study Comparing 3 different crestal sinus grafting techniques: 2-year results. J Clin Periodontol 33(Suppl 7):47

Nedir R, Bischof M, Vazquez L, Szmukler-Moncler S, Bernard J-P (2006) Osteotome sinus floor elevation without grafting material: a 1-year prospective pilot study with ITI implants. Clin Oral Implants Res 17:679–686. doi:10.1111/j.1600-0501.2006.01264.x

Nedir R, Bischof M, Vazquez L, Nurdin N, Szmukler-Moncler S, Bernard J-P (2009) Osteotome sinus floor elevation technique without grafting material: 3-year results of a prospective pilot study. Clin Oral Implants Res 20:701–707. doi:10.1111/j.1600-0501.2008.01696.x

Nkenke E, Schlegel A, Schultze-Mosgau S, Neukam FW, Wiltfang J (2002) The endoscopically controlled osteotome sinus floor elevation: a preliminary prospective study. Int J Oral Maxillofac Implants 17:557–566

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35:216–240. doi:10.1111/j.1600-051X.2008.01272.x

Pjetursson BE, Ignjatovic D, Matuliene G, Brägger U, Schmidlin K, Lang NP (2009a) Transalveolar maxillary sinus floor elevation using osteotomes with or without grafting material. Part II: Radiographic tissue remodeling. Clin Oral Implants Res 20:677–683. doi:10.1111/j.1600-0501.2009.01721.x

Pjetursson BE, Rast C, Brägger U, Schmidlin K, Zwahlen M, Lang NP (2009b) Maxillary sinus floor elevation using the (transalveolar) osteotome technique with or without grafting material. Part I: implant survival and patients' perception. Clin Oral Implants Res 20:667–676. doi:10.1111/j.1600-0501.2009.01704.x

Rosen PS, Summers R, Mellado JR, Salkin LM, Shanaman RH, Marks MH, Fugazzotto PA (1999) The bone-added osteotome sinus floor elevation technique: multicenter retrospective report of consecutively treated patients. Int J Oral Maxillofac Implants 14:853–858

Schmidlin PR, Müller J, Bindl A, Imfeld H (2008) Sinus floor elevation using an osteotome technique without grafting materials or membranes. Int J Periodontics Restorative Dent 28:401–409

Sendyk WR, Sendyk CL (2002) Reconstrução óssea por meio do levantamento do assoalho do seio maxilar. In: Gomes LA (ed), Implantes osseointegrados – Técnica e Arte. São Paulo, Ed. Santos, pp 109–122

Si M, Zhuang L, Gu Y, Mo J, Qiao S, Lai H (2013) Osteotome sinus floor elevation with or without grafting: a 3-year randomized controlled clinical trial. J Clin Periodontol 40:396–403. doi:10.1111/jcpe.12066

Soardi C, Wang HL (2012) New crestal approach for lifting the sinus in the extremely atrophic upper maxillae. Clin Adv Periodontics 2(3):179–184

Soltan M, Smiler DG (2005) Antral membrane balloon elevation. J Oral Implantol 31:85–90. doi:10.1563/0-773.1

Sotirakis EG, Gonshor A (2005) Elevation of the maxillary sinus floor with hydraulic pressure. J Oral Implantol 31:197–204. doi:10.1563/1548-1336(2005)31[197:EOTMSF]2.0.CO;2

Srouji S, Kizhner T, Ben David D, Riminucci M, Bianco P, Livne E (2009) The Schneiderian membrane contains osteoprogenitor cells: in vivo and in vitro study. Calcif Tissue Int 84: 138–145. doi:10.1007/s00223-008-9202-x

Summers RB (1994a) A new concept in maxillary implant surgery: the osteotome technique. Compendium (Newtown Pa) 15:152, 154–156, 158 passim; quiz 162

Summers RB (1994b) The osteotome technique: part 3 – less invasive methods of elevating the sinus floor. Compendium (Newtown Pa) 15:698, 700, 702–704 passim; quiz 710

Summers RB (1994c) The osteotome technique: part 2 – the ridge expansion osteotomy (REO) procedure. Compendium (Newtown Pa) 15:422, 424, 426, passim; quiz 436

Summers RB (1995) The osteotome technique: Part 4 – future site development. Compend Contin Educ Dent 16:1090, 1092 passim; 1094–1096, 1098, quiz 1099

Summers RB (1998) Sinus floor elevation with osteotomes. J Esthet Dent 10:164–171

Tan WC, Lang NP, Zwahlen M, Pjetursson BE (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II: transalveolar technique. J Clin Periodontol 35:241–254. doi:10.1111/j.1600-051X.2008.01273.x

Tatum H Jr (1986) Maxillary and sinus implant reconstructions. Dent Clin North Am 30:207–229

Toffler M, Toscano N, Holtzclaw D (2010) Osteotome-mediated sinus floor elevation using only platelet-rich fibrin: an early report on 110 patients. Implant Dent 19:447–456. doi:10.1097/ID.0b013e3181f57288

Tonetti M, Palmer R, Working Group 2 of the VIII European Workshop on Periodontology (2012) Clinical research in implant dentistry: study design, reporting and outcome measurements: consensus report of Working Group 2 of the VIII European Workshop on Periodontology. J Clin Periodontol 39(Suppl 12):73–80. doi:10.1111/j.1600-051X.2011.01843.x

Winter AA, Pollack AS, Odrich RB (2003) Sinus/alveolar crest tenting (SACT): a new technique for implant placement in atrophic maxillary ridges without bone grafts or membranes. Int J Periodontics Restorative Dent 23:557–565

Zitzmann NU, Schärer P (1998) Sinus elevation procedures in the resorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:8–17

Zitzmann NU, Naef R, Schärer P (1997) Resorbable versus nonresorbable membranes in combination with Bio-Oss for guided bone regeneration. Int J Oral Maxillofac Implants 12:844–852

7 Use of Grafting Materials in Sinus Floor Elevation: Biologic Basis and Current Updates

Georges Khoury, Pierre Lahoud, and Ronald Younes

Contents

G. Khoury, DDS, MSc (✉)
Department of implantology and bone reconstruction,
Paris-Diderot University, Paris, France
e-mail: dr.georges.khoury@gmail.com

P. Lahoud, DDS • R. Younes, DDS, PhD
Department of Oral Surgery, Faculty of Dentistry,
Saint Joseph University, Beirut, Lebanon
e-mail: pierre@lahouddentalclinic.com; ronald.younes@usj.edu.lb,
ronald.younes@hotmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_7

7.1 Patterns of Bone Healing in Sinus Floor Elevation (SFE)

With the increased need for the replacement of missing teeth in the posterior maxilla through dental implant therapy, a need arose for a method to provide patients with a sufficient bony support in cases where maxillary sinuses residual height was deficient for implant placement. One of the aims of the SFE is the creation of vital bone to achieve the osseointegration of dental implants placed in the posterior maxilla. With this goal in mind, various bone substitutes (BS) have been used for SFE procedures, including autografts, allografts, xenografts, and alloplasts.

The choice of an optimal grafting material for SFE is still an important debate topic in implant dentistry.

Guaranteeing both bone quantity and quality is essential in order to achieve a successful placement of dental implants of sufficient length and satisfying initial and long-term stability.

The ultimate goal of SFE procedure should be a complete "bone regeneration "of the grafted area of the posterior maxilla in order to ensure an optimal bone surrounding the implants inserted in the grafted sites.

The term *regeneration* implies that, during treatment, a specific volume or space, preferably in a specific geometry, is filled with viable bone tissue to restore function and/or esthetics. *Regeneration* is commonly understood as replacement of vanishing or lost components in the body.

Physiologic regeneration, occurring in many tissues or organ systems, represents a continuous replacement of cells or tissue elements.

Remodeling of cortical and trabecular bone represents regeneration. Not only are cells replaced, but also matrix.

Reparative regeneration takes place when tissues are lost because of injury or disease. Supporting tissues have different repair capacities; fibrous connective tissue appears to possess a good capacity for repair. The bone has the unique potential to restore its original structure completely, but there are some limitations. Likewise, some basic conditions have to be ensured, such as ample blood supply and mechanical stability, provided by a solid base. The principle of bone regeneration is independent of bone type and how the defect came about. It always follows the same pattern.

In addition to bone regeneration, the ultimate goal of SFE should be to ensure a long-term bone remodeling.

The coordinated actions of osteoblasts and osteoclasts occur within two biological contexts: bone modeling and remodeling.

Bone modeling is the process that adapts structure to loading by changing bone size and shape and removes damage and so maintains bone strength.

This process occurs at a low rate throughout life and is required for repair and adaptation to changes in mechanical loading. In this process, bone resorption and formation occur in an uncoupled manner and on separate surfaces.

In contrast, *bone remodeling* is the mechanism that ensures tissue turnover while maintaining bone mass. Bone remodeling is based on the coupled and balanced

activities of bone resorption and formation that occur in packages of cells along specific sites on the same bone surface (basic multicellular units).

Three healing phases are observed following SFE: early healing phase, biological bone regeneration, and remodeling; they occur in defects and fractures healing and the order is always the same (Cordioli et al. 2001).

1. *Early healing phase*
   Goal: rapid closure of the defect. During this early phase, bone clot turns to fibrous callus, which will be progressively mineralized.
2. *Biological bone regeneration*
   Goal: restoration of biological function.
   During this second phase, osteoprogenitor cells and osteoblasts become active in addition to fibroblasts and angiogenic cells. They restore the bone to its original state.
3. *Biological remodeling*
   Goal: adaptation to changing biomechanical loads.

This process continuously takes place in healthy bone and is maintained by the interaction of bone-resorbing osteoclasts and bone-building osteoblasts. The bone mass is maintained through a continuous process of the bone structure adaptation to biomechanical load according to the principles of Wolff"s law of transformation.

The bone trabecular always arranges themselves along the load lines to bear the applied forces.

Currently, a significant variation in the quality of bone obtained following SFE exists. In the past years, a considerable effort has been directed to develop tissue engineering strategies to enhance the SFE procedure to achieve consistent bone quality and shorten healing time (Lundgren et al. 1996; Moy et al. 1993).

7.2 Factors Influencing Bone Healing After SFE

SFE procedure is quiet challenging, since the maxillary sinus represents a unique environment with a reduced vascularity, reduced oxygen tension, and is subject to varying levels of intra-antral pressures that have been shown to influence bone graft healing (Jensen et al. 1998; Scharf et al. 1995).

Researchers aimed to identify and understand the factors that may have a critical impact on the outcomes of SFE.

These factors include systemic diseases, smoking habits, implant surface characteristics, BS utilized, and surgical procedures applied.

Moreover, several authors have pointed out the importance of anatomic variables. Fenner et al. (2009) evaluated the influence of remaining alveolar bone height (RBH) on stability and osseointegration of dental implants placed in maxillary posterior segments. Rios et al. (2009) evaluated in a review the correlation between RBH and implant surviual rate (ISR) after SFE and concluded that a higher ISR can be expected as available RBH increases.

Successful graft consolidation relies on the progressive apposition of newly formed bone, followed by functional remodeling and progressive replacement of the grafting material by vital tissue (Jensen 2006). This process requires the presence of a stable scaffold, adequate angiogenesis (blood supply), and the migration of osteogenic cells. These events could be slowed down in situations where the dimensions of the maxillary sinus cavity or the lateral window are excessive. Delayed or insufficient bone maturation may occur in cases where the sinus cavity presents larger dimension.

The distance from the buccal (lateral) to the palatal (medial) wall of the sinus cavity may have an important role in bone maturation after SFE (Avila et al. 2010).

Bone formation in the sinus cavity can be induced by various technical and surgical procedures, as peeling off the sinus membrane will stimulate bone formation, and osteoblast activity will be maintained by the presence of granulation tissue (Boyne and Kruger 1962; Smiler and Holmes 1987).

During organization of granulation tissue, inconspicuous perivascular cells are activated and, ultimately, form bone (Schenk et al. 1994).

To summarize, following the biological concept of guided bone regeneration (GBR), maxillary SFE induces bone formation by promoting osteoconduction from surrounding bony walls (Avera et al. 1997; Block and Kent 1997) and is dependent on the rates of revascularization and osteoblast recruitment (Block and Kent 1997). The augmented maxillary sinus space must be filled with BS able to be transformed to viable bone to restore the optimal function. The viable bone must be maintained for an adequate period to ensure healing or complete bone formation (Asai et al. 2002).

7.3 The Role of Grafting Material in SFE

Finding an ideal grafting material to fill the newly formed space has been the goal of researchers for many years, with varying degrees of success. Clinicians who deal with ridge augmentation and the reconstruction of maxillary sinuses have used various categories of grafting material. These encompass varied materials, material sources, and origins (natural vs. synthetic). Ideally, augmentation aims to ensure good bone tissue integration, osteoinduction, and long-term stability. Grafting material should be bioactive and biocompatible. It should maintain mechanical stability and volume during the initial healing and then subsequently resorbs completely, being replaced by newly formed bone (Isaksson 1992).

It is generally accepted that the gold standard of bone grafting is autogenous bone graft (AB). However, in an attempt to avoid separate surgical procedures involving remote donor sites and reduce postsurgical pain, patient inconvenience, operating time, and cost, clinicians have increased their use of alternative bone substitutes (BS). These are derived from human, animal, and synthetic sources.

BS should act via three different mechanisms: osteogenesis, osteoinduction, and osteoconduction (Pjetursson et al. 2008).

Osteogenesis Is the formation of new bone from bone-forming cells (osteoblasts) that are transplanted as a viable cellular component in autogenous bone graft. These osteoblasts produce an important quantity of growth factors when autogenous bone graft is maintained revascularized.

Osteoinduction This term means that primitive, undifferentiated, and pluripotent cells are stimulated to develop into the bone-forming cell lineage. One proposed definition is the process by which osteogenesis is induced (Jensen 2006). Urist defined induction as bone formation in ectopic sites (subdermal). This happens by implantation of growth factors like BMPs. Those are mainly located in cortical bone (Albrektsson and Johansson 2001).

Osteoconduction Or *creeping substitution* is cell growth on BS. An osteoconductive surface is one that permits bone growth on its surface or down into pores, channels, or pipes. There is an ingrowth of sprouting capillaries, perivascular mesenchymal tissues, and osteoprogenitor cells from the recipient host bed into the three-dimensional structure of an implant or graft (Albrektsson and Johansson 2001).

In osteoconduction, the implanted material usually serves as a scaffold for the ingrowth of capillaries, perivascular tissue, and osteoprogenitor cells from the recipient bed. This process generally is enhanced in presence of multiple walls, which is obviously the case of SFE procedure (favorable anatomy of the maxillary sinus).

AB is the most predictable material that possesses both osteoconductive and osteoinductive properties; it stimulates non-differentiated mesenchymal cells to form bone cells and also serves as a scaffold for new bone ingrowth. Osteogenesis is not significant in this case due to vascularization rupture when the bone is harvested.

Synthetic and processed bones (except demineralized bone) have only osteoconductive properties. In case of addition of growth factors, potential osteoinductive activity may occur. They should not only replace missing bone but encourage osseointegration as well, i.e., act as a scaffold for guided bone regeneration (GBR) into the graft, so helping the body to repair its own lost bone (Carson and Bostrom 2007). This bone ingrowth strengthens the grafted area by forming a bridge between the existing bone and the graft material. Ideally with remodeling over time, the newly formed bone should replace a large amount of the graft.

Available BS are composed of various materials, and many are formed from composites of one or more types of material. BS used in the treatment of bone defects can be classified according to their resorptive behavior in body fluid, to the manufacturing method, to substance classes, or to the origin of their primary materials. We classify them as autogenous (harvested) bone, allografts, xenografts, and alloplastics (synthetics). Adjunctives might be associated such as related growth factors like bone morphogenetic protein-7 (BMP-7, also known as osteogenic protein-1 or OP-1).

7.4 Autogenous Bone Graft (AB)

The gold standard of bone grafting is considered to be harvesting autogenous bone (AB). Autogenous grafts are transferred from one location to another within the same individual and are harvested either from intraoral or extraoral donor sites.

Historically, first SFE procedures used AB from the iliac crest (Boyne and James 1980; Tatum 1986), but the procedure is affected with problems of donor site morbidity (Summers and Eisenstein 1989) and limited availability. Calvarium bone is another extraoral site considered more predictable for SFE with less resorbability.

AB is very popular for SFE, since it possesses osteoconductive, osteoinductive, and supposed osteogenic properties (Galindo-Moreno et al. 2008).

Nevertheless, some authors reject the theoretical of osteogenesis activity. Osteogenesis can only occur when harvested bone is maintained vascularized. It is commonly known that cells survival can only occur when they are maintained at less than 1 mm from a vascular source.

If a bone graft is fragmented into small particles, living bone is killed and can no longer be osteogenic. The main advantages of AB are their excellent integration and the absence of risk of disease transmission.

However, *disadvantages* include potential morbidity at the donor site, availability in limited quantities, requires donor site surgery and risk of wound infection, increased blood loss, and prolonged anesthetic time (Kübler et al. 1999; Nkenke et al. 2001, 2002, 2004); depending on the bone quality, resorption could be more or less predictable.

Harvesting AB from intraoral sites can be associated with complications like devitalization of anterior mandibular teeth, possible nerve injury, changes in facial esthetics, and increased risk of mandibular ramus fracture (Galindo-Moreno et al. 2007). Moreover, harvesting AB increases the operating time (Peleg et al. 2004).

Bone harvested from extraoral iliac sites may cause hernia through the donor site, hemorrhage, adynamic ileus, instability of the sacroiliac joint, or gait disturbances (Kalk et al. 1996). Moreover, surgery is performed under general anesthesia (Iturriaga and Ruiz 2004; Watzek et al. 1998).

As a consequence, the use of AB for SFE has been questioned (Tadjoedin et al. 2002).

The clinical efficacy of AB graft is still not clear despite the high number of applications of "the golden standard" AB graft. We have only few evidence-based papers (Zimmermann and Moghaddam 2011) that showed an efficacy of the use of AB.

AB resorption is another main disadvantage extensively demonstrated in numerous SFE studies (Zimmermann and Moghaddam 2011), showing significantly lower total bone volume between 4.5 and 9 months (Klijn et al. 2010a, b) due to the initial resorption of the inserted graft and the steady replacement of de novo bone (Baumgarten 2010; Consolo et al. 2007; Hallman et al. 2002; Klijn et al. 2010a, b; Lundgren et al. 1996; Pejrone et al. 2002; Simunek et al. 2008; Szabó et al. 2005; Zijderveld et al. 2005). Therefore, resorption of AB and subsequent repneumatization have been mentioned as reasons to choose nonresorbable or slowly resorbable BS in SFE.

However, Block et al. (1998) showed that AB grafts were maintained after SFE with time and with regard to the vertical dimension, better than a combination of AB and demineralized bone.

Several studies have stated that intramembranous bone is more resistant to resorption than enchondral bone (Jensen and Sindet-Pedersen 1991; Kusiak et al. 1985; Zins and Whitaker 1983) due to the longer time needed for revascularization for enchondral bone grafts (Kusiak et al. 1985).

Resorption rates of up to 55 % during the first 6 months have been reported (Johansson et al. 1998) with enchondral AB, while Reinert et al. (2003) reported a vertical bone resorption of 7 % during the first year after grafting and a minimal bone loss after 12 months.

However, no data revealed that resorption of the graft material has an influence on implant survival (Hallman and Nordin 2004; Kim et al. 2009) and should not prompt the clinician to prefer or abandon AB. Dental implants inserted in sinuses augmented with AB have demonstrated high survival rates as documented in several reviews (Chiapasco et al. 2009; Del Fabbro et al. 2004; Esposito et al. 2006; Jensen and Terheyden 2009; Nkenke and Stelzle 2009; Pjetursson et al. 2008; Tong et al. 1998; Wallace and Froum 2003). Moreover, implant survival rate in AB is not superior to BS materials (Nkenke and Stelzle 2009; Szabó et al. 2005).

Several authors have reported that addition of AB to BS such as porous hydroxyapatite, alloplasts, or xenografts increased the amount of vital bone in biopsy cores retrieved from augmented sinus cavities (Froum et al. 1998; Hürzeler et al. 1997; Quiñones et al. 1997).

In 1996, probably, the most important conclusion reached in the consensus conference (Jensen et al. 1998) on the SFE procedure was that AB is the gold standard. Nevertheless, the morbidity involved in its use (requires two surgical areas) leads many patients to decline this treatment.

7.5 Bone Substitutes

Although SFE can be performed under local anesthesia, harvesting AB from the chin, retromolar region, iliac crest, or calvarium complicates the treatment and sometimes requires general anesthesia and hospitalization. It is, therefore, an additional barrier for patient selection. To overcome extensive bone grafting correlated to donor site morbidity, several BS have been used.

Initially, BS materials were developed to serve as temporary scaffolds or templates to facilitate osteogenesis. It is generally accepted that an optimal BS should be fully biocompatible, actively stimulate new bone formation, able to serve as an anchoring surface for host cells, and have a structure that allows osteoconduction. At the same time it should be mechanically stable and progressively resorbed during the initial healing and subsequently resorbed completely, replaced by the new bone (Jensen 2006). No such ideal BS exists today. However, numerous BS have been described and evaluated throughout the years with varying success rates in SFE.

7.5.1 Allografts

The limitations associated with the harvesting of AB for grafting can be overcome by the use of allografts. Allograft is defined as a tissue that has been harvested from one individual and implanted into another individual of the same species.

Allograft bone could be obtained from living donors and from cadavers with variable osteoinductive and osteoconductive properties. Allografts are available in both demineralized and mineralized forms; both of them are considered safe regarding bacterial and viral diseases.

Advantages of allografts include ready availability in large quantities, elimination of need of a donor site, reduced anesthesia and surgical time, decreased blood loss, and fewer complications.

Allogenic bone grafts are nowadays the most commonly used BS to restore adequate bone volume in oral surgery.

The bone is a composite material made up of collagen, other organic molecules, and a calcium hydroxyapatite. Bone matrix could be preserved and the main treatment concerns the bacterial and viral decontamination. (Irradiated cancellous bone is the most commonly used.)

Depending on the different processes applied to the human bone, the final composition of mineral and organic parts will be changed; consequently, there are three forms of allografts (Pappalardo and Guarnieri 2013):

1. Unprocessed bone matrix: Sterilized through a variety of techniques such as irradiated cancellous bone, freeze-dried bone allograft (FDBA), and fresh frozen bone
2. Demineralized bone matrix (DBM) preserving the organic matrix such: Demineralized freeze-dried bone allograft (DFDBA)
3. Mineral bone allograft: Delipidizated or defatted (partially deproteinized bone), preserves the mineral matrix and most of the times a part of the organic matrix, mainly collagen type I; PS: Puros, TBF, Biobank, etc.

Unprocessed and frozen material can be ordered from several bone banks and consists of all growth factors and a normal ultrastructure. Processed allografts are defatted and the bone marrow is removed. Frozen allografts are mechanically stable, whereas freeze-dried bone is mechanically less resistant, but can be stored at room temperature.

Both FDBA and DFDBA are obtained from cortical of long bones that contain bone-inductive proteins. Bone allografts come in various configurations, including powder, cortical chips, cancellous cubes, and cortical granules among others. Although allografts are available in different block forms, their mechanical properties remain slightly lower than those of AB cortical blocks (Haas et al. 1998a). DFDBA forms may have even less risk of disease transmission than FDBA, because

demineralization allows most affective removal of viruses and blood elements reducing immunological reactions (Haas et al. 2002).

Unconventional disease agents, including bovine spongiform encephalopathy (Creutzfeldt-Jakob Disease) requires specific processes and mainly concern proteinized bone characterized by unusual biological and physical-chemical properties, especially due to their high tenacity (Kaaden 1994).

Processed bone allografts do not include any living cells, and therefore, they lack osteogenic activity. Rather, they provide an osteoconductive scaffold and loose their risk of immunogenicity or disease transmission.

Allografts disadvantages are primarily associated with use of tissues from another person. The use of cadaver bone for grafting is avoided by many clinicians due to its potential risk of infectious disease (Hürzeler et al. 1997).

Nevertheless, allografts have been used for more than 30 years without any reported incidence of disease transmission. The risk of HIV infection through allograft implantation has been estimated to be 1 in 1.6 million, compared with the risk of 1 in 450,000 in blood transfusions. Still, there is some controversy regarding association of allograft bone with the transmission of infectious agents, a major concern which is virtually eliminated through tissue processing and sterilization including freezing, demineralization, and lyophilization.

Allografts are essentially osteoconductive, and depending how they are processed, they may have some osteoinductive properties (Haas et al. 1998b). As with AB, allografts are replaced over time by creeping substitution (Figs. 7.1 and 7.2).

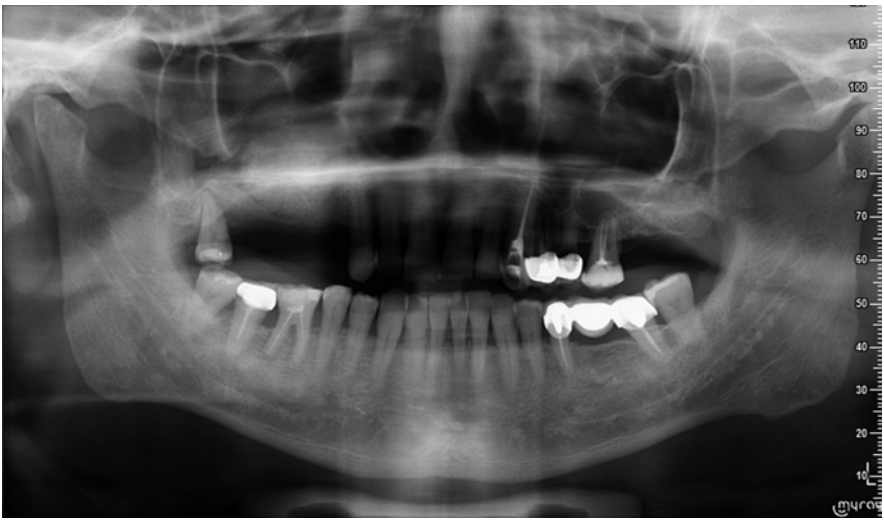


Fig. 7.1 Panoramic radiograph showing the allograft remodeling at 3 months. Note its low density similar to the native residual bone

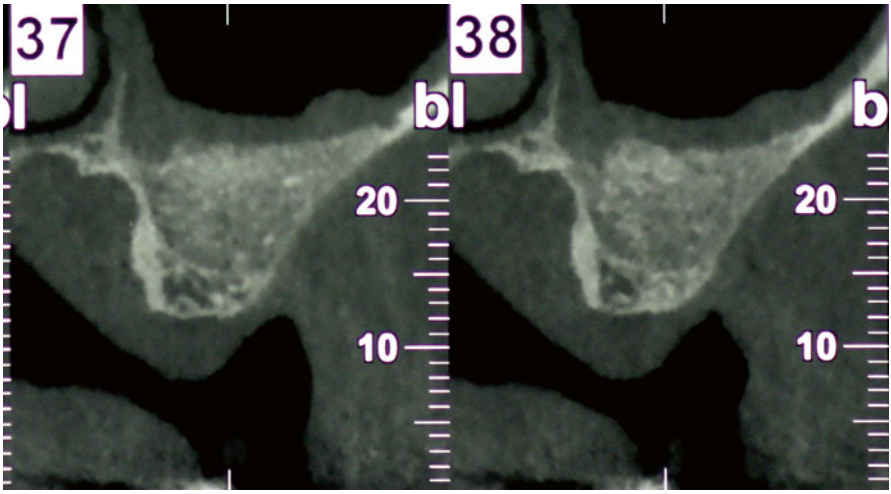


Fig. 7.2 CBCT at 5 months showing heterogeneous density of a composite particulate graft (a mixture of Mineralized Bone Allograft (Puros®, Zimmer Dental, Carlsbad, CA, USA) with mineral bovine bone (Bio-Oss®, Geistlich-Parma AG, Switzerland))

7.5.1.1 Unprocessed Allografts: Freeze-Dried Bone Allograft (FDBA)

FDBA undergoes the steps of freezing, drying, and desiccation, and it always contains its mineralized matrix, which necessitates an osteoclastic activity to liberate bone GF by the mean of "creeping substitution."

Mineralized bone matrix has no active BMPs and therefore it lacks osteoinductive properties, although it has osteoconductive properties. In an in vitro experiment, Herold et al. (2002) claimed that the FDBA expressed less osteoblastic activity when compared to DFDBA, due to the demineralization process that released the BMPs.

On the contrary, Piatelli et al. (1996a) demonstrated that the FDBA had greater osteoinductivity than DFDBA when compared together histologically and histochemically in humans.

FDBA hardens faster than DFDBA due to its mineralization. Clinically, the residual presence of mineralized bone particles may give the impression of a more dense graft, and the longer turnover time may be of clinical benefit in larger defects in terms of gaining increased volume (Kolerman et al. 2012).

The resorption time of FDBA is extended when compared to demineralized bone, due to presence of a mineralized matrix. However, the potential advantages of the increased turnover time of the FDBA may be a disadvantage in terms of bioavailability and activity of BMPs. In theory, the mineralized component must be resorbed in order to expose the BMPs and make them biologically active. If osteoinduction is desired, one rational approach may be to combine the mineralized allograft with DFDBA or AB. With such a combination, one may take advantage of the presumed osteoinductivity and more rapid turnover time of the demineralized or AB combined with the prolonged turnover time and higher density achieved with the mineralized allograft tissue (Jensen 2006).

In a maxillary bone defect (rhesus monkey) Yukna et al. (2002) reported that the FDBA produced more novo-bone formation at a faster rate and larger quantities when compared with the DFDBA.

FDBA have been also used successfully in SFE.

It has been stated that DFDBA is less effective than FDBA in SFE (Valentini and Abensur 1997; Jensen et al. 1998) while FDBA results in more new bone growth (Cammack et al. 2005).

Clinical experience has shown that performing SFE with DFDBA resulted in the presence of a cartilaginous material after 6 months, whereas grafting with FDBA resulted in the presence of a hard, bone-like substance, which is essential when implant defects are treated, which demonstrates that the use of FDBA is more effective than DFDBA (Haas et al. 2002).

Only a limited number of human histomorphometric studies (Cammack et al. 2005) investigated the use of FDBA in SFE.

A clinical histological and histomorphometrical study (Kolerman et al. 2008) evaluated the regenerative potential of FDBA in SFE. New bone growth (29.1 %) was lower compared to the values recorded by Cammack et al. (2005) who used FDBA (41 %) or DFDBA (36 %) as BS.

This study is in agreement with Froum et al. (2006) who reported 28.3 % vital bone using a mineralized cancellous bone allograft for SFE supporting the claim that FDBA are osteoconductive BS.

Despite their clinical proven success, the use of non-processed bone allograft (FDBA) is limited by the potential risk of disease transmission (Barriga et al. 2004) and its healing that can be inconsistent (Togawa et al. 2004).

7.5.1.2 Demineralized Bone Matrix (DBM; e.g., DFDBA)

DBM biologic activity is presumably attributable to the demineralization process leading to an exposure of GF (mainly BMPs) of the allograft thought to enhance the osteogenic potential of the graft material (Urist and Strates 1971).

Allogenic DBM derived from human tissues is thought to have osteoconductive and osteoinductive potential but has no osteogenic capacity because of its processing (Boyan et al. 2006). Despite *DBM* has demonstrated the ability to induce an osteoinductive response (for improved bone growth and fusion), the amount of BMPs (less than normal human bone) in any single allograft has shown dramatic variability (Minichetti et al. 2004; Schwartz et al. 1998), and contradictory opinions about its biological properties are still present in literature (Becker et al. 1995; Frost et al. 1982; Kübler et al. 1993; Wetzel et al. 1995; Whittaker et al. 1989). Many variables such as donor variability, particle size and shape, varying demineralizing time, percent composition of DBM powder, processing, and sterilization techniques have been considered as the consequences of the differences in the fusion rates of different commercial products (Alanay et al. 2008).

One of the major differences in processing the DBM materials is the sterilization of the allograft material to prevent the potential for disease transmission from the donor to the recipient and the graft contamination. Tissue banks take preventive measures to minimize the risk of disease transmission and contamination. The allograft tissues are treated in two steps to prevent the disease transmission

and graft contamination. The first step is typically aseptic processing through chemical and physical tissues cleaning to help reduce the bioburden and the cellular antigens in the grafts. The next step is the terminal sterilization to effectively clean the allograft usually done by using irradiation or the ethylene oxide technique (Jensen 2006).

DBM does not induce any significant local immunogenic reaction, as the antigenic surface structure of the bone is destroyed during demineralization (Tuli and Singh 1978). The biological activity of DBM is most probably attributable to proteins and various GF present in the extracellular matrix and made available to the host environment by the demineralization process. Prepared by acid extraction of allografts, it retains collagen and other proteins as well as (BMPs).

The amount of BMPs in DBM is highly variable, unlike the constant low levels of GF; between and even within batches of commercially available DBM products, there are big differences (intervariability and intravariability) in BMPs (Bae et al. 2006; Wildemann et al. 2007). DBM can also be mixed with AB in the presence of large defects. A Commonly Used DBM Is Demineralized Freeze-Dried Bone (DFDBA). FDBA and DFDBA are both harvested from cadaverous sources in the same manner, with the difference being that the DFDBA material undergoes the additional step of decalcification (Mellonig et al. 1981).

The process of freeze drying reduces the antigenicity of the material (Quattlebaum et al. 1988), and the decalcification stresses the osteogenic potential by exposing BMPs, inducing host cells to differentiate into osteoblasts (Mellonig et al. 1981). DFDBA forms are processed by acid, and 40 % of the mineral content is removed leaving the organic matrix intact. This process preserves the BMPs present in the bone and therefore enhances osteoinductivity (Jensen 2006) by exposing collagen and GF such BMPs. Moreover, the collagen matrix present in DFDBA acts as a scaffold that provides osteoconductive properties alongside the osteoinductive behavior. DFDBA particles are available in a variety of sizes, and similar results have been shown with the use of particles ranging from 200 to 1,000 μm (Abubaker 1999).

Histologically, new bone formation is observed on the surface of DFDBA particles as they are simultaneously resorbed. Six to twelve months are required at least for resorption and replacement by the vital bone. Some non-vital bone particles may be observed in sites grafted with DFDBA many years after implantation (Hürzeler et al. 1997).

A long-term clinical, histologic, radiographic, and histomorphometric study (Froum et al. 1998) of the use of BS in SFE considered several factors: graft material, time allowed for graft maturation, and effect of barrier membrane placement. They found that vital bone formation in grafting procedures is time dependent. Moreover, the addition of DFDBA to the xenograft material produced a moderate increase in bone production over xenograft alone (Froum et al. 1998).

In SFE, the augmented bone height was significantly higher when DFDBA was used in comparison with the empty control group, where only a blood clot was available (Kao et al. 2012). Thick, newly formed trabecular bone was observed adjacent to the cortical bone wall of the sinus cavity. In the center of the augmented

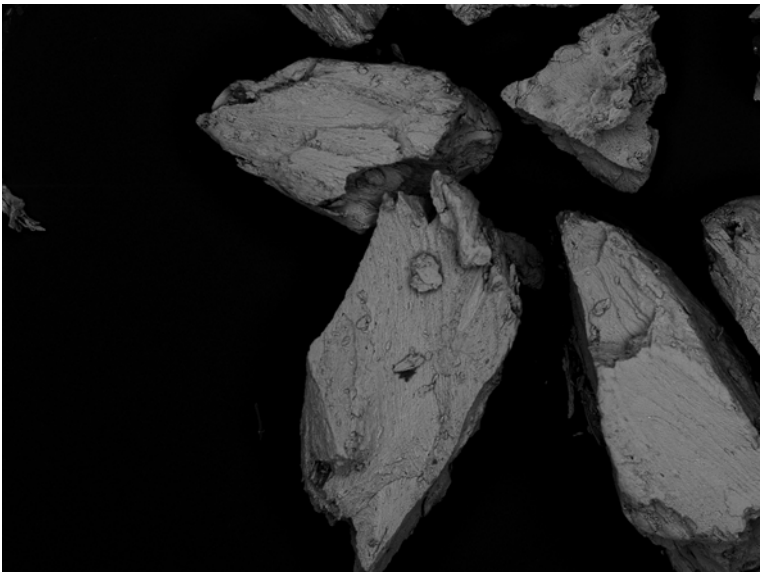


Fig. 7.3 Scanning electron microscopy (magnification ×80) of an allograft (encore®, Osteogenics, Lubbock, TX) composed of a mixture of FDBA-DFDBA (70–30)

space, the particles were surrounded by fibrous connective tissue. Furthermore, the bone area was significantly higher in the small-particle DFDBA group (29 %) than in the large-particle DFDBA group (20 %) (Xu et al. 2003). In the small-particle group, newly formed bone showed many interconnections and appeared in most areas of the sinus at 8 week, while in the large-particle group, the center of the sinus cavity contained fibrous connective tissue with no evidence of ossification. Moreover, the demineralization of FDBA (DFDBA) did not yield a greater percentage of new bone formed in maxillary sinus and mandibular ridge augmentations compared to mineralized FDBA.

Overall, contradictory opinions were discussed about the real osteoinductive property of DBM (e.g., DFDBA), stating that DBM is just providing an optimal osteoconductive scaffold. DBM has also potential disadvantages such transmission of diseases that has not yet been reported but is theoretically possible (Zimmermann and Moghaddam 2011). *In 1996, the Sinus Conference stated that DFDBA is not an appropriate BS because of the risk for disease transmission and pronounced resorption* (Jensen et al. 1998) (Fig. 7.3).

7.5.1.3 Mineralized Bone Allograft (MBA) Cancellous or Cortical Particles (Defatted Allograft) (e.g., Puros, TBF, Biobank, etc.)

MBA is a human mineralized bone (e.g., Puros®, Biobank®, TBF®) used as an alternative allograft.

Different processing techniques for cleaning and sterilizing allografts influence the bone properties, depending on each company.

The mineralized bone allograft material is associated to type I collagen almost equal to the pristine bone. The matrix structure allows the ingrowth of vascular, cellular, and connective tissue as a critical part of de novo bone formation and remodeling. Because particle surfaces are first to interact with the host tissue, it is important to understand how various processing techniques can affect and perhaps alter the natural structure of the surface as well as the chemical composition of MBA resulting in a deleterious effect on initial healing events.

Data have demonstrated that, after processing the unwanted microbes are destroyed, but the porous bone structure is maintained, including the mineral and collagen components, in contrast to other forms of bone treatment, providing excellent bone matrix and load-bearing capabilities. The natural extracellular collagen matrix proteins are known to be important for cell attachment and bone remodeling.

In addition, animal data have confirmed that the biotolerability of the solvent-dehydrated grafts is comparable with that of cryopreserved bone grafting materials (Minichetti et al. 2004).

Although its mechanism in bone formation is still unclear, a closed-wound rabbit model experiment demonstrated that the solvent-preserved bone did not elicit a foreign body reaction and that it was the most effective graft material in inducing bone formation among the various graft materials used (Scharf 1990).

Gamma irradiation is the most commonly used form of ensuring a terminally sterilized BS. Limited-dose gamma irradiation is a key step in MBA process, since it is generally accepted that high-dose gamma sterilization (over 25 kGy) can cause damage to the collagen structure of the bone and cause denaturation of the proteins, including bone morphogenetic proteins (BMP) (Alanay et al. 2008).

In addition, this method of processing has been shown to inactivate the HIV virus and the agent responsible for Creutzfeldt-Jakob disease (Masullo C.); Taking into consideration the Estimation of the theoretical risk of transmission of Creutzfeldt-Jakob disease by human dura mater grafts manufactured by the Tutoplast® process.

Mineralized cortical bone allograft (MCBA) has biocompatible and osteoconductive potential as demonstrated in a SFE study, (Kolerman et al. 2012), permitting new bone formation (Figs. 7.4 and 7.5).

Schmitt et al. (2013) used MCBA in SFE and demonstrated comparable results to those of Froum et al. (2006) who reported averages of 28.25 and 7.65 % for vital and non-vital bone, respectively.

Other comparisons were similar (Noumbissi et al. 2005; Wood and Moore 1988). Grafting with AB or MCBA demonstrated similar outcomes; the use of MCBA tends to result in a slightly lower level of new bone formation compared to AB, but this tendency was not significant in a meta-analysis (Klijn et al. 2010a, b). MCBA can therefore be regarded as a BS that is totally resorbed and replaced by AB, integrating well into the organism (Noumbissi et al. 2005). Moreover, there is no evidence that the AB transplant is preferable regarding implant survival (Nkenke and Stelzle 2009).

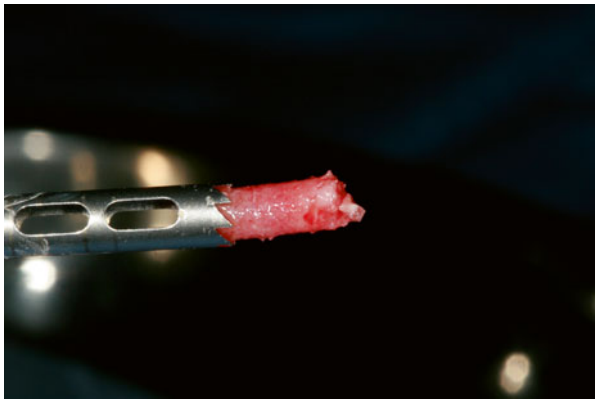


Fig. 7.4 Trephine retrieving a bone core at the implant site for histomorphometrical analysis of the bone augmentation (allograft) 5 months later: note the favorable vascularized aspect of the newly formed bone

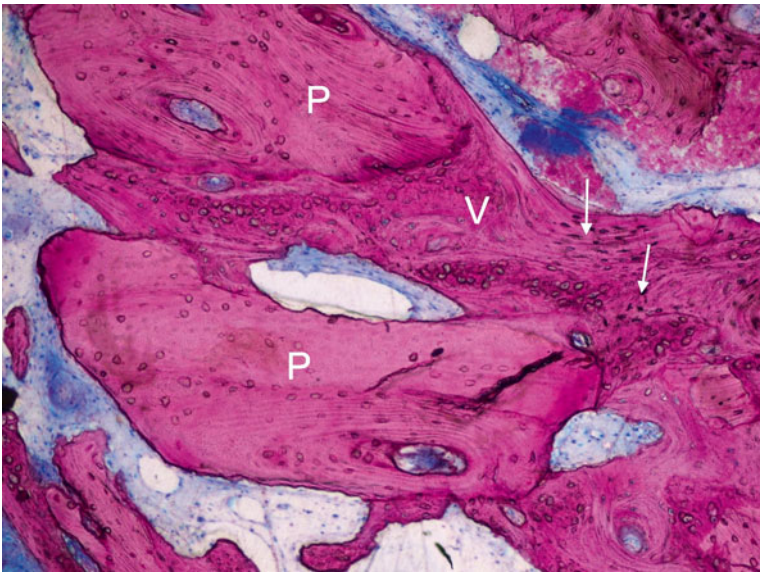


Fig. 7.5 Non-decalcified histological section showing the close contact of the newly formed bone (V) with the MCBA allograft particles (P- Puros®, Zimmer Dental, Carlsbad, CA USA). Giemsa-Paragon stain. The *arrows* indicate the osteocytes. *P* puros particles, *V* vital novo-bone

In conclusion, Allografts revealed the most promising results among BS in SFE.

The main advantage remains in their remodeling properties that are very similar to AB. Nevertheless, in addition to the fact that many clinicians due to their potential risk of infectious disease avoid allografts, a main concern remains regarding the maintenance of the physical dimension of the augmented bone and the long-term peri-implant bone stability.

On the other hand, any bone allograft can be enriched with growth factors (GF or cultured stromal stem cells in order to stimulate vascular invasion of the graft and

new bone formation (Delloye and Bannister 2004; Delloye et al. 2004; Lucarelli et al. 2005; Schecroun and Delloye 2004).

Supplementation with these expensive biological materials appears to promote the incorporation of the bone into the host in experimental conditions, but adverse results have also been observed (Delloye and Bannister 2004). More experience with these techniques is required before they can be recommended.

7.5.2 Xenografts (e.g., Anorganic Bovine Bone)

The xenogenic grafts are taken from a donor of another species. Commonly used are anorganic bovine bone (ABB, e.g., Bio-Oss® (Geistlich Biomaterials GmbH)) and porous hydroxyapatite (pHA), derived from coral skeletons. The mineral structure and surface of ABB resembles AB. One gram of ABB has a surface of 80 m (Weibrich et al. 2000) and can therefore act as a suitable osteoconductive material (Browaeys et al. 2007). ABB contains macroscopic and microscopic structures with an interconnecting pore system that serves as a physical scaffold for the immigration of osteogenic cells (Tapety et al. 2004) (Figs. 7.6, 7.7, and 7.8). ABB osteoconductive properties, confirmed by numerous studies (Del Fabbro et al. 2008; Schlegel and Donath 1998; Schlegel 1996), derive from its chemical composition as well as macro and micromorphology. Histological studies (Froum et al. 1998; Wallace et al. 2005) revealed the presence of osteoblasts and osteoid tissue as well as apposition directly on the surface of the xenografts particles. Vital bone has been observed to bridge the gaps between xenograft particles and has been shown histologically to increase over time (Wallace et al. 1996).

Nevertheless, the use of nonresorbable BS results in a composite of newly formed bone and BS, not in a homogenous bone structure (Merkx et al. 2003; Petrungaro and Amar 2005).

Fig. 7.6 Trephine retrieving xenograft bone core at the implant site for histomorphometrical analysis

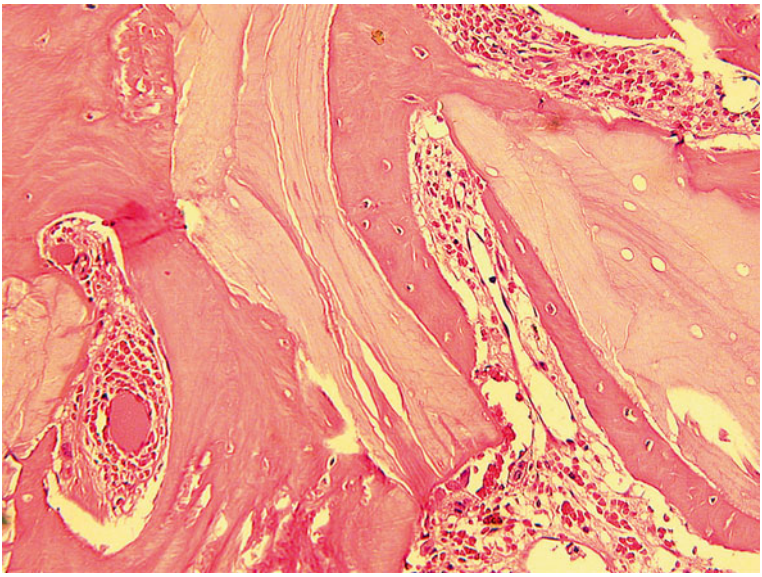


Fig. 7.7 Histologic section with hematoxylin eosin stain showing the xenograft particles (Bio-Oss®) surrounded by de novo bone

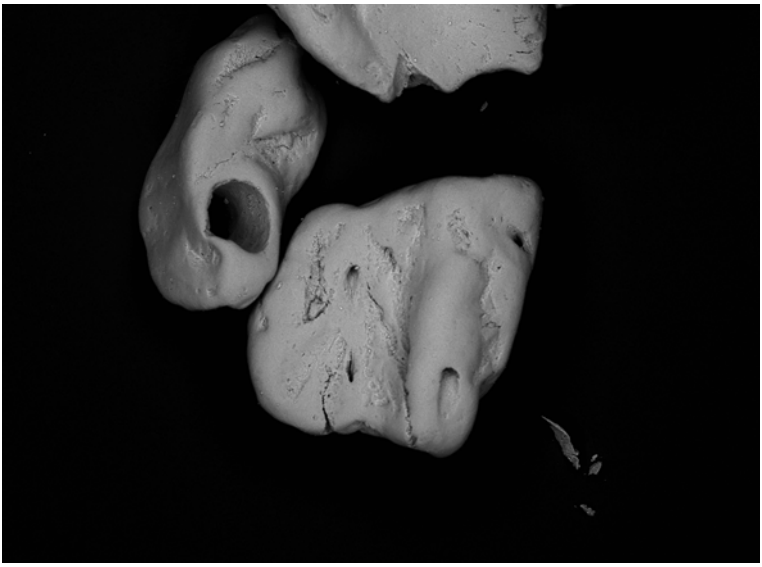


Fig. 7.8 Scanning electron microscopy (magnification ×80) of a mineral bovine bone (OCS-B®) composed of crystalline hydroxyapatite

Although this material appears to lack osteoinductive properties, it still undergoes physiologic remodeling and becomes incorporated into the bone over time (Hislop et al. 1993). Mixed clinical results with this bovine bone product have prompted some clinicians to recommend its use only as a composite graft with autogenous or allogenic bone (Gross 1997).

On the other hand, ABB appears to undergo slow or no resorption (Meijndert et al. 2005). Histologic studies based on clinical biopsies confirmed the presence of remaining ABB particles after 4.5 years (Ewers et al. 2004), 6 years (Schlegel and Donath 1998), and even 14-year post-grafting (Lezzi et al. 2007). The incomplete resorption of the ABB particles after a long period might be due to the high calcium concentration present on the biomaterial surface that could inhibit the osteoclastic resorption (Yamada et al. 1997).

Conflicting data are present in the literature about the performance of ABB over the long term, and human histologic reports are quite rare in the literature (Hämmerle et al. 1998). Resorption or a decrease in the density of the grafted area has been reported to occur over time (Sartori et al. 2003; Wallace et al. 1996), whereas other researchers found a lack of breakdown of the material (Artzi et al. 2005; Ewers et al. 2004; Merkx et al. 2003; Piattelli et al. 1999; Schlegel and Donath 1998; Skoglund et al. 1997; Valentini and Abensur 1997).

A highly purified bovine xenograft characterized by preservation of the type I collagen matrix associated with spindle-shaped hydroxyapatite crystals (Laddec® T650 Lubboc®, BioHorizons, Birmingham, USA) (Chappard et al. 1993; Poumarat and Squire 1993) has been also successfully used in SFE but showed the highest residual bone resorption 6 months when compared to AB (Papa et al. 2005).

Another study (Butz et al. 2011) demonstrated that a xenograft in the form of a putty material (PepGen P15® Putty can be used successfully for maxillary sinus augmentation.). It comprises a cell attachment peptide (P-15) that is irreversibly bound to anorganic bone matrix particles (Osteograf/N300); sodium hyaluronate (the putty) serves as a carrier material.

Referring to the authors, implant placement may be possible even after only 2 months of healing, based on histomorphometric results indicating no statistically significant difference in the newly formed bone fraction in the biopsy specimens analyzed at 2 months (21.3 % ± 2.33), at 4 months (21.9 % ± 8.9), at 6 months 28.5 % (± 6.9), and at 9 months (29.8 % ± 11.8).

Wheeler et al. (1996) found an increase in novo-bone volume from 16.38 % after 4–10 months of healing to 45.30 % after 36 months in sinus augmented with porous hydroxyapatite alone. In a clinical case report, Wallace et al. (1996) documented the sequential healing process of a sinus (4, 8, 12, and 20 months) grafted with a composite 80 % ABB (OsteoGraf) and 20 % AB. They observed slow bone formation in the sinus cavity augmented: 12–20-month period was required to convert this composite graft into a vital bone. Similar conclusions were reported by Lundgren et al. (1996) with SFE with particulated mandible and by Froum et al. (1998) with ABB.

Histological and histomorphometric studies demonstrated a better bone-to-graft contact for the ABB group compared to other BS (BCP). ABB appears to have a high osteoconductivity (Cordaro et al. 2008).

Moreover, the use of Xenografts in the sinus has been well documented in the literature. (Artzi et al. 2002; Del Fabbro et al. 2004; Hallman et al. 2002; Valentini and Abensur 2003; Wallace and Froum 2003), and numerous practitioners consider this material, alone or in combination with AB, as the BS of choice in SFE procedures. In fact, 8 published evidence-based systematic reviews concluded that the results with xenografts are the most favorable and complete (Aghaloo and Moy 2007; Del Fabbro et al. 2008; 2004; Esposito et al. 2010; Jensen and Terheyden 2009; Nkenke and Stelzle 2009; Pjetursson et al. 2008; Wallace and Froum 2003).

On the other hand, implant survival rates with ABB have been reported to be as high as or higher than those achieved with AB (Del Fabbro et al. 2008; Wallace and Froum 2003). An evidence-based review (Wallace and Froum 2003) of SFE using xenograft alone or in combination with AB or mixed with PRP showed that the survival rate of the implant placed in xenograft was statistically the same as for implant placed in particulate AB grafts. Del Fabbro et al. (2004) reported an average SR of 87.7 % of implants placed in AB, significantly lower than the 84.9 % SR of implants placed in a mixture of AB and Xenograft, and 96 % SR of implants placed in Xenograft alone. Other studies (Hallman et al. 2002; Valentini and Abensur 2003) confirmed the previous results with higher survival rates (100 %) for implants placed in sinuses using pure xenograft compared to AB or AB + xenograft.

While a main concern about AB bone resorption when used in SFE was reported at 3 years, the use of xenograft seems on the contrary to reduce the volumetric resorption as demonstrated in the Sinus Consensus Conference in 1996 (Jensen et al. 1998). Moreover, there is no evidence that this residual BS adversely affects osseointegration and, ultimately, ISR; its continual presence does not lessen the adaptive capability of the newly formed bone. The stability of the regenerated area seems to be a very important factor for the patient (Schilling et al. 2004). This is in contrast to AB, which, after 8 months of healing, have shown resorption of >50 % of the original volume (Hallman et al. 2001). It is also possible that the mechanical properties of the bone formed around the xenograft particles will improve over time in relation to bone remodeling and to the replacement of woven bone by lamellar bone (Hallman et al. 2001; Valentini et al. 1998). (Figs. 7.9, 7.10, and 7.11)

To summarize, xenografts (ABB) has been demonstrated to be resorbed very slowly (Iezzi et al. 2007; Meijndert et al. 2005; Piattelli et al. 1999); no clear evidence indicates whether this situation is an advantage or a disadvantage. As a possible advantage, this structure could represent a type of protection against bone resorption, guaranteeing the maintenance of the physical dimension and long-term stability of peri-implant bone within the augmented maxillary sinus.

However, a more recent study (Schmitt et al. 2014) evaluated the 5-year ISR after SFE with ABB and ABB plus AB with a ratio of 1/1 and found leads to a comparable amount of newly formed bone for both following SFE.

Considering that ABB is a nonresorbable BS, it can be hypothesized that this leads to stable bone over time and long-term implant success. Importantly, in the sole use of ABB, AB grafting and therefore donor site morbidities can be avoided.

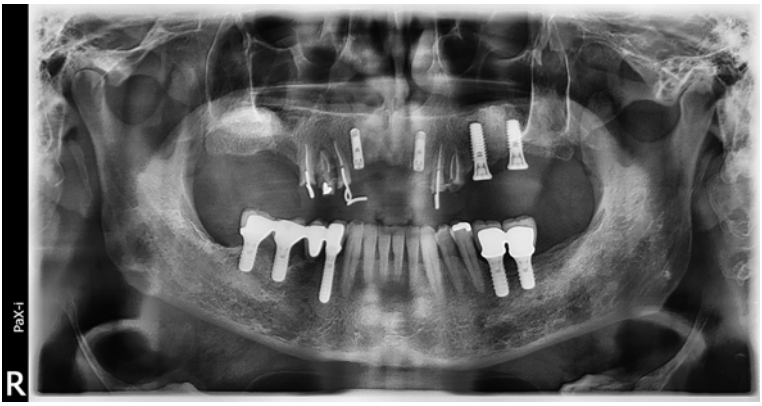


Fig. 7.9 Panoramic radiograph showing at 6 months sinus radiopacity after a bilateral SFE using a mineral bovine xenograft (Bio-Oss®, Geistlich-Parma AG, Switzerland)

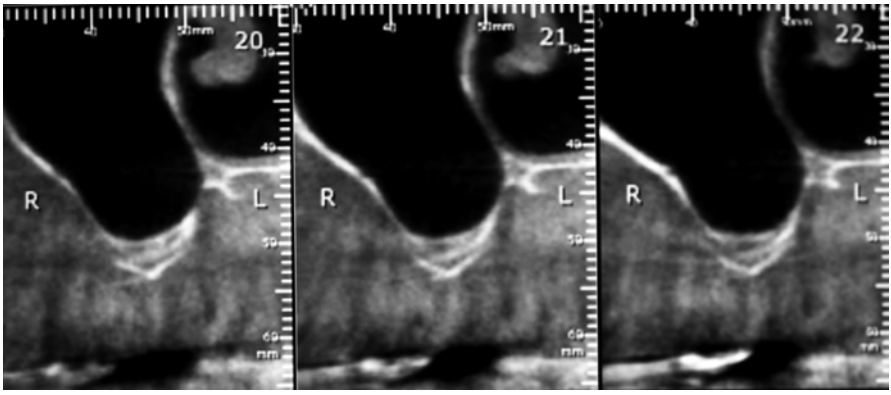


Fig. 7.10 Preoperative CBCT radiograph showing the sub-sinus residual bone volume prior to SFE

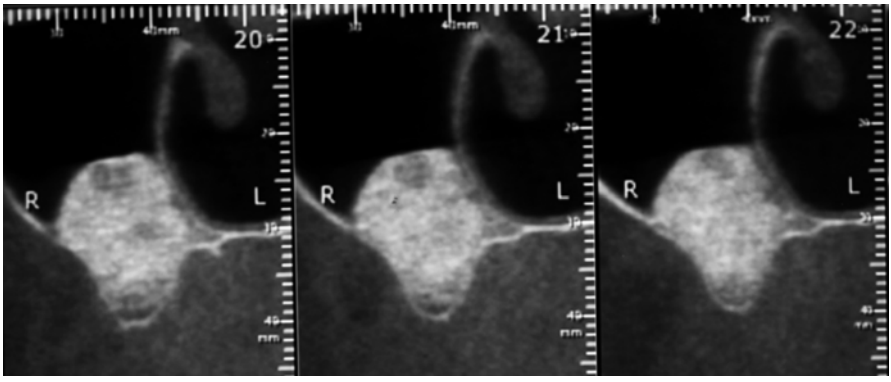


Fig. 7.11 Postoperative CBCT radiograph at 6 months showing the high density of the mineralized bovine bone (Bio-Oss, Geistlich Pharma AG, Switzerland)

7.5.3 Alloplastics (Synthetics)

Allografts and xenografts used as alternatives to AB have a potential for disease transmission (Cordioli et al. 2001). The fear of bovine spongiform encephalopathy (mad cow disease) transferring to humans (Creutzfeldt–Jakob disease) (although no report has been made in the literature) (Sogal and Tofe 1999) and the discovery of human immunodeficiency viruses surviving in allogenic bone after tissue processing have underscored concerns about disease transmission from xenografts and allografts (Marthy and Richter 1998). To what degree such BS can be considered free of prions and what are the risks of transmission of the disease to humans? Therefore, the need for safer BS has led to the development of alloplastic grafting materials.

Alloplastic materials are synthetic BS made of biocompatible, inorganic, or organic materials. They include any synthetic material not derived from a human or animal source. The main advantage of alloplasts is that they have no potential for disease transmission. They are only osteoconductive. Alloplastic materials are available in a variety of textures, sizes, and shapes. Based on their porosity, they can be classified as dense, macroporous, or microporous, and they can be either crystalline or amorphous, granular, or molded (Jensen 2006). This varying nature determines their biological features and their resorption times (Kao and Scott 2007).

However, in spite of these good properties, synthetic materials have limitations due to their poor mechanical properties and uncontrolled biodegradation in vivo (Julien et al. 2007). Therefore, surgeons have attempted to augment the activity and physical properties with composite grafts combining molecular, cellular, and genetic tissue engineering technologies (Boyne et al. 1998; Howell et al. 1997a; Margolin et al. 1998).

There are several types of alloplastic substances in clinical use nowadays: calcium phosphate-based (CaPs), other ceramics (e.g., Hydroxyapatite – HA), biphasic calcium phosphate (BCP), tricalcium phosphate (TCP), calcium sulfate, and biocompatible composite polymers.

7.5.3.1 Calcium Phosphate-Based Ceramics

The calcium phosphate family of synthetic bone grafts has both osteointegrative and osteoconductive properties. They have an excellent record of biocompatability with no reports of systemic toxicity or foreign body reactions (Hollinger and Battistone 1986).

Among different ceramic-based graft materials, hydroxyapatite (HA) and β-tricalcium phosphate (β –TCP) are the most commonly used. They are made from inorganic, nonmetallic materials with a crystalline structure, usually processed at a high temperature.

The osteoconductive CaP biomaterials allow attachment, proliferation, migration, and phenotypic expression of bone cells leading to formation of new bone in direct apposition to the CaP biomaterial. Their resorption is determined by different factors such as host and material, osteoclasts, and foreign body giant cells and should preferably go slowly. The commercial forms are granular, cement, paste, and pre-shaped wedges and shapes (Zimmermann and Moghaddam 2011).

However, CaP ceramics' main disadvantage is their volumetric instability, which is important to facilitate bone ingrowth. Dissimilar results were found concerning the degradation of these BS (Berger et al. 1995; Daculsi 1998) as well as their biomechanical properties (Kessler et al. 2002).

In vitro dissolution of Ca–P materials depends on composition and the geometrical structural features such as particle size, porosity, surface area, shape, and crystallinity that characterize the various scaffolds.

These scaffolds should have an internal structure permissive for osseous invasion (Eggli et al. 1988; Hing et al. 2004), and their chemical composition is crucial for the osteoconductive properties of the material (Mastrogiacomo et al. 2005).

The structure of a bioceramic must possess nanopores, micropores, and macropores as these intervene in the different phases of protein adsorption, cell adhesion, and depositing of new bone over and within the BS (Fan et al. 2007; Gauthier et al. 1999).

Porosity is an important factor that influences the speed of degradability. The higher is the materials porosity, the faster is the degradability. The pore size should be ideally similar to that of spongious bone (Daculsi et al. 1988, 1990).

Calcium Hydroxyapatite (HA)

HA is a highly crystalline form of calcium phosphate, produced through a high-temperature reaction between 700 and 1,300 °C to form a highly crystalline structure. Its chemical composition is $Ca_{10}(PO_4)_6(OH)_2$. The most unique property of this material is its chemical similarity to the mineralized phase of the bone; this similarity accounts for its osteoconductive potential and excellent biocompatibility (Erbe et al. 2001; Ghosh et al. 2008).

HA has been established to be an excellent carrier of osteoinductive GF and osteogenic cell populations, which greatly adds to their future utility as bioactive delivery vehicles (Noshi et al. 2000).

Histologically, the HA-grafted sinuses exhibited a significant amount of new bone formation. The HA granules appeared integrated with the newly formed bone. Histomorphometric analysis revealed that delayed implant placement resulted in a greater amount of direct mineralized bone-to-implant contact in the augmented area than the simultaneous implant placement. The percentage of direct mineralized bone-to-implant contact was, however, more significant in the residual bone than in the augmented area (Browaeys et al. 2007).

No significant difference between HA and AB in terms of BIC was found (Haas et al. 2002), but both materials showed a significantly greater BIC than the control group, in which a sinus lift was executed without the use of autogenous bone or any biomaterial.

In a sinus study (Cosso et al. 2013), the mixture of HA and AB showed lower degree of resorption and higher dimensional stability when compared with autogenous bone graft alone.

Tricalcium Phosphate (TCP)

TCPs are porous, resorbable, biocompatible materials which have been used for two decades as synthetic bone space fillers in orthopedic and dental applications

(Hak 2007) They provoke little if any inflammatory response, permit the ingrowth of cells and vessels (Wang et al. 1998), and have a direct connection with bony structure.

The chemical composition and crystallinity of the material are similar to those of the mineral phase of the bone.

The nominal composition of TCP is $Ca_3(PO_4)_2$. It exists in either α- or ß-crystalline forms (Hak 2007). TCP is more quickly resorbable and less mechanically stable compared to HA. But, like HA, TCP is bioabsorbable and biocompatible.

TCP demonstrated good bone bonding behavior in the sinus. This was associated with the expression of alkaline phosphatase, collagen type I, osteocalcin, and bone sialoprotein in the newly formed bone and osteogenic mesenchyme in contact with the degrading particles. At 6 months, bone formation and matrix mineralization were still actively progressing in the tissue surrounding the β-TCP particles (Knabe et al. 2008) (Fig. 7.12).

The small-particle size and interconnected sponge-like microporosity are believed to improve osteoconductive properties and promote timely resorption concomitant with the process of remodeling (Ghosh et al. 2008; Hing et al. 2007).

Typically, it has been used in its granular porous form. Porous granules tend to migrate less than solid granules due to earlier fixation by fibrovascular ingrowth (Byrd et al. 1993). β-TCP undergoes reabsorption via dissolution and fragmentation over a 6–18 month period.

Knabe et al. (2008) compared two TCPs with different porosity grafted in the sinus. They observed a larger amount of bone formation and particle degradation in the apical area with TCP of higher porosity group and thus at the largest distance from the crestal bone compared to the group with lower porosity. Consequently,

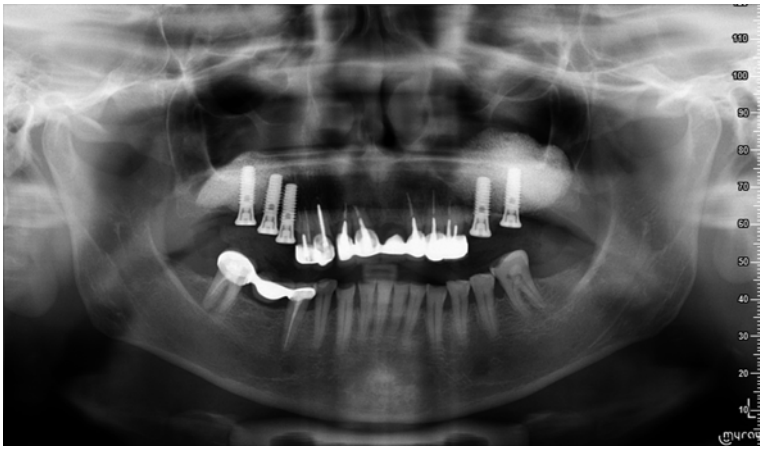


Fig. 7.12 Radiograph showing the high radiopacity of the alloplastic **β**-TCP Bioactive Synthetic Bone Particles (IngeniOs®) at 7 months. The grafting particles are made from silicated pure-phase beta-tricalcium phosphate

a greater porosity appears to be advantageous for enhancing bone formation and particle degradation.

Unfortunately, the replacement of β–TCP by the bone does not occur in an equitable way. That is why there is always less bone volume produced than the volume of β–TCP reabsorbed (Hollinger et al. 1996). For this reason, the clinical use of β–TCP has been as an adjunctive with other less reabsorbable bone graft substitutes or as an expander for AB graft.

Biphasic Calcium Phosphate (BCP) (e.g., BoneCeramic®, Institut Straumann AG, Basel, Switzerland)

Although hydroxyapatite (HA)-sintered ceramics are widely used due to their osteoconductivity, its bioresorbability is so low that HA remains in the body for a long time after implantation. In contrast, tricalcium phosphate (TCP) ceramics show resorbable characters during bone regeneration and can be completely substituted for the bone tissue after stimulation of bone formation. Therefore, much attention is paid to TCP ceramics as scaffold materials for supporting bone regeneration.

The idea of mixing the HA and TCP resulted in producing BCP which is a well-known synthetic bone substitute showing biocompatibility and osteoconductive properties (Friedmann et al. 2009; Froum et al. 2008; Piattelli et al. 1996b) consisting of 60 % hydroxyapatite (HA) and 40 % beta-form of tricalcium phosphate (β–TCP), known for its osteoconductive potential that offers better bone healing conditions during the graft maturation period.

These compositions lead to partial resorption after insertion and to increased bone formation (Cordaro et al. 2008; Froum et al. 2008).

This statement was described as a possible beneficial effect on bone healing and maturation around the biomaterial particles provided by the β-TCP component of BCP during graft maturation (Cordaro et al. 2008).

Schmitt et al. (2013) showed in augmented sinuses significant less BS when using BCP compared to ABB. BCP is therefore a convenient osteoconductive BS leading to rapid bone formation at 5 months post-op. The well-known BS resorption raises the question of the long-term stability of the graft and the inserted implants. A 5-year follow-up investigation suggested the effectiveness of BCP (BoneCeramic©) in SFE, with an implant survival rate of 92.5 % after a mean follow-up of 15 months (Covani et al. 2011).

A more recent study (Piccinini et al. 2013) demonstrated the beneficial role of a composite BS, HA/TTCP (tetracalcium phosphate) in the acceleration of new bone formation, thus reducing the time needed for the graft healing in SFE.

Authors using BCP in augmented sinuses revealed a greater bone formation in areas close to the native residual bone (Avila et al. 2010; Cordaro et al. 2008; Tosta et al. 2013), while AB did not show any statistically significant differences between grafted areas far and close to the native bone. Consequently, bone formation was not predictable around the biomaterial particles in areas far from the interface with the native bone.

Similar studies also found approximately 25 % of vital bone formation in grafted sites (Artzi et al. 2005; Frenken et al. 2010; Zerbo et al. 2005). However, despite the

fact that AB grafts achieved more vital bone formation in Tosta study, this had no negative clinical effect on implant outcomes, as no implant loss was observed in the BCP.

To summarize, synthetic calcium phosphate BS are widely used in SFE due to their osteoconductive and biocompatible properties. Hydroxyapatite (HA), beta-tricalcium phosphate (β-TCP), and HA/β-TCP composite are the most applied materials.

7.5.3.2 Bioactive Glasses

Bioactive glasses consist of sodium oxide, calcium oxide, phosphorus pentoxide, and silicon dioxide. Silicon dioxide (also known as silicate) forms the main component. Forms can be produced that are soluble in vivo by varying the proportions of its components.

Bioactive glasses has been shown to enhance bone repair not only by the osteoconductive properties of the particles but also by their osteo-stimulative potential defined as bone formation within internal pouches excavated within the bioglass particles away from the preexisting bony defect walls (Schepers and Ducheyne 1997).

A mechanically strong bond between bioactive glass and bone forms as a result of a silica-rich gel layer that forms on the surface of the bioactive glass when exposed to physiologic aqueous solutions. Within this gel Ca^{2+} and PO_4^{2-} ions combine to form crystals of hydroxyapatite (HA) similar to that of the bone, hence a strong chemical bond (Gross et al. 1981; Hench and Wilson 1984).

Schepers and Ducheyne (1997) demonstrated bone formation in protective pouches created within the glass particles through gelation and corrosion phenomena arising from the interfacial ion exchange between the glass particles and the surrounding tissue fluids.

In a sinus study, Cordioli et al. (2001) demonstrated the presence of bands of osteoid tissue in the biopsy cores indicating that bone formation was still taking place after a healing period of 9–12 months. At that time, bioactive glass particles became smaller compared to their original size because of their partial dissolution (Schepers and Ducheyne 1997). As reported with other composite grafts (Lorenzetti et al. 1998; Wallace et al. 1996; Wheeler et al. 1996), prolonged healing periods may be required to allow bone maturation and complete resorption and substitution by bone of all bioactive glasses particles.

A variation of the bioactive glasses is the bioactive ceramics. Bioactive ceramics generally have higher strengths and improved mechanical properties over bioactive glass but both still have low fracture toughness in relation to the cortical bone (Moore et al. 2001).

Of recent interest are the bioactive glass composites, which have more elastic characteristics than the rest of the bioactive glass family. The most favorable yet is a combination of bioactive glass with a polysulfone polymer (Thompson and Hench 1998). This most closely resembles the cortical bone and is dependent on a combination of bioactivity, strength, fracture toughness, and modulus of elasticity.

To summarize, regarding recently developed alloplastic biomaterials, there is a lack of information concerning their potential to support new bone formation and maintain the gained bone volume.

Prospective studies with larger patient groups are needed to confirm the present data and also to evaluate the long-term performance of dental implants inserted in areas augmented with the most recent BS.

Some advantages of these synthetic BS are:

1. They are osteoconductive.
2. They have a long shelf life.
3. There is no risk of disease/virus transfer.
4. They are available in every shape, porosity, and composition.
5. There is an unlimited supply.

Some disadvantages are:

1. The handling of some synthetics is not optimal.
2. Synthetics do not have cortical stability.
3. They are never osteoinductive or osteogenic by themselves.

7.5.4 Adjunctives, e.g., PRP, PGRF, BMPs, Others…

Development of the bioactive surgical additives is one of the great challenges of clinical research, which has been used to regulate inflammation and increase the speed of healing process.

Several SFE studies including the addition of adjunct materials such as growth factors (GF), platelet-rich plasma (PRP), fibrin glue, or venous blood were evaluated in the literature.

Growth factors (GF) have demonstrated their efficiency in bone regeneration and can be added to all BS to promote bone regeneration. GF are present at low concentrations in bone matrix and plasma and are essential mediators of tissue repair through their stimulatory effects on angiogenesis, cell differentiation, cell proliferation, and matrix synthesis.

Numerous studies have demonstrated better results regarding the amount and rate of new bone formation when these agents were compared with traditional BS (Nevins et al. 2009; 2005).

The incorporation of GF such as transforming growth factor (TGF-βs), insulin-like growth factor (IGFs), fibroblast growth factor (FGFs), and platelet-derived growth factor (PDGFs) into the sinus graft is used as a method to reduce the healing time and enhance bone formation within the subantral environment.

The commercial availability of these growth factors (GF) has given oral and maxillofacial surgeons an additional option for the reconstruction of bony defects, but despite their potential usefulness, GF are still not available for routine use in practice.

7.5.4.1 PDGF

Among the numerous GF, recombinant human platelet-derived growth factor (rhPDGF) has received the most attention and is a well-characterized tissue GF.

PDGF is a wound-healing hormone that is naturally produced by the body at sites of soft tissue and bone injury. It has been proven to be safe and effective in a series of well-controlled human clinical trials as well as in patient use for nearly 10 years (Camelo et al. 2003; Howell et al. 1997b; Lynch et al. 1989b; Nevins et al. 2003).

The inclusion of rhPDGF in the SFE protocol used along with Bio-Oss has been associated with enhanced clinical results (Nevins et al. 2009).

7.5.4.2 Platelets-Rich Plasma (PRP)

Another GF approach is to use the patient's own blood, separating out the platelet-rich plasma (PRP) and adding this concentrated group of autologous GFs to the grafting material (Marx et al. 1998).

Platelets are a known source of GF such as PDGF and TGF-β (Pierce et al. 1989). PRP is a platelet concentrate derived from the blood. Thus, PRP is considered to be a rich source of autologous GFs, and the contribution of PRP formulations to the bone healing process is thought to be based on the GFs contained (Harrison and Cramer 1993; Jones et al. 1992; Linder et al. 1979; Miyadera et al. 1995; Möhle et al. 1997).

Platelet gel allows access to autologous GF, which are capable of accelerating the normal processes of bone regeneration. PRP has been proposed as a useful instrument for increasing the quality and final quantity of regenerated bone in oral and maxillofacial surgery. However, the literature is conflicting with respect to the adjuvant use of PRP in SFE. The use of PRP is based on the theoretical premise that by concentrating platelets, the effects of the released growth factors (PDGF, TGF-β, IGF-I, and IGF-II) will increase. PRP growth factors do not induce osteoprogenitor cell differentiation, as is seen with the bone morphogenetic proteins, but instead act via stimulation of chemotaxis, mitogenesis, and angiogenesis of surrounding cells, acting as a catalyst in the very early phases of bone remodeling.

PRP has been used in conjunction with allografts as a source of autologous GFs (Landesberg et al. 1998), but improvement in bone formation has not been demonstrated clearly when PRP is added to BS (Sánchez et al. 2003). Another SFE study demonstrated that neither the addition of PRP to ABB (Fuerst et al. 2004) nor to AB (Jakse et al. 2003) did not show any significant improvement than the BS alone. This was expected, since PRP would act in the very early healing period, as the lifespan of a platelet in a wound and the period of the direct influence of its GF are less than 5 days (Marx et al. 1998).

The addition of PRP to ABB and AB did not improve osseointegration (Fuerst et al. 2004; Jakse et al. 2003; Roldán et al. 2004). Nevertheless, a pilot study in rabbit skull bone concluded that adding PRP to ABB is potentially beneficial (Aghaloo et al. 2004). The effect of PRP in bone graft reconstructions was demonstrated by both radiographic and histomorphometric data, which revealed more early bone

formation and a higher trabecular bone density after a 6-month healing period (Marx et al. 1998).

On the contrary, other studies demonstrated that the addition of PRP to AB showed a more rapid and dense bone formation compared to AB used alone (Marx et al. 1998).

It is clear that further studies are needed to evaluate the effects of PRP on different grafting materials in SFE.

7.5.4.3 Platelet-Rich Fibrin (PRF)

Platelet-rich fibrin (PRF) is a fibrin matrix in which platelet cytokines, growth factors, and cells are trapped and may be released after a certain time and that can serve as a resorbable membrane (Naik et al. 2013). It belongs to a new generation of platelet concentrates, with simplified processing and without biochemical blood handling. Although PRF belongs to a new generation of platelet concentrates, the biologic activity of fibrin molecule is enough in itself to account for significant cicatricial capacity of the PRF. The slow polymerization mode confers to PRF membrane as a particularly favorable physiologic architecture to support the healing process. The use of platelet gel to improve bone regeneration is a recent technique in implantology. However, the biologic properties and real effects of such products remain controversial. PRF proved a slower release of growth factors than PRP and observed better healing properties with PRF (Dohan et al. 2006).

PRF was used as an additive in SFE studies. Histologic analysis in sinuses grafted using a mixture of FDBA and PRF demonstrated a reduction of healing time (to 4 months) prior to implant placement (Choukroun et al. 2006), but large-scale studies are still necessary to validate these results. Only a perfect understanding of its components and their significance will enable us to comprehend the clinical results obtained and subsequently extend the fields of therapeutic application of this protocol (Naik et al. 2013).

7.5.4.4 Bone Morphogenetic Proteins (BMPs)

The molecular approach using BMPs has received the most attention over the past decade. BMPs are differentiation factors that are members of the transforming growth factor (TGF-β) superfamily (Schmitt et al. 1999), acting as potent regulators during embryogenesis and bone and cartilage formation and repair.

A well-known GF is the bone morphogenetic protein (BMP-7 or OP-1), which is osteoinductive and may have the potential to stimulate mesenchymal cells to differentiate into bone-forming cells (Wozney et al. 1988). BMP-7 has been found to be osseoinductive and osseopromotive for osseointegration. Some studies reported the supplementation of autogenous bone-derived cells (ABC) to a cell-free grafting material such as ABB (Fuerst et al. 2004). The reason is to add AB-containing osteoblasts, combined with PRP, with the purpose of using the osteoinductive capacity of the bone.

Numerous studies reported promising results with BMPs for SFE, while others have been less enthusiastic. A human study (Boyne et al. 1997) demonstrated that recombinant BMP-2 and BMP-7 (osteogenic protein-1 [OP-1]) are each capable

of stimulating bone formation in SFE. Another study in pigs suggested that rhOP-1 delivered in ABB was superior to ABB alone in SFE with simultaneous implant placement (Terheyden et al. 1999). This report concluded that there was twice the amount of bone to implant contact in the rhOP-1 group compared to the BS alone. The addition of BMP-7 to ABB resulted in significant better results compared with the combination of PRP and ABB (Roldán et al. 2004). Moreover, in SFE, BMP- 7, in addition to ABB as a growth factor, produced a significantly superior outcome, compared with ABB alone (Margolin et al. 1998; Terheyden et al. 1999).

BMP-7 in combination with an appropriate matrix has been demonstrated to be effective in accelerating osseointegration (Roldán et al. 2004). The addition of BMP-7 is dose dependent, with 2.5 mg/g collagen matrix as the most optimal concentration for inducing radiographic and histological evidence of bone formation (Margolin et al. 1998).

From a histomorphometric point of view with the BIC as parameter, the combination of ABB + BMP-7 showed the best results after 6 months. Without the addition of GF, ABB alone resulted in less BIC after 6 months (Schlegel et al. 2003).

Nevertheless, the appropriate dosage and delivery vehicles for SFE have been debated since the selected dosage of rhBMP-2 (from 1.8 to 3.4 mg) showed insufficient amounts of new bone to allow placement of dental implants; therefore, higher doses were suggested.

Moreover, a human study using rhOP-1 in SFE found that the results were too inconsistent to warrant its clinical use in SFE (Groeneveld et al. 1999).

Another SFE study investigated the bone-forming potential of rhOP-1 combined with a collagen carrier compared with AB grafts (van den Bergh et al. 2000). At 6 months, the rhOP-1 group revealed the inconsistent presence of a well-vascularized bone-like tissue. On the opposite, in the AB grafted sinuses, a bone appearance similar to the normal maxillary bone was observed histologically and clinically; implant placement was predictable at 6 months after SFE.

Based on these findings, the behavior of rhOP-1 delivered via a collagen carrier is insufficiently predictable in SFE. Further investigation is needed to demonstrate its efficiency instead of other BS.

Nowadays, BMPs are regarded as effective and safe products to enhance bone healing in SFE and will gain more and more importance in the treatment of bone defects.

However, the wide variation in results may lead to a more careful use of BMP-7 in SFE.

7.5.4.5 Hyaluronic Acid

Hyaluronic acid (HyA) is a natural polymer that has shown to be clinically advantageous due to its excellent biological properties (Lisignoli et al. 2001; Manferdini et al. 2010). In a recent study Stiller et al. (2014) mixed hyaluronic acid with β–TCP and compared this mixture with β–TCP alone in the sinus. HyA material enhanced the handling properties of the β–TCP. They concluded that both TCP grafting materials actively supported bone formation and matrix

mineralization 6 months after SFE. Histomorphometric and radiologic results of TPC with HyA expressed statistically significant differences, compared to TCP alone, in terms of volume reduction, volume stability, and bone formation. Immunohistochemical osteogenic marker expression displayed also a higher tendency for TCP with HyA.

To summarize, the role of adjunctive materials in enhancing the bone graft maturation and reducing the healing time has not been completely elucidated yet. ISR in sinuses grafted with AB with adjunctive materials was 81.2 %; AB combined with allograft and adjunctive materials showed 95.3 % ISR; alloplast with adjunctive materials showed a 95.1 % ISR; and xenograft with adjunctive materials showed a 96 % ISR (Aghaloo and Moy 2007).

7.6 Graft Remodeling After the Use of Bone Substitutes

Although numerous SFE procedures have been performed to date, only a few controlled trials have addressed the healing process and the tissue changes encountered following SFE.

Graft volume stability must be considered as critical for the procedure. In fact, due to the repneumatization of the maxillary sinuses and the bone graft resorption, grafted areas may adapt considerably in shape and volume. Grafting techniques that initially only used AB showed similar results (Del Fabbro et al. 2004; Tong et al. 1998). The use of different BS has, however, introduced another variable in evaluating volume change (Kirmeier et al. 2008).

AB resorbability is a main disadvantage extensively demonstrated in numerous SFE studies (Zimmermann and Moghaddam 2011), showing significantly lower total bone volume between 4.5 and 9 months (Klijn et al. 2010a, b) due to the initial resorption of the inserted graft and the steady replacement of de novo bone (Baumgarten 2010; Consolo et al. 2007; Hallman et al. 2002; Klijn et al. 2010a, b; Lundgren et al. 1996; Pejrone et al. 2002; Simunek et al. 2008; Szabó et al. 2005; Zijderveld et al. 2005).

However, Block et al. (1998) showed that AB grafts were maintained after SFE with time and with regard to the vertical dimension, better than a combination of AB and demineralized bone.

On the other hand, intramembranous bone is more resistant to resorption than enchondral bone (Jensen and Sindet-Pedersen 1991; Kusiak et al. 1985; Zins and Whitaker 1983) due to the longer time needed for revascularization for enchondral bone grafts (Kusiak et al. 1985).

Resorption rates of up to 55 % during the first 6 months have been reported (Johansson et al. 1998) with enchondral AB, while Reinert et al. (2003) reported a vertical bone resorption of 7 % during the first year after grafting and a minimal bone loss after 12 months.

Nevertheless, no data revealed that resorption of the graft material has an influence on implant survival (Hallman and Nordin 2004; Kim et al. 2009) and should not prompt the clinician to prefer or abandon AB.

Therefore, resorption of AB and subsequent repneumatization have been mentioned as reasons to choose nonresorbable or slowly resorbable BS in SFE.

From a theorical point of view, nonresorbable BS will not remodel and functionally adapt to surrounding bone following implant placement and might be a negative mechanical factor, because it may prevent the new bone from reaching the surface of the implant. Despite the fact that the graft height is well maintained in time, it would not provide an optimal bony attachment on the implant surface (Figs. 7.3 and 7.4).

Radiological studies (Hallman et al. 2002; Hatano et al. 2004) reported a decrease in graft height 1–3 years after SFE, but subsequent changes were minimal. A significantly greater maintenance of bone height was found in intraoral grafts when compared to allografts. A combination of different BS (AB + ABB, or allograft + ABB), extensively documented lately, would be a suitable solution to promote both osteogenesis and remodeling (Hatano et al. 2004).

Bioactive glass particles, similar to composite grafts, require prolonged healing periods to allow bone maturation and complete resorption and substitution by the bone (Lorenzetti et al. 1998; Wallace et al. 1996; Wheeler et al. 1996).

In a sinus study, Cordioli et al. (2001) demonstrated the presence of bands of osteoid tissue in the biopsy cores indicating that bone formation was still taking place after a healing period of 9–12 months;

Consequently, the resorption time and the ultimate replacement of some BS with newly formed bone present a wide variation and are still not fully understood, but these BS have a relevant role in clinical practice. So the timing of implant placement should be taken in consideration when selecting a grafting material. Moreover, extended healing periods may be risky since bone volume stability may be jeopardized; therefore, implant loading may be required to limit the bone resorption, which may lead to an uncontrolled peri-implant bone loss. Below is a guide-chart table reporting healing time/loading time, based on an extensive literature review (Table 7.1).

Table 7.1 Mean healing time with different bone substitutes

Grafting material	Optimal healing time for implant placement following SFE (months)
Autogenous bone	4–5
Allografts	5–6
Xenografts	7–10
Synthetics	6–12

7.7 Implant Survival Rate (ISR) After SFE with Different Grafting Materials

A systematic review (Del Fabbro et al. 2004) of ISR in SFE including 6,913 implants revealed an overall ISR of 91.49 %: 87.7 % when AB alone was used, 94.88 % when AB was combined with other BS, and 95.98 % when BS were used alone.

Numerous reviews demonstrated equal or better ISR with BS than those achieved with AB.

In contrast, a more recent systematic review (Aghaloo and Moy 2007) of the main database of ISR with different BS used for SFE reported that the ISR for a total of 5,128 implants was 92 % for implants placed in a mixture of autogenous/composite grafts (2,904 implants), 93.3 % for implants ($n=189$) placed into allogenic/non-autogenous composite grafts, 95.6 % for implants ($n=443$) placed into xenograft materials alone, and only 81 % for implants placed into alloplast and alloplast/xenograft materials. However, when the iliac crest was utilized, 1845 implants displayed an ISR of 88 %. This is comparable to alloplastic materials, where 190 implants showed an ISR of 81 %; the studies on alloplast and allograft BS appeared to be more heterogeneous.

Another systematic review of ISR in SFE included 6,913 implants placed in 2,046 patients combined from 39 studies (Graziani et al. 2004). The analysis determined an ISR of 91.49 % overall and 87.7 % ISR when AB alone was used versus 94.88 % when it was combined with other materials and 95.98 % when BS were used alone. Smooth-surface implants had an 85.64 % ISR versus a 95.98 % ISR for rough-surface implants. Finally, delayed implant placement showed a 92.93 % survival, which was similar to the survival rate demonstrated for simultaneous graft and implant placement (92.17 %).

In a more recent systematic review (Del Fabbro et al. 2013), based on nine preceding systematic reviews (Aghaloo and Moy 2007; Del Fabbro et al. 2008; 2004; Esposito et al. 2010; Graziani et al. 2004; Jensen and Terheyden 2009; Nkenke and Stelzle 2009; Pjetursson et al. 2008; Wallace and Froum 2003), the authors found that in the group using 100 % AB, the overall ISR was 85.32 %, while in the group using composites grafts (BS + AB) (BS was Hydroxyapatite), ISR was 87.70 %. In the group using 100 % BS, the ISR was 96.25 %. Once again, the overall ISR using 100 % AB was significantly lower than that using 100 % BS.

On the other hand, another variable that may affect ISR is the implant surface configuration. Histologic and clinical evidence have suggested that rough-surfaced implants provide a more favorable outcome following SFE than machined-surfaced implants (Buser et al. 1991; Cochran et al. 1998; Khang et al. 2001; Kumar et al. 2002; Lazzara et al. 1999; Stach and Kohles 2003) irrespectively of whether AB, combinations of AB and BS, or BS alone were utilized.

To summarize, the SFE has been well documented, and the long-term clinical success/survival (>5 years) of implants placed into augmented bone, regardless of BS used, appears to be similar to or better than that of implants placed using conventional protocol with no need for a grafting procedure.

7.8 Bone Healing Specificity of the Sinus

The mechanism of the observed bone formation in the maxillary sinus remains to be determined. Knowledge about bone healing has mainly been gained from studies of healing fractures and bone defects. However, the maxillary sinus is unique as it requires the bone to be formed beyond the skeletal contour and not in a bone fracture or defect (Lundgren et al. 2008). SFE is nowadays considered as the most predictable implant site development option for bone augmentation in both maxillas. Nevertheless, many parameters related to the healing specificity of SFE are still debated, including:

- Favorable healing due to the number of walls in the sinus cavity?
- Importance of sinus volume: e.g., buccolingual distance?
- Is there a real potential for the sinus membrane in accelerating bone healing?

The sinus bony defect healing follows the principle of guided bone regeneration (GBR) and is obviously favorable, since it is a contained defect with a favorable number of walls surrounding the sinus cavity.

However, graft consolidation requires adequate angiogenesis and the recruitment, migration, and differentiation of osteogenic cells involved in bone remodeling. It is speculated that these biologic events are greatly determined by the dimensions of the maxillary sinus cavity. Delayed or insufficient bone maturation may occur in cases where the sinus cavity presents larger dimensions or in cases where limited alveolar bone remains after tooth loss. The influence of these factors on SFE outcome remains unclear. Several authors have pointed out the importance of the anatomic variables. Avila et al. (2010) assessed the influence of the distance from the lateral to the medial wall (buccolingual distance) of the maxillary sinus on the outcomes of SFE procedures. They showed that the proportion of the vital bone formation after SFE is inversely proportional to the bucco-palatal distance of the maxillary sinus. This information should be considered for the selection of the most suitable BS and the timing of implant placement.

In a human SFE study, Artzi et al. (2008) evaluated the osteoconductive properties of different BS. After a 12-month healing period, the proportion of vital bone (VB) increased significantly from superficial to internal sections regardless of the BS. These findings indicate that the lack of a bony wall may hinder VB formation. In fact, a successful graft consolidation relies on the progressive apposition of newly formed VB, followed by functional remodeling and progressive replacement of the BS by vital tissue (Watzek et al. 1998). This process requires the presence of a stable scaffold, adequate angiogenesis (blood supply), and the migration of osteogenic cells. These events could be hindered in situations where the dimensions of the maxillary sinus cavity or the lateral window are excessive.

A variety of factors may influence bone maturation and the resulting outcome of SFE including:

- The distance from the buccal (lateral) to the palatal (medial) wall of the sinus cavity (bucco-palatal distance [BPD])
- The residual bone height (RBH)
- The incidence of Schneiderian membrane perforation
- The size of the lateral window
- The total sinus volume
- Finally we should emphasize on the importance of the selection of the most appropriate BS for each clinical situation: e.g., AB or a mixture of AB/BS is important in larger cavities where osteoinductive properties are necessary.

Sinus Membrane Potential for Healing The Schneiderian membrane is composed of a few layers including the epithelial lining, the richly vascularized lamina propria, and the maxillary bone interface. It has been stated that a genuine osteogenic potential is associated with the sinus and can contribute to development of successful sinus augmentation techniques.

Therefore, several studies demonstrated that a graft-less approach achieves similar results when compared to the conventional use of BS in SFE. The lifting of the periosteum would initiate a resorption process, exposure of the bone marrow, and access of stem cells to the sinus cavity, a sequence of events that has been described in animal studies (Lundgren et al. 2000; Slotte and Lundgren 2002). Gruber et al. (2004) revealed that the sinus mucosa contains mesenchymal progenitor cells and cells committed to the osteogenic lineage, which may constitute another source of bone-forming cells with sinus membrane elevation. A more recent study has shown that the periosteum of the maxillary bone does include osteoprogenitor cells (Cicconetti et al. 2007). It was also shown (Srouji et al. 2009) that cells derived from explants of human sinus membrane can be grown in culture, express markers of osteoprogenitor cells, be induced to osteogenic differentiation, and be transplanted in vivo, with histological evidence of the new bone formation at the site of transplantation. The authors assume that a periosteum-like membrane also lines the maxillary bone forming the sinus floor at the site where this interfaces with the maxillary sinus mucosa and that lifting of the sinus mucosa results in lifting of this periosteum-like membrane as well. This would explain the osteogenic response associated with SFE in clinical settings.

The studies presented have revealed the formation of a blood clot around titanium implants placed in the maxillary sinus. Examinations at 6–12 months post-implant placement showed shrinkage and ossification of the blood clot and the formation of a new sinus floor.

In sum, these observations described here suggest that, in spite of an ongoing bone remodeling, bone deposition is the result of the Schneiderian membrane elevation without the need for BS, while a resorptive process of BS predominates in bone-grafted sites. The tissue regeneration field has firmly established the importance of the coagulum and its endogenous growth factors for bone formation, and it seems that the osteoinductive properties of a coagulum are limited mainly by lack

of a properly maintained space (Dahlin et al. 1989; Ellegaard et al. 1997; Jensen et al. 1995; Leghissa et al. 1999; Lundgren et al. 2004; Lynch et al. 1989a; Smukler et al. 1995; Tal et al. 1996). Numerous authors (Ellegaard et al. 1997; Haas et al. 2002; Lundgren et al. 2003, 2004; Winter et al. 2003) have observed that bone formation after SFE with no use of bone grafts Palma et al. (2006) were the first to describe the process histologically and to evaluate the integration potential of implants with different surfaces in sinus sites.

A simple elevation of the maxillary sinus membrane with simultaneous implant placement results in bone formation and osseointegration. Histologically, the de novo bone tends to be deposited in contact with the sinus membrane after its elevation, pointing to the osseoinductive potential of the sinus membrane.

To summarize, despite the statement claiming that the amount of bone formation does not seem to differ when performing SFE with or without bone grafts, this approach should be only considered in case of favorable sinus anatomy (narrow bony defect) with no need for an important bone augmentation volume.

Moreover, surface-modified implants seem to favor a stronger bone response in graft-less approach than machined implants in maxillary sites receiving SFE (Lundgren et al. 2008).

Conclusion

Nowadays, biological mechanisms involved in SFE are better understood:

- The sole presence of a stable blood clot is required to recreate the bone under the sinus membrane, and the ossification of this clot is initiated in a concentric manner from the intramaxillary bone walls.
- The insertion of AB or BS in the space created under the sinus has no major role in bone promotion. However, it allows a three-dimensional stability of the clot against intra-sinus pressures.
- Due to a biological understanding of SFE procedure and based on numerous publications, similar results are obtained when using AB or BS in SFE.

In fact, the efficiency of different BS is multifactorial. It is most often assessed through a single variable: implant survival rate (ISR). ISR is in reality a poor parameter for comparing different BS because osseointegration is always present regardless of the BS used. Moreover, no conclusive data have established the minimal amount of the vital bone that is necessary for implant integration despite some evidence-based reviews correlated with histologic studies, focusing on the percentage of the vital bone formed when using different BS (Klijn et al. 2010a). Although AB resulted in higher "total bone volume" (TBV) than BS, it must be emphasized that the consequence of the TBV for ISR is still unraveled yet.

On the other hand, to date, more studies are needed for the clarification of the influence of the RBH, simultaneous or delayed implant placement, and graft resorption on ISR in dependence of the BS used. The aspects of donor site morbidity, disease transmission, and costs have also not been treated adequately.

All in all, the current literature provides only a low level of evidence as far as the decision-making between the use of AB and BS is concerned.

Currently, AB and allografts are the main sources for predictable bone grafting procedures in terms of histologic results. AB has by far the most osteogenic potential followed by allograft, and it is still the best choice for a lot of applications where bone grafting is needed. But there are disadvantages: the relatively high donor morbidity and the limited amount that can be harvested, which will eventually lead to a very restricted use of it. Allografts do not have these limitations, but in the form of demineralized bone matrix, they have very variable osteoinductive properties and can possibly transmit diseases. Allografts represent an important source when structural or large volumes of grafts are needed. Concerns related to the use of both autograft and allograft have led to the search for alternatives.

The alloplastic BS has yet offered only a part solution to the management of localized bone loss. They possess some of the desired mechanical qualities of the bone as well as osteoconductive properties but are largely reliant on viable periosteum/bone for their success. Ideally a synthetic BS should mimic the native bone in both mechanical and osteogenic properties. The advent of composite synthetic BS and biologically active factors moves us ever closer to this goal.

Although most BS have little biological activity when compared to AB, the available evidence neither supports nor refutes the superiority of AB over other BS for SFE with regard to ISR or complications at the recipient site. ISR may be confounded by factors other than the graft material used for SFE.

BS act as fillers and have variable osteointegrative and conductive properties. To ensure effective activity as a delivery system, it is likely that controlled resorption of the BS is required. This is necessary to ensure a timely and predictable release of factors incorporated within the BS and the subsequent complete replacement of the BS by the host bone.

New-generation BS are being designed with the aim that once implanted they will help the body to heal itself. One desirable characteristic of these BS is their ability to be remodeled, i.e., that osteoclasts resorb the material and it is subsequently replaced by the newly formed bone through osteoblastic activity.

Thinking on the mechanisms behind bioactivity and biocompatibility in the bone, which is a requirement for biological integration, a fuller understanding of the interactions between cells and the materials used could bring better understanding about bone healing. Lately, a considerable effort to improve the management of bone loss leaded to the identification of osteoinductive proteins and other factors involved in the promotion of osteoblastic proliferation, differentiation, and function.

Bone tissue engineering aims to combine BS with osteoconductive properties and potential osteoinductive substances with viable osteoprogenitor cells, which are expected to be responsible for the osteogenesis process. Combining an osteoinductive protein in an osteoconductive carrier medium facilitates timed-release delivery and/or provides a material scaffold for bone formation.

Resulting bioactive BS framework has the potential to maximize repair of large bone defects.

Future synthetic bone grafts will be more and more of interest, especially if there are further developments in stability and handling which is currently still suboptimal. Future biosynthetic BS may obviate the need for AB grafts. Consequently, the selection of a suitable BS for SFE relies on:

- The healing period required for implant placement after the SFE procedure.
- The sinus volume: bucco-palatally and mesiodistally (a bigger volume necessitates higher osteoconductive/inductive properties).
- The long-term graft stability of the regenerated peri-implant bone volume.
- The aspect of cost cannot be ignored.

The ideal scaffold for SFE should have the following properties:

- Biologically *compatible*, promoting cell adhesion and activity.
- Highly *conductive* and potentially *inductive* in order to facilitate and enhance bone cell ingrowth.
- Inductives spontaneously without adjunction of exogenic growth factors.
- Resorption kinetics should be equal to the bone repair rate to facilitate load transfer to developing bone.
- R*esorbable* but particularly in SFE, partial resorbability might be interesting in order to prevent total remodeling and subsequent resorption in case of postponing implant placement and prosthetic rehabilitation for a long period following SFE.
- *Hydrophilic* in order to facilitate vessels ingrowth.
- Create a stable interface with the host bone without the formation of scar tissue.
- *Easy to handle* and easily conserved under normal conditions.
- Act as a three-dimensional template for bone regeneration.
- Offer mechanical properties similar to the host bone.
- Have a structural integrity, providing a framework for host bone formation, and act as delivery systems for factors important in regulating local bone responses.
- The by-products produced should be non-toxic and easily excreted by the body.
- Non-supportive of local pathogens or cross-infection, ideally synthetic.
- Match the physical structure of the natural trabecular bone from macrostructure to microstructure and ideally the nanostructure and provide scaffolding for new bone ingrowth.

Overall, augmentation with BS should include good bone tissue integration, osteoinduction, and long-term stability. Actually, a constant debate relates to whether or not an increased amount of newly formed bone and a decreased

amount of BS (AB or allograft) are preferable over a larger amount of nonresorbable BS and decreased de novo bone formation (ABB)?

The ideal BS should provide both a high percentage of vital bone after a reasonable maturation time (the shortest possible) and an ISR that is equal to or better than those achieved with AB.

However, despite tremendous research efforts, such a BS in its pure form does not yet exist.

Meanwhile, the "temporary solution" would be the use of a composite grafting material combining two different components allowing both fast and slow remodeling properties in order to preserve the bone volume over time. Moreover, at least one of these two components should be osteogenic (AB), osteoinductive (AB, allografts), or at least highly osteoconductive.

The search continues for the optimal BS for SFE….

References

Abubaker OA (1999) Diagnosis and treatment of diseases and disorders of the maxillary sinus, applied anatomy of the maxillary sinus, oral maxillofac. Surg Clin N Am 11:1–13

Aghaloo TL, Moy PK (2007) Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 22(Suppl):49–70

Aghaloo TL, Moy PK, Freymiller EG (2004) Evaluation of platelet-rich plasma in combination with anorganic bovine bone in the rabbit cranium: a pilot study. Int J Oral Maxillofac Implants 19:59–65

Alanay A, Wang JC, Shamie AN, Napoli A, Chen C, Tsou P (2008) A novel application of high-dose (50 kGy) gamma irradiation for demineralized bone matrix: effects on fusion rate in a rat spinal fusion model. Spine J 8:789–795. doi:10.1016/j.spinee.2007.06.009

Albrektsson T, Johansson C (2001) Osteoinduction, osteoconduction and osseointegration. Eur Spine J 10:S96–S101. doi:10.1007/s005860100282

Artzi Z, Nemcovsky CE, Dayan D (2002) Bovine-HA spongiosa blocks and immediate implant placement in sinus augmentation procedures. Histopathological and histomorphometric observations on different histological stainings in 10 consecutive patients. Clin Oral Implants Res 13:420–427

Artzi Z, Kozlovsky A, Nemcovsky CE, Weinreb M (2005) The amount of newly formed bone in sinus grafting procedures depends on tissue depth as well as the type and residual amount of the grafted material. J Clin Periodontol 32:193–199. doi:10.1111/j.1600-051X.2005.00656.x

Artzi Z, Weinreb M, Carmeli G, Lev-Dor R, Dard M, Nemcovsky CE (2008) Histomorphometric assessment of bone formation in sinus augmentation utilizing a combination of autogenous and hydroxyapatite/biphasic tricalcium phosphate graft materials: at 6 and 9 months in humans. Clin Oral Implants Res 19:686–692. doi:10.1111/j.1600-0501.2008.01539.x

Asai S, Shimizu Y, Ooya K (2002) Maxillary sinus augmentation model in rabbits: effect of occluded nasal ostium on new bone formation. Clin Oral Implants Res 13:405–409

Avera SP, Stampley WA, McAllister BS (1997) Histologic and clinical observations of resorbable and nonresorbable barrier membranes used in maxillary sinus graft containment. Int J Oral Maxillofac Implants 12:88–94

Avila G, Wang H-L, Galindo-Moreno P, Misch CE, Bagramian RA, Rudek I, Benavides E, Moreno-Riestra I, Braun T, Neiva R (2010) The influence of the bucco-palatal distance on sinus augmentation outcomes. J Periodontol 81:1041–1050. doi:10.1902/jop.2010.090686

Bae HW, Zhao L, Kanim LEA, Wong P, Delamarter RB, Dawson EG (2006) Intervariability and intravariability of bone morphogenetic proteins in commercially available demineralized bone matrix products. Spine 31:1299–1306. doi:10.1097/01.brs.0000218581.92992.b7; discussion 1307–1308

Barriga A, Díaz-de-Rada P, Barroso JL, Alfonso M, Lamata M, Hernáez S, Beguiristáin JL, San-Julián M, Villas C (2004) Frozen cancellous bone allografts: positive cultures of implanted grafts in posterior fusions of the spine. Eur Spine J 13:152–156. doi:10.1007/s00586-003-0633-9

Baumgarten S (2010) Sinus grafting with mineralized allograft and staged implant placement. Quintessence Int 1985(41):197–202

Becker W, Schenk R, Higuchi K, Lekholm U, Becker BE (1995) Variations in bone regeneration adjacent to implants augmented with barrier membranes alone or with demineralized freeze-dried bone or autologous grafts: a study in dogs. Int J Oral Maxillofac Implants 10:143–154

Berger G, Gildenhaar R, Ploska U (1995) Rapid resorbable, glassy crystalline materials on the basis of calcium alkali orthophosphates. Biomaterials 16:1241–1248

Block MS, Kent JN (1997) Sinus augmentation for dental implants: the use of autogenous bone. J Oral Maxillofac Surg 55:1281–1286

Block MS, Kent JN, Kallukaran FU, Thunthy K, Weinberg R (1998) Bone maintenance 5 to 10 years after sinus grafting. J Oral Maxillofac Surg 56:706–714; discussion 714–715

Boyan BD, Ranly DM, Schwartz Z (2006) Use of growth factors to modify osteoinductivity of demineralized bone allografts: lessons for tissue engineering of bone. Dent Clin N Am 50:217–228, viii. doi:10.1016/j.cden.2005.11.007

Boyne PJ, James RA (1980) Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1965(38):613–616

Boyne PJ, Kruger GO (1962) Fluorescence microscopy of alveolar bone repair. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 15:265–281

Boyne PJ, Marx RE, Nevins M, Triplett G, Lazaro E, Lilly LC, Alder M, Nummikoski P (1997) A feasibility study evaluating rhBMP-2/absorbable collagen sponge for maxillary sinus floor augmentation. Int J Periodontics Restorative Dent 17:11–25

Boyne PJ, Nath R, Nakamura A (1998) Human recombinant BMP-2 in osseous reconstruction of simulated cleft palate defects. Br J Oral Maxillofac Surg 36:84–90

Browaeys H, Bouvry P, De Bruyn H (2007) A literature review on biomaterials in sinus augmentation procedures. Clin Implant Dent Relat Res 9:166–177. doi:10.1111/j.1708-8208.2007.00050.x

Buser D, Schenk RK, Steinemann S, Fiorellini JP, Fox CH, Stich H (1991) Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs. J Biomed Mater Res 25:889–902. doi:10.1002/jbm.820250708

Butz F, Bächle M, Ofer M, Marquardt K, Kohal RJ (2011) Sinus augmentation with bovine hydroxyapatite/synthetic peptide in a sodium hyaluronate carrier (PepGen P-15 Putty): a clinical investigation of different healing times. Int J Oral Maxillofac Implants 26:1317–1323

Byrd HS, Hobar PC, Shewmake K (1993) Augmentation of the craniofacial skeleton with porous hydroxyapatite granules. Plast Reconstr Surg 91:15–22; discussion 23–26

Camelo M, Nevins ML, Schenk RK, Lynch SE, Nevins M (2003) Periodontal regeneration in human Class II furcations using purified recombinant human platelet-derived growth factor-BB (rhPDGF-BB) with bone allograft. Int J Periodontics Restorative Dent 23:213–225

Cammack GV 2nd, Nevins M, Clem DS 3rd, Hatch JP, Mellonig JT (2005) Histologic evaluation of mineralized and demineralized freeze-dried bone allograft for ridge and sinus augmentations. Int J Periodontics Restorative Dent 25:231–237

Carson JS, Bostrom MPG (2007) Synthetic bone scaffolds and fracture repair. Injury 38(Suppl 1): S33–S37. doi:10.1016/j.injury.2007.02.008

Chappard D, Zhioua A, Grizon F, Basle MF, Rebel A (1993) Biomaterials for bone filling: comparisons between autograft, hydroxyapatite and one highly purified bovine xenograft. Bull Assoc Anat (Nancy) 77:59–65

Chiapasco M, Casentini P, Zaniboni M (2009) Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants 24(Suppl):237–259

Choukroun J, Diss A, Simonpieri A, Girard M-O, Schoeffler C, Dohan SL, Dohan AJJ, Mouhyi J, Dohan DM (2006) Platelet-rich fibrin (PRF): a second-generation platelet concentrate. Part V: histologic evaluations of PRF effects on bone allograft maturation in sinus lift. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101:299–303. doi:10.1016/j.tripleo.2005.07.012

Cicconetti A, Sacchetti B, Bartoli A, Michienzi S, Corsi A, Funari A, Robey PG, Bianco P, Riminucci M (2007) Human maxillary tuberosity and jaw periosteum as sources of osteoprogenitor cells for tissue engineering. Oral Surg Oral Med Oral Pathol Oral Radio Endod 104:618. e1–12. doi:10.1016/j.tripleo.2007.02.022

Cochran DL, Schenk RK, Lussi A, Higginbottom FL, Buser D (1998) Bone response to unloaded and loaded titanium implants with a sandblasted and acid-etched surface: a histometric study in the canine mandible. J Biomed Mater Res 40:1–11

Consolo U, Zaffe D, Bertoldi C, Ceccherelli G (2007) Platelet-rich plasma activity on maxillary sinus floor augmentation by autologous bone. Clin Oral Implants Res 18:252–262. doi:10.1111/j.1600-0501.2006.01330.x

Cordaro L, Bosshardt DD, Palattella P, Rao W, Serino G, Chiapasco M (2008) Maxillary sinus grafting with Bio-Oss or Straumann Bone Ceramic: histomorphometric results from a randomized controlled multicenter clinical trial. Clin Oral Implants Res 19:796–803. doi:10.1111/j.1600-0501.2008.01565.x

Cordioli G, Mazzocco C, Schepers E, Brugnolo E, Majzoub Z (2001) Maxillary sinus floor augmentation using bioactive glass granules and autogenous bone with simultaneous implant placement. Clinical and histological findings. Clin Oral Implants Res 12:270–278

Cosso MG, de Brito RB Jr, Piattelli A, Shibli JA, Zenóbio EG (2013) Volumetric dimensional changes of autogenous bone and the mixture of hydroxyapatite and autogenous bone graft in humans maxillary sinus augmentation. A multislice tomographic study. Clin Oral Implants Res. doi:10.1111/clr.12261

Covani U, Orlando B, Giacomelli L, Cornelini R, Barone A (2011) Implant survival after sinus elevation with Straumann(®) BoneCeramic in clinical practice: ad-interim results of a prospective study at a 15-month follow-up. Clin Oral Implants Res 22:481–484. doi:10.1111/j.1600-0501.2010.02042.x

Daculsi G (1998) Biphasic calcium phosphate concept applied to artificial bone, implant coating and injectable bone substitute. Biomaterials 19:1473–1478

Daculsi G, Hartmann DJ, Heughebaert M, Hamel L, Le Nihouannen JC (1988) *In vivo* cell interactions with calcium phosphate bioceramics. J Submicrosc Cytol Pathol 20:379–384

Daculsi G, LeGeros RZ, Heughebaert M, Barbieux I (1990) Formation of carbonate-apatite crystals after implantation of calcium phosphate ceramics. Calcif Tissue Int 46:20–27

Dahlin C, Sennerby L, Lekholm U, Linde A, Nyman S (1989) Generation of new bone around titanium implants using a membrane technique: an experimental study in rabbits. Int J Oral Maxillofac Implants 4:19–25

Del Fabbro M, Testori T, Francetti L, Weinstein R (2004) Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 24:565–577

Del Fabbro M, Rosano G, Taschieri S (2008) Implant survival rates after maxillary sinus augmentation. Eur J Oral Sci 116:497–506. doi:10.1111/j.1600-0722.2008.00571.x

Del Fabbro M, Wallace SS, Testori T (2013) Long-term implant survival in the grafted maxillary sinus: a systematic review. Int J Periodontics Restorative Dent 33:773–783

Delloye C, Bannister GC (2004) Impaction bone grafting in revision arthroplasty, 1st edn. CRC Press, New York

Delloye C, Suratwala SJ, Cornu O, Lee FY (2004) Treatment of allograft nonunions with recombinant human bone morphogenetic proteins (rhBMP). Acta Orthop Belg 70:591–597

Dohan DM, Choukroun J, Diss A, Dohan SL, Dohan AJJ, Mouhyi J, Gogly B (2006) Platelet-rich fibrin (PRF): a second-generation platelet concentrate. Part III: leukocyte activation: a new

feature for platelet concentrates? Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101: e51–e55. doi:10.1016/j.tripleo.2005.07.010

Eggli PS, Müller W, Schenk RK (1998) Porous hydroxyapatite and tricalcium phosphate cylinders with two different pore size ranges implanted in the cancellous bone of rabbits. A comparative histomorphometric and histologic study of bony ingrowth and implant substitution. Clin Orthop 232:127–138

Ellegaard B, Kølsen-Petersen J, Baelum V (1997) Implant therapy involving maxillary sinus lift in periodontally compromised patients. Clin Oral Implants Res 8:305–315

Erbe EM, Marx JG, Clineff TD, Bellincampi LD (2001) Potential of an ultraporous beta-tricalcium phosphate synthetic cancellous bone void filler and bone marrow aspirate composite graft. Eur Spine J 10(Suppl 2):S141–S146. doi:10.1007/s005860100287

Esposito M, Grusovin MG, Coulthard P, Worthington HV (2006) The efficacy of various bone augmentation procedures for dental implants: a Cochrane systematic review of randomized controlled clinical trials. Int J Oral Maxillofac Implants 21:696–710

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington HV, Coulthard P (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev (3):CD008397. doi:10.1002/14651858.CD008397

Ewers R, Goriwoda W, Schopper C, Moser D, Spassova E (2004) Histologic findings at augmented bone areas supplied with two different bone substitute materials combined with sinus floor lifting. Report of one case. Clin Oral ants Res 15:96–100

Fan H, Ikoma T, Tanaka J, Zhang X (2007) Surface structural biomimetics and the osteoinduction of calcium phosphate biomaterials. J Nanosci Nanotechnol 7:808–813

Fenner M, Vairaktaris E, Stockmann P, Schlegel KA, Neukam FW, Nkenke E (2009) Influence of residual alveolar bone height on implant stability in the maxilla: an experimental animal study. Clin Oral Implants Res 20:751–755. doi:10.1111/j.1600-0501.2008.01570.x

Frenken JWFH, Bouwman WF, Bravenboer N, Zijderveld SA, Schulten EAJM, ten Bruggenkate CM (2010) The use of Straumann Bone Ceramic in a maxillary sinus floor elevation procedure: a clinical, radiological, histological and histomorphometric evaluation with a 6-month healing period. Clin Oral Implants Res 21:201–208. doi:10.1111/j.1600-0501.2009.01821.x

Friedmann A, Dard M, Kleber B-M, Bernimoulin J-P, Bosshardt DD (2009) Ridge augmentation and maxillary sinus grafting with a biphasic calcium phosphate: histologic and histomorphometric observations. Clin Oral Implants Res 20:708–714. doi:10.1111/j.1600-0501.2009.01708.x

Frost DE, Fonseca RJ, Burkes EJ Jr (1982) Healing of interpositional allogeneic lyophilized bone grafts following total maxillary osteotomy. J Oral Maxillofac Surg 40:776–786

Froum SJ, Tarnow DP, Wallace SS, Rohrer MD, Cho SC (1998) Sinus floor elevation using anorganic bovine bone matrix (OsteoGraf/N) with and without autogenous bone: a clinical, histologic, radiographic, and histomorphometric analysis–Part 2 of an ongoing prospective study. Int J Periodontics Restorative Dent 18:528–543

Froum SJ, Wallace SS, Elian N, Cho SC, Tarnow DP (2006) Comparison of mineralized cancellous bone allograft (Puros) and anorganic bovine bone matrix (Bio-Oss) for sinus augmentation: histomorphometry at 26 to 32 weeks after grafting. Int J Periodontics Restorative Dent 26:543–551

Froum SJ, Wallace SS, Cho S-C, Elian N, Tarnow DP (2008) Histomorphometric comparison of a biphasic bone ceramic to anorganic bovine bone for sinus augmentation: 6- to 8-month postsurgical assessment of vital bone formation. A pilot study. Int J Periodontics Restorative Dent 28:273–281

Fuerst G, Tangl S, Gruber R, Gahleitner A, Sanroman F, Watzek G (2004) Bone formation following sinus grafting with autogenous bone-derived cells and bovine bone mineral in minipigs: preliminary findings. Clin Oral Implants Res 15:733–740. doi:10.1111/j.1600-0501.2004.01077.x

Galindo-Moreno P, Avila G, Fernández-Barbero JE, Aguilar M, Sánchez-Fernández E, Cutando A, Wang H-L (2007) Evaluation of sinus floor elevation using a composite bone graft mixture. Clin Oral Implants Res 18:376–382. doi:10.1111/j.1600-0501.2007.01337.x

Galindo-Moreno P, Avila G, Fernández-Barbero JE, Mesa F, O'Valle-Ravassa F, Wang H-L (2008) Clinical and histologic comparison of two different composite grafts for sinus augmentation: a pilot clinical trial. Clin Oral Implants Res 19:755–759. doi:10.1111/j.1600-0501.2008.01536.x

Gauthier O, Boix D, Grimandi G, Aguado E, Bouler JM, Weiss P, Daculsi G (1999) A new injectable calcium phosphate biomaterial for immediate bone filling of extraction sockets: a preliminary study in dogs. J Periodontol 70:375–383. doi:10.1902/jop.1999.70.4.375

Ghosh SK, Nandi SK, Kundu B, Datta S, De DK, Roy SK, Basu D (2008) *In vivo* response of porous hydroxyapatite and beta-tricalcium phosphate prepared by aqueous solution combustion method and comparison with bioglass scaffolds. J Biomed Mater Res B Appl Biomater 86:217–227. doi:10.1002/jbm.b.31009

Graziani F, Donos N, Needleman I, Gabriele M, Tonetti M (2004) Comparison of implant survival following sinus floor augmentation procedures with implants placed in pristine posterior maxillary bone: a systematic review. Clin Oral Implants Res 15:677–682. doi:10.1111/j.1600-0501.2004.01116.x

Groeneveld EH, van den Bergh JP, Holzmann P, ten Bruggenkate CM, Tuinzing DB, Burger EH (1999) Histomorphometrical analysis of bone formed in human maxillary sinus floor elevations grafted with OP-1 device, demineralized bone matrix or autogenous bone. Comparison with non-grafted sites in a series of case reports. Clin Oral Implants Res 10:499–509

Gross JS (1997) Bone grafting materials for dental applications: a practical guide. Compend Contin Educ Dent 18:1013–1018, 1020–1022, 1024, passim; quiz

Gross U, Brandes J, Strunz V, Bab I, Sela J (1981) The ultrastructure of the interface between a glass ceramic and bone. J Biomed Mater Res 15:291–305. doi:10.1002/jbm.820150302

Gruber R, Kandler B, Fuerst G, Fischer MB, Watzek G (2004) Porcine sinus mucosa holds cells that respond to bone morphogenetic protein (BMP)-6 and BMP-7 with increased osteogenic differentiation in vitro. Clin Oral Implants Res 15:575–580. doi:10.1111/j.1600-0501.2004.01062.x

Haas R, Donath K, Födinger M, Watzek G (1998a) Bovine hydroxyapatite for maxillary sinus grafting: comparative histomorphometric findings in sheep. Clin Oral Implants Res 9:107–116

Haas R, Mailath G, Dörtbudak O, Watzek G (1998b) Bovine hydroxyapatite for maxillary sinus augmentation: analysis of interfacial bond strength of dental implants using pull-out tests. Clin Oral Implants Res 9:117–122

Haas R, Baron M, Donath K, Zechner W, Watzek G (2002) Porous hydroxyapatite for grafting the maxillary sinus: a comparative histomorphometric study in sheep. Int J Oral Maxillofac Implants 17:337–346

Hak DJ (2007) The use of osteoconductive bone graft substitutes in orthopaedic trauma. J Am Acad Orthop Surg 15:525–536

Hallman M, Nordin T (2004) Sinus floor augmentation with bovine hydroxyapatite mixed with fibrin glue and later placement of nonsubmerged implants: a retrospective study in 50 patients. Int J Oral Maxillofac Implants 19:222–227

Hallman M, Cederlund A, Lindskog S, Lundgren S, Sennerby L (2001) A clinical histologic study of bovine hydroxyapatite in combination with autogenous bone and fibrin glue for maxillary sinus floor augmentation. Results after 6 to 8 months of healing. Clin Oral Implants Res 12:135–143

Hallman M, Sennerby L, Lundgren S (2002) A clinical and histologic evaluation of implant integration in the posterior maxilla after sinus floor augmentation with autogenous bone, bovine hydroxyapatite, or a 20:80 mixture. Int J Oral Maxillofac Implants 17:635–643

Hämmerle CH, Chiantella GC, Karring T, Lang NP (1998) The effect of a deproteinized bovine bone mineral on bone regeneration around titanium dental implants. Clin Oral Implants Res 9:151–162

Harrison P, Cramer EM (1993) Platelet alpha-granules. Blood Rev 7:52–62

Hatano N, Shimizu Y, Ooya K (2004) A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 15:339–345. doi:10.1111/j.1600-0501.2004.00996.x

Hench LL, Wilson J (1984) Surface-active biomaterials. Science 226:630–636
Herold RW, Pashley DH, Cuenin MF, Niagro F, Hokett SD, Peacock ME, Mailhot J, Borke J (2002) The effects of varying degrees of allograft decalcification on cultured porcine osteoclast cells. J Periodontol 73:213–219. doi:10.1902/jop.2002.73.2.213
Hing KA, Best SM, Tanner KE, Bonfield W, Revell PA (2004) Mediation of bone ingrowth in porous hydroxyapatite bone graft substitutes. J Biomed Mater Res A 68:187–200. doi:10.1002/jbm.a.10050
Hing KA, Wilson LF, Buckland T (2007) Comparative performance of three ceramic bone graft substitutes. Spine J 7:475–490. doi:10.1016/j.spinee.2006.07.017
Hislop WS, Finlay PM, Moos KF (1993) A preliminary study into the uses of anorganic bone in oral and maxillofacial surgery. Br J Oral Maxillofac Surg 31:149–153
Hollinger JO, Battistone GC (1986) Biodegradable bone repair materials. Synthetic polymers and ceramics. Clin Orthop 207:290–305
Hollinger JO, Brekke J, Gruskin E, Lee D (1996) Role of bone substitutes. Clin Orthop 324:55–65
Howell TH, Fiorellini J, Jones A, Alder M, Nummikoski P, Lazaro M, Lilly L, Cochran D (1997a) A feasibility study evaluating rhBMP-2/absorbable collagen sponge device for local alveolar ridge preservation or augmentation. Int J Periodontics Restorative Dent 17:124–139
Howell TH, Fiorellini JP, Paquette DW, Offenbacher S, Giannobile WV, Lynch SE (1997b) A phase I/II clinical trial to evaluate a combination of recombinant human platelet-derived growth factor-BB and recombinant human insulin-like growth factor-I in patients with periodontal disease. J Periodontol 68:1186–1193. doi:10.1902/jop.1997.68.12.1186
Hürzeler MB, Quiñones CR, Kirsch A, Schüpbach P, Krausse A, Strub JR, Caffesse RG (1997) Maxillary sinus augmentation using different grafting materials and dental implants in monkeys. Part III Evaluation of autogenous bone combined with porous hydroxyapatite. Clin Oral Implants Res 8:401–411
Iezzi G, Degidi M, Scarano A, Petrone G, Piattelli A (2007) Anorganic bone matrix retrieved 14 years after a sinus augmentation procedure: a histologic and histomorphometric evaluation. J Periodontol 78:2057–2061. doi:10.1902/jop.2007.070062
Isaksson S (1992) Aspects of bone healing and bone substitute incorporation. An experimental study in rabbit skull bone defects. Swed Dent J Suppl 84:1–46
Iturriaga MTM, Ruiz CC (2004) Maxillary sinus reconstruction with calvarium bone grafts and endosseous implants. J Oral Maxillofac Surg 62:344–347
Jakse N, Tangl S, Gilli R, Berghold A, Lorenzoni M, Eskici A, Haas R, Pertl C (2003) Influence of PRP on autogenous sinus grafts. An experimental study on sheep. Clin Oral Implants Res 14:578–583
Jensen OT (2006) The sinus bone graft, 2nd edn. Quintessence Pub Co, Chicago
Jensen J, Sindet-Pedersen S (1991) Autogenous mandibular bone grafts and osseointegrated implants for reconstruction of the severely atrophied maxilla: a preliminary report. J Oral Maxillofac Surg 49:1277–1287
Jensen SS, Terheyden H (2009) Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. Int J Oral Maxillofac Implants 24(Suppl):218–236
Jensen OT, Greer RO Jr, Johnson L, Kassebaum D (1995) Vertical guided bone-graft augmentation in a new canine mandibular model. Int J Oral Maxillofac Implants 10:335–344
Jensen OT, Shulman LB, Block MS, Iacono VJ (1998) Report of the sinus consensus conference of 1996. Int J Oral Maxillofac Implants 13(Suppl):11–45
Johansson B, Grepe A, Wannfors K (1998) CT- scan in assessing volumes of bone grafts to the heavily resorbed maxilla. Craniomaxillofac Surg 26:85
Jones CL, Witte DP, Feller MJ, Fugman DA, Dorn GW 2nd, Lieberman MA (1992) Response of a human megakaryocytic cell line to thrombin: increase in intracellular free calcium and mitogen release. Biochim Biophys Acta 1136:272–282
Julien M, Khairoun I, LeGeros RZ, Delplace S, Pilet P, Weiss P, Daculsi G, Bouler JM, Guicheux J (2007) Physico-chemical-mechanical and in vitro biological properties of calcium

phosphate cements with doped amorphous calcium phosphates. Biomaterials 28:956–965. doi:10.1016/j.biomaterials.2006.10.018

Kaaden OR (1994) Unconventional disease agents–a danger for humans and animals? Berl Munch Tierarztl Wochenschr 107:44–48

Kalk WW, Raghoebar GM, Jansma J, Boering G (1996) Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 54:1424–1429; discussion 1430

Kao ST, Scott DD (2007) A review of bone substitutes. Oral Maxillofac Surg Clin N Am 19:513–521, vi. doi:10.1016/j.coms.2007.06.002

Kao DWK, Kubota A, Nevins M, Fiorellini JP (2012) The negative effect of combining rhBMP-2 and Bio-Oss on bone formation for maxillary sinus augmentation. Int J Periodontics Restorative Dent 32:61–67

Kessler S, Mayr-Wohlfart U, Ignatius A, Puhl W, Claes L, Günther KP (2002) Histomorphological, histomorphometrical and biomechanical analysis of ceramic bone substitutes in a weight-bearing animal model. J Mater Sci Mater Med 13:191–195

Khang W, Feldman S, Hawley CE, Gunsolley J (2001) A multi-center study comparing dual acid-etched and machined-surfaced implants in various bone qualities. J Periodontol 72:1384–1390. doi:10.1902/jop.2001.72.10.1384

Kim Y-K, Yun P-Y, Kim S-G, Kim B-S, Ong JL (2009) Evaluation of sinus bone resorption and marginal bone loss after sinus bone grafting and implant placement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 107:e21–e28. doi:10.1016/j.tripleo.2008.09.033

Kirmeier R, Payer M, Wehrschuetz M, Jakse N, Platzer S, Lorenzoni M (2008) Evaluation of three-dimensional changes after sinus floor augmentation with different grafting materials. Clin Oral Implants Res 19:366–372. doi:10.1111/j.1600-0501.2007.01487.x

Klijn RJ, Meijer GJ, Bronkhorst EM, Jansen JA (2010a) A meta-analysis of histomorphometric results and graft healing time of various biomaterials compared to autologous bone used as sinus floor augmentation material in humans. Tissue Eng Part B Rev 16:493–507. doi:10.1089/ten.TEB.2010.0035

Klijn RJ, Meijer GJ, Bronkhorst EM, Jansen JA (2010b) Sinus floor augmentation surgery using autologous bone grafts from various donor sites: a meta-analysis of the total bone volume. Tissue Eng Part B Rev 16:295–303. doi:10.1089/ten.TEB.2009.0558

Knabe C, Koch C, Rack A, Stiller M (2008) Effect of beta-tricalcium phosphate particles with varying porosity on osteogenesis after sinus floor augmentation in humans. Biomaterials 29:2249–2258. doi:10.1016/j.biomaterials.2008.01.026

Kolerman R, Tal H, Moses O (2008) Histomorphometric analysis of newly formed bone after maxillary sinus floor augmentation using ground cortical bone allograft and internal collagen membrane. J Periodontol 79:2104–2111. doi:10.1902/jop.2008.080117

Kolerman R, Samorodnitzky-Naveh GR, Barnea E, Tal H (2012) Histomorphometric analysis of newly formed bone after bilateral maxillary sinus augmentation using two different osteoconductive materials and internal collagen membrane. Int J Periodontics Restorative Dent 32:e21–e28

Kübler N, Reuther J, Kirchner T, Priessnitz B, Sebald W (1993) Osteoinductive, morphologic, and biomechanical properties of autolyzed, antigen-extracted, allogeneic human bone. J Oral Maxillofac Surg 51:1346–1357

Kübler NR, Will C, Depprich R, Betz T, Reinhart E, Bill JS, Reuther JF (1999) Comparative studies of sinus floor elevation with autologous or allogeneic bone tissue. Mund- Kiefer-Gesichtschirurgie MKG 3(Suppl 1):S53–60

Kumar A, Jaffin RA, Berman C (2002) The effect of smoking on achieving osseointegration of surface-modified implants: a clinical report. Int J Oral Maxillofac Implants 17:816–819

Kusiak JF, Zins JE, Whitaker LA (1985) The early revascularization of membranous bone. Plast Reconstr Surg 76:510–516

Landesberg R, Moses M, Karpatkin M (1998) Risks of using platelet rich plasma gel. J Oral Maxillofac Surg 56:1116–1117

Lazzara RJ, Testori T, Trisi P, Porter SS, Weinstein RL (1999) A human histologic analysis of osseotite and machined surfaces using implants with 2 opposing surfaces. Int J Periodontics Restorative Dent 19:117–129

Leghissa GC, Zaffe D, Assenza B, Botticelli AR (1999) Guided bone regeneration using titanium grids: report of 10 cases. Clin Oral Implants Res 10:62–68

Linder BL, Chernoff A, Kaplan KL, Goodman DS (1979) Release of platelet-derived growth factor from human platelets by arachidonic acid. Proc Natl Acad Sci U S A 76:4107–4111

Lisignoli G, Zini N, Remiddi G, Piacentini A, Puggioli A, Trimarchi C, Fini M, Maraldi NM, Facchini A (2001) Basic fibroblast growth factor enhances in vitro mineralization of rat bone marrow stromal cells grown on non-woven hyaluronic acid based polymer scaffold. Biomaterials 22:2095–2105

Lorenzetti M, Mozzati M, Campanino PP, Valente G (1998) Bone augmentation of the inferior floor of the maxillary sinus with autogenous bone or composite bone grafts: a histologic-histomorphometric preliminary report. Int J Oral Maxillofac Implants 13:69–76

Lucarelli E, Fini M, Beccheroni A, Giavaresi G, Di Bella C, Aldini NN, Guzzardella G, Martini L, Cenacchi A, Di Maggio N, Sangiorgi L, Fornasari PM, Mercuri M, Giardino R, Donati D (2005) Stromal stem cells and platelet-rich plasma improve bone allograft integration. Clin Orthop 435:62–68

Lundgren S, Moy P, Johansson C, Nilsson H (1996) Augmentation of the maxillary sinus floor with particulated mandible: a histologic and histomorphometric study. Int J Oral Maxillofac Implants 11:760–766

Lundgren AK, Lundgren D, Hämmerle CH, Nyman S, Sennerby L (2000) Influence of decortication of the donor bone on guided bone augmentation. An experimental study in the rabbit skull bone. Clin Oral Implants Res 11:99–106

Lundgren S, Andersson S, Sennerby L (2003) Spontaneous bone formation in the maxillary sinus after removal of a cyst: coincidence or consequence? Clin Implant Dent Relat Res 5:78–81

Lundgren S, Andersson S, Gualini F, Sennerby L (2004) Bone reformation with sinus membrane elevation: a new surgical technique for maxillary sinus floor augmentation. Clin Implant Dent Relat Res 6:165–173

Lundgren S, Cricchio G, Palma VC, Salata LA, Sennerby L (2008) Sinus membrane elevation and simultaneous insertion of dental implants: a new surgical technique in maxillary sinus floor augmentation. Periodontol 2000(47):193–205. doi:10.1111/j.1600-0757.2008.00264.x

Lynch SE, Colvin RB, Antoniades HN (1989a) Growth factors in wound healing. Single and synergistic effects on partial thickness porcine skin wounds. J Clin Invest 84:640–646. doi:10.1172/JCI114210

Lynch SE, Williams RC, Polson AM, Howell TH, Reddy MS, Zappa UE, Antoniades HN (1989b) A combination of platelet-derived and insulin-like growth factors enhances periodontal regeneration. J Clin Periodontol 16:545–548

Manferdini C, Guarino V, Zini N, Raucci MG, Ferrari A, Grassi F, Gabusi E, Squarzoni S, Facchini A, Ambrosio L, Lisignoli G (2010) Mineralization behavior with mesenchymal stromal cells in a biomimetic hyaluronic acid-based scaffold. Biomaterials 31:3986–3996. doi:10.1016/j.biomaterials.2010.01.148

Margolin MD, Cogan AG, Taylor M, Buck D, McAllister TN, Toth C, McAllister BS (1998) Maxillary sinus augmentation in the non-human primate: a comparative radiographic and histologic study between recombinant human osteogenic protein-1 and natural bone mineral. J Periodontol 69:911–919. doi:10.1902/jop.1998.69.8.911

Marthy S, Richter M (1998) Human immunodeficiency virus activity in rib allografts. J Oral Maxillofac Surg 56:474–476

Marx RE, Carlson ER, Eichstaedt RM, Schimmele SR, Strauss JE, Georgeff KR (1998) Platelet-rich plasma: growth factor enhancement for bone grafts. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:638–646

Mastrogiacomo M, Muraglia A, Komlev V, Peyrin F, Rustichelli F, Crovace A, Cancedda R (2005) Tissue engineering of bone: search for a better scaffold. Orthod Craniofac Res 8:277–284. doi:10.1111/j.1601-6343.2005.00350.x

Meijndert L, Raghoebar GM, Schüpbach P, Meijer HJA, Vissink A (2005) Bone quality at the implant site after reconstruction of a local defect of the maxillary anterior ridge with chin bone or deproteinised cancellous bovine bone. Int J Oral Maxillofac Surg 34:877–884. doi:10.1016/j.ijom.2005.04.017

Mellonig JT, Bowers GM, Cotton WR (1981) Comparison of bone graft materials. Part II New bone formation with autografts and allografts: a histological evaluation. J Periodontol 52:297–302. doi:10.1902/jop.1981.52.6.297

Merkx MAW, Maltha JC, Stoelinga PJW (2003) Assessment of the value of anorganic bone additives in sinus floor augmentation: a review of clinical reports. Int J Oral Maxillofac Surg 32:1–6. doi:10.1054/ijom.2002.0346

Minichetti JC, D'Amore JC, Hong AYJ, Cleveland DB (2004) Human histologic analysis of mineralized bone allograft (Puros) placement before implant surgery. J Oral Implant 30:74–82. doi:10.1563/0.693.1

Miyadera K, Sumizawa T, Haraguchi M, Yoshida H, Konstanty W, Yamada Y, Akiyama S (1995) Role of thymidine phosphorylase activity in the angiogenic effect of platelet derived endothelial cell growth factor/thymidine phosphorylase. Cancer Res 55:1687–1690

Möhle R, Green D, Moore MA, Nachman RL, Rafii S (1997) Constitutive production and thrombin-induced release of vascular endothelial growth factor by human megakaryocytes and platelets. Proc Natl Acad Sci U S A 94:663–668

Moore WR, Graves SE, Bain GI (2001) Synthetic bone graft substitutes. ANZ J Surg 71: 354–361

Moy PK, Lundgren S, Holmes RE (1993) Maxillary sinus augmentation: histomorphometric analysis of graft materials for maxillary sinus floor augmentation. J Oral Maxillofac Surg 51:857–862

Naik B, Karunakar P, Jayadev M, Marshal VR (2013) Role of Platelet rich fibrin in wound healing: a critical review. J Conserv Dent 16:284–293. doi:10.4103/0972-0707.114344

Nevins M, Camelo M, Nevins ML, Schenk RK, Lynch SE (2003) Periodontal regeneration in humans using recombinant human platelet-derived growth factor-BB (rhPDGF-BB) and allogenic bone. J Periodontol 74:1282–1292. doi:10.1902/jop.2003.74.9.1282

Nevins M, Giannobile WV, McGuire MK, Kao RT, Mellonig JT, Hinrichs JE, McAllister BS, Murphy KS, McClain PK, Nevins ML, Paquette DW, Han TJ, Reddy MS, Lavin PT, Genco RJ, Lynch SE (2005) Platelet-derived growth factor stimulates bone fill and rate of attachment level gain: results of a large multicenter randomized controlled trial. J Periodontol 76:2205–2215. doi:10.1902/jop.2005.76.12.2205

Nevins M, Garber D, Hanratty JJ, McAllister BS, Nevins ML, Salama M, Schupbach P, Wallace S, Bernstein SM, Kim DM (2009) Human histologic evaluation of anorganic bovine bone mineral combined with recombinant human platelet-derived growth factor BB in maxillary sinus augmentation: case series study. Int J Periodontics Restorative Dent 29:583–591

Nkenke E, Stelzle F (2009) Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. Clin Oral Implants Res 20(Suppl 4):124–133. doi:10.1111/j.1600-0501.2009.01776.x

Nkenke E, Schultze-Mosgau S, Radespiel-Tröger M, Kloss F, Neukam FW (2001) Morbidity of harvesting of chin grafts: a prospective study. Clin Oral Implants Res 12:495–502

Nkenke E, Radespiel-Tröger M, Wiltfang J, Schultze-Mosgau S, Winkler G, Neukam FW (2002) Morbidity of harvesting of retromolar bone grafts: a prospective study. Clin Oral Implants Res 13:514–521

Nkenke E, Weisbach V, Winckler E, Kessler P, Schultze-Mosgau S, Wiltfang J, Neukam FW (2004) Morbidity of harvesting of bone grafts from the iliac crest for preprosthetic augmentation procedures: a prospective study. Int J Oral Maxillofac Surg 33:157–163. doi:10.1054/ijom.2003.0465

Noshi T, Yoshikawa T, Ikeuchi M, Dohi Y, Ohgushi H, Horiuchi K, Sugimura M, Ichijima K, Yonemasu K (2000) Enhancement of the *in vivo* osteogenic potential of marrow/hydroxyapatite composites by bovine bone morphogenetic protein. J Biomed Mater Res 52:621–630

Noumbissi SS, Lozada JL, Boyne PJ, Rohrer MD, Clem D, Kim JS, Prasad H (2005) Clinical, histologic, and histomorphometric evaluation of mineralized solvent-dehydrated bone allograf (Puros) in human maxillary sinus grafts. J Oral Implantol 31:171–179. doi:10.1563/1548-1336(2005)31[171:CHAHEO]2.0.CO;2

Palma VC, Magro-Filho O, de Oliveria JA, Lundgren S, Salata LA, Sennerby L (2006) Bone reformation and implant integration following maxillary sinus membrane elevation: an experimental study in primates. Clin Implant Dent Relat Res 8:11–24. doi:10.2310/j.6480.2005.00026.x

Papa F, Cortese A, Maltarello MC, Sagliocco R, Felice P, Claudio PP (2005) Outcome of 50 consecutive sinus lift operations. Br J Oral Maxillofac Surg 43:309–313. doi:10.1016/j.bjoms.2004.08.027

Pappalardo S, Guarnieri R (2013) Efficacy of platelet-rich-plasma (PRP) and highly purified bovine xenograft (Laddec(®)) combination in bone regeneration after cyst enucleation: radiological and histological evaluation. J Oral Maxillofac Res 4:e3. doi:10.5037/jomr.2012.4303

Pejrone G, Lorenzetti M, Mozzati M, Valente G, Schierano GM (2002) Sinus floor augmentation with autogenous iliac bone block grafts: a histological and histomorphometrical report on the two-step surgical technique. Int J Oral Maxillofac Surg 31:383–388. doi:10.1054/ijom.2002.0286

Peleg M, Garg AK, Misch CM, Mazor Z (2004) Maxillary sinus and ridge augmentations using a surface-derived autogenous bone graft. J Oral Maxillofac Surg 62:1535–1544

Petrungaro PS, Amar S (2005) Localized ridge augmentation with allogenic block grafts prior to implant placement: case reports and histologic evaluations. Implant Dent 14:139–148

Piattelli A, Scarano A, Corigliano M, Piattelli M (1996a) Comparison of bone regeneration with the use of mineralized and demineralized freeze-dried bone allografts: a histological and histochemical study in man. Biomaterials 17:1127–1131

Piattelli A, Scarano A, Mangano C (1996b) Clinical and histologic aspects of biphasic calcium phosphate ceramic (BCP) used in connection with implant placement. Biomaterials 17:1767–1770

Piattelli M, Favero GA, Scarano A, Orsini G, Piattelli A (1999) Bone reactions to anorganic bovine bone (Bio-Oss) used in sinus augmentation procedures: a histologic long-term report of 20 cases in humans. Int J Oral Maxillofac Implants 14:835–840

Piccinini M, Rebaudi A, Sglavo VM, Bucciotti F, Pierfrancesco R (2013) A new HA/TTCP material for bone augmentation: an *in vivo* histological pilot study in primates sinus grafting. Implant Dent 22:83–90. doi:10.1097/ID.0b013e31827afc19

Pierce GF, Mustoe TA, Lingelbach J, Masakowski VR, Griffin GL, Senior RM, Deuel TF (1989) Platelet-derived growth factor and transforming growth factor-beta enhance tissue repair activities by unique mechanisms. J Cell Biol 109:429–440

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35:216–240. doi:10.1111/j.1600-051X.2008.01272.x

Poumarat G, Squire P (1993) Comparison of mechanical properties of human, bovine bone and a new processed bone xenograft. Biomaterials 14:337–340

Quattlebaum JB, Mellonig JT, Hensel NF (1988) Antigenicity of freeze-dried cortical bone allograft in human periodontal osseous defects. J Periodontol 59:394–397. doi:10.1902/jop.1988.59.6.394

Quiñones CR, Hürzeler MB, Schüpbach P, Kirsch A, Blum P, Caffesse RG, Strub JR (1997) Maxillary sinus augmentation using different grafting materials and osseointegrated dental implants in monkeys. Part II Evaluation of porous hydroxyapatite as a grafting material. Clin Oral Implants Res 8:487–496

Reinert S, König S, Bremerich A, Eufinger H, Krimmel M (2003) Stability of bone grafting and placement of implants in the severely atrophic maxilla. Br J Oral Maxillofac Surg 41:249–255

Rios HF, Avila G, Galindo P, Bratu E, Wang H-L (2009) The influence of remaining alveolar bone upon lateral window sinus augmentation implant survival. Implant Dent 18:402–412. doi:10.1097/ID.0b013e3181b4af93

Roldán JC, Jepsen S, Schmidt C, Knüppel H, Rueger DC, Açil Y, Terheyden H (2004) Sinus floor augmentation with simultaneous placement of dental implants in the presence of platelet-rich plasma or recombinant human bone morphogenetic protein-7. Clin Oral Implants Res 15:716–723. doi:10.1111/j.1600-0501.2004.01070.x

Sánchez AR, Sheridan PJ, Kupp LI (2003) Is platelet-rich plasma the perfect enhancement factor? A current review. Int J Oral Maxillofac Implants 18:93–103

Sartori S, Silvestri M, Forni F, Icaro Cornaglia A, Tesei P, Cattaneo V (2003) Ten-year follow-up in a maxillary sinus augmentation using anorganic bovine bone (Bio-Oss). A case report with histomorphometric evaluation. Clin Oral Implants Res 14:369–372

Scharf, H. (1990). Humane Tibialis-anterior-Sehnen als lösungsmittelkonserciertes Transplantat für den Kreuzbandersatz. Universität Ulm, 23-28.
Scharf KE, Lawson W, Shapiro JM, Gannon PJ (1995) Pressure measurements in the normal and occluded rabbit maxillary sinus. Laryngoscope 105:570–574. doi:10.1288/00005537-199506000-00002
Schecroun N, Delloye C (2004) In vitro growth and osteoblastic differentiation of human bone marrow stromal cells supported by autologous plasma. Bone 35:517–524. doi:10.1016/j.bone.2004.03.029
Schenk RK, Buser D, Hardwick WR, Dahlin C (1994) Healing pattern of bone regeneration in membrane-protected defects: a histologic study in the canine mandible. Int J Oral Maxillofac Implants 9:13–29
Schepers EJ, Ducheyne P (1997) Bioactive glass particles of narrow size range for the treatment of oral bone defects: a 1–24 month experiment with several materials and particle sizes and size ranges. J Oral Rehabil 24:171–181
Schilling AF, Linhart W, Filke S, Gebauer M, Schinke T, Rueger JM, Amling M (2004) Resorbability of bone substitute biomaterials by human osteoclasts. Biomaterials 25:3963–3972. doi:10.1016/j.biomaterials.2003.10.079
Schlegel AK (1996) Bio-Oss bone replacement material. Long-term results with Bio-Oss bone replacement material. Schweiz Monatsschrift Für Zahnmed 106:141–149
Schlegel AK, Donath K (1998) BIO-OSS–a resorbable bone substitute? J Long Term Eff Med Implants 8:201–209
Schlegel KA, Fichtner G, Schultze-Mosgau S, Wiltfang J (2003) Histologic findings in sinus augmentation with autogenous bone chips versus a bovine bone substitute. Int J Oral Maxillofac Implants 18:53–58
Schmitt JM, Hwang K, Winn SR, Hollinger JO (1999) Bone morphogenetic proteins: an update on basic biology and clinical relevance. J Orthop Res 17:269–278. doi:10.1002/jor.1100170217
Schmitt CM, Doering H, Schmidt T, Lutz R, Neukam FW, Schlegel KA (2013) Histological results after maxillary sinus augmentation with Straumann® BoneCeramic, Bio-Oss®, Puros®, and autologous bone. A randomized controlled clinical trial. Clin Oral Implants Res 24:576–585. doi:10.1111/j.1600-0501.2012.02431.x
Schmitt CM, Moest T, Lutz R, Neukam FW, Schlegel KA (2014) Anorganic bovine bone (ABB) vs. autologous bone (AB) plus ABB in maxillary sinus grafting. A prospective non-randomized clinical and histomorphometrical trial. Clin Oral Implants Res. doi:10.1111/clr.12396
Schwartz Z, Somers A, Mellonig JT, Carnes DL Jr, Wozney JM, Dean DD, Cochran DL, Boyan BD (1998) Addition of human recombinant bone morphogenetic protein-2 to inactive commercial human demineralized freeze-dried bone allograft makes an effective composite bone inductive implant material. J Periodontol 69:1337–1345. doi:10.1902/jop.1998.69.12.1337
Simunek A, Kopecka D, Somanathan RV, Pilathadka S, Brazda T (2008) Deproteinized bovine bone versus beta-tricalcium phosphate in sinus augmentation surgery: a comparative histologic and histomorphometric study. Int J Oral Maxillofac Implants 23:935–942
Skoglund A, Hising P, Young C (1997) A clinical and histologic examination in humans of the osseous response to implanted natural bone mineral. Int J Oral Maxillofac Implants 12:194–199
Slotte C, Lundgren D (2002) Impact of cortical perforations of contiguous donor bone in a guided bone augmentation procedure: an experimental study in the rabbit skull. Clin Implant Dent Relat Res 4:1–10
Smiler DG, Holmes RE (1987) Sinus lift procedure using porous hydroxyapatite: a preliminary clinical report. J Oral Implantol 13:239–253
Smukler H, Barboza EP, Burliss C (1995) A new approach to regeneration of surgically reduced alveolar ridges in dogs: a clinical and histologic study. Int J Oral Maxillofac Implants 10:537–551
Sogal A, Tofe AJ (1999) Risk assessment of bovine spongiform encephalopathy transmission through bone graft material derived from bovine bone used for dental applications. J Periodontol 70:1053–1063. doi:10.1902/jop.1999.70.9.1053

Srouji S, Kizhner T, Ben David D, Riminucci M, Bianco P, Livne E (2009) The Schneiderian membrane contains osteoprogenitor cells: *in vivo* and in vitro study. Calcif Tissue Int 84:138–145. doi:10.1007/s00223-008-9202-x

Stach RM, Kohles SS (2003) A meta-analysis examining the clinical survivability of machined-surfaced and osseotite implants in poor-quality bone. Implant Dent 12:87–96

Stiller M, Kluk E, Bohner M, Lopez-Heredia MA, Müller-Mai C, Knabe C (2014) Performance of β-tricalcium phosphate granules and putty, bone grafting materials after bilateral sinus floor augmentation in humans. Biomaterials 35:3154–3163. doi:10.1016/j.biomaterials.2013.12.068

Summers BN, Eisenstein SM (1989) Donor site pain from the ilium. A complication of lumbar spine fusion. J Bone Joint Surg (Br) 71:677–680

Szabó G, Huys L, Coulthard P, Maiorana C, Garagiola U, Barabás J, Németh Z, Hrabák K, Suba Z (2005) A prospective multicenter randomized clinical trial of autogenous bone versus beta-tricalcium phosphate graft alone for bilateral sinus elevation: histologic and histomorphometric evaluation. Int J Oral Maxillofac Implants 20:371–381

Tadjoedin ES, de Lange GL, Lyaruu DM, Kuiper L, Burger EH (2002) High concentrations of bioactive glass material (BioGran) vs. autogenous bone for sinus floor elevation. Clin Oral Implants Res 13:428–436

Tal H, Pitaru S, Moses O, Kozlovsky A (1996) Collagen gel and membrane in guided tissue regeneration in periodontal fenestration defects in dogs. J Clin Periodontol 23:1–6

Tapety FI, Amizuka N, Uoshima K, Nomura S, Maeda T (2004) A histological evaluation of the involvement of Bio-Oss in osteoblastic differentiation and matrix synthesis. Clin Oral Implants Res 15:315–324. doi:10.1111/j.1600-0501.2004.01012.x

Tatum H Jr (1986) Maxillary and sinus implant reconstructions. Dent Clin N Am 30:207–229

Terheyden H, Jepsen S, Möller B, Tucker MM, Rueger DC (1999) Sinus floor augmentation with simultaneous placement of dental implants using a combination of deproteinized bone xenografts and recombinant human osteogenic protein-1. A histometric study in miniature pigs. Clin Oral Implants Res 10:510–521

Thompson ID, Hench LL (1998) Mechanical properties of bioactive glasses, glass-ceramics and composites. Proc Inst Mech Eng H 212:127–136

Togawa D, Bauer TW, Lieberman IH, Sakai H (2004) Lumbar intervertebral body fusion cages: histological evaluation of clinically failed cages retrieved from humans. J Bone Joint Surg Am 86-A:70–79

Tong DC, Rioux K, Drangsholt M, Beirne OR (1998) A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 13:175–182

Tosta M, Cortes ARG, Corrêa L, Pinto DDS Jr, Tumenas I, Katchburian E (2013) Histologic and histomorphometric evaluation of a synthetic bone substitute for maxillary sinus grafting in humans. Clin Oral Implants Res 24:866–870. doi:10.1111/j.1600-0501.2011.02384.x

Tuli SM, Singh AD (1978) The osteoninductive property of decalcified bone matrix. An experimental study. J Bone Joint Surg (Br) 60:116–123

Urist MR, Strates BS (1971) Bone morphogenetic protein. J Dent Res 50:1392–1406

Valentini P, Abensur D (1997) Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): a clinical study of 20 patients. Int J Periodontics Restorative Dent 17:232–241

Valentini P, Abensur DJ (2003) Maxillary sinus grafting with anorganic bovine bone: a clinical report of long-term results. Int J Oral Maxillofac Implants 18:556–560

Valentini P, Abensur D, Densari D, Graziani JN, Hämmerle C (1998) Histological evaluation of Bio-Oss in a 2-stage sinus floor elevation and implantation procedure. A human case report. Clin Oral Implants Res 9:59–64

Van den Bergh JP, ten Bruggenkate CM, Groeneveld HH, Burger EH, Tuinzing DB (2000) Recombinant human bone morphogenetic protein-7 in maxillary sinus floor elevation surgery in 3 patients compared to autogenous bone grafts. A clinical pilot study. J Clin Periodontol 27:627–636

Wallace SS, Froum SJ (2003) Effect of maxillary sinus augmentation on the survival of endosseous dental implants. Ann Periodontol Am Acad Periodontol 8:328–343. doi:10.1902/annals.2003.8.1.328

Wallace SS, Froum SJ, Tarnow DP (1996) Histologic evaluation of a sinus elevation procedure: a clinical report. Int J Periodontics Restorative Dent 16:46–51

Wallace SS, Froum SJ, Cho S-C, Elian N, Monteiro D, Kim BS, Tarnow DP (2005) Sinus augmentation utilizing anorganic bovine bone (Bio-Oss) with absorbable and nonabsorbable membranes placed over the lateral window: histomorphometric and clinical analyses. Int J Periodontics Restorative Dent 25:551–559

Wang J, Chen W, Li Y, Fan S, Weng J, Zhang X (1998) Biological evaluation of biphasic calcium phosphate ceramic vertebral laminae. Biomaterials 19:1387–1392

Watzek G, Weber R, Bernhart T, Ulm C, Haas R (1998) Treatment of patients with extreme maxillary atrophy using sinus floor augmentation and implants: preliminary results. Int J Oral Maxillofac Surg 27:428–434

Weibrich G, Trettin R, Gnoth SH, Götz H, Duschner H, Wagner W (2000) Determining the size of the specific surface of bone substitutes with gas adsorption. Mund-Kiefer-Gesichtschirurgie MKG 4:148–152

Wetzel AC, Stich H, Caffesse RG (1995) Bone apposition onto oral implants in the sinus area filled with different grafting materials. A histological study in beagle dogs. Clin Oral Implants Res 6:155–163

Wheeler SL, Holmes RE, Calhoun CJ (1996) Six-year clinical and histologic study of sinus-lift grafts. Int J Oral Maxillofac Implants 11:26–34

Whittaker JM, James RA, Lozada J, Cordova C, GaRey DJ (1989) Histological response and clinical evaluation of heterograft and allograft materials in the elevation of the maxillary sinus for the preparation of endosteal dental implant sites. Simultaneous sinus elevation and root form implantation: an eight-month autopsy report. J Oral Implantol 15:141–144

Wildemann B, Kadow-Romacker A, Haas NP, Schmidmaier G (2007) Quantification of various growth factors in different demineralized bone matrix preparations. J Biomed Mater Res A 81:437–442. doi:10.1002/jbm.a.31085

Winter AA, Pollack AS, Odrich RB (2003) Sinus/alveolar crest tenting (SACT): a new technique for implant placement in atrophic maxillary ridges without bone grafts or membranes. Int J Periodontics Restorative Dent 23:557–565

Wood RM, Moore DL (1988) Grafting of the maxillary sinus with intraorally harvested autogenous bone prior to implant placement. Int J Oral Maxillofac Implants 3:209–214

Wozney JM, Rosen V, Celeste AJ, Mitsock LM, Whitters MJ, Kriz RW, Hewick RM, Wang EA (1988) Novel regulators of bone formation: molecular clones and activities. Science 242:1528–1534

Xu H, Shimizu Y, Asai S, Ooya K (2003) Experimental sinus grafting with the use of deproteinized bone particles of different sizes. Clin Oral Implants Res 14:548–555

Yamada S, Heymann D, Bouler JM, Daculsi G (1997) Osteoclastic resorption of biphasic calcium phosphate ceramic in vitro. J Biomed Mater Res 37:346–352

Yukna R, Salinas TJ, Carr RF (2002) Periodontal regeneration following use of ABM/P-1 5: a case report. Int J Periodontics Restorative Dent 22:146–155

Zerbo IR, Bronckers ALJJ, de Lange G, Burger EH (2005) Localisation of osteogenic and osteoclastic cells in porous beta-tricalcium phosphate particles used for human maxillary sinus floor elevation. Biomaterials 26:1445–1451. doi:10.1016/j.biomaterials.2004.05.003

Zijderveld SA, Zerbo IR, van den Bergh JPA, Schulten EAJM, ten Bruggenkate CM (2005) Maxillary sinus floor augmentation using a beta-tricalcium phosphate (Cerasorb) alone compared to autogenous bone grafts. Int J Oral Maxillofac Implants 20:432–440

Zimmermann G, Moghaddam A (2011) Allograft bone matrix versus synthetic bone graft substitutes. Injury 42(Suppl 2):S16–S21. doi:10.1016/j.injury.2011.06.199

Zins JE, Whitaker LA (1983) Membranous versus endochondral bone: implications for craniofacial reconstruction. Plast Reconstr Surg 72:778–785

8 Complications of Maxillary Sinus Bone Augmentation: Prevention and Management

Bahige Tourbah and Harry Maarek

Contents

B. Tourbah (✉)
Private Practice in Oral Implantology, Oral and Maxillofacial Surgery Clinic, Montpellier, France
e-mail: bahigetourbah@gmail.com

H. Maarek
Department of Otolaryngology-Head and Neck Surgery, Pitie Salpetriere Hospital, Paris, France
e-mail: hmaarek001@rss.fr

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_8

8.1 Introduction

Although sinus augmentation of the posterior maxilla is nowadays considered as a reliable and safe technique, it is still subject to endosinus complications. These complications may jeopardize the implant treatment planning with persistence in some cases of endosinus sequelae. The peroperative and postoperative complications and their proper management are discussed below.

8.2 Peroperative Complications

8.2.1 Sinus Membrane Perforation

During sinus lifting, the elevation of the Schneiderian membrane is a delicate procedure. This membrane is considered as a barrier for the protection of the sinus cavity. To reduce the risk of infections and optimize clinical outcomes in terms of bone regeneration, care must be taken to preserve its integrity (Proussaefs et al. 2004; Wiltfang et al. 2000).

The perforation of the Schneiderian membrane represents the major intraoperative complication of maxillary sinus augmentation (Proussaefs et al. 2004; Schwartz-Arad et al. 2004).

8.2.1.1 Prevalence

Its *prevalence* during lateral window approach ranges from 3.6 to as high as 56 % (Schwartz-Arad et al. 2004; Wallace et al. 2007; Toscano et al. 2010). The incidence rates vary considerably between different reports because of the different surgical techniques used and the capacity to diagnose a perforated membrane. Through a small window, the visual access is limited so the integrity of the membrane is more difficult to evaluate. While using autologous bone block graft to create a new sinus floor (or performing a top-hinge-trap-door technique), the membrane perforation is less regarded so the surgeon is less cautious and perforations occur more frequently. Wallace et al. (2007) and Toscano et al. (2010) have shown that the use of piezoelectric instruments is related to a lesser percentage of perforations.

Viewing this disparity in the rates reported in the literature, we might consider that frequently the perforations remain undetected.

8.2.1.2 Perforation Diagnosis

The most reliable way to *detect a perforation* remains the direct visual inspection.

Valsalva maneuver should be considered with care and even avoided. It can cause a perforation in the presence of a very thin membrane or enlarge a small perforation if the patient blows hard. It is not reliable because sometimes Valsalva maneuver is negative even though the Schneiderian membrane is perforated.

Another way that is proposed by surgeons is to see the elevated membrane movement while the patient is breathing from his nose. This technique is harmless but not always precise because sometimes even with an intact membrane the amplitude of the membrane movement is very small. Postoperative radiologic

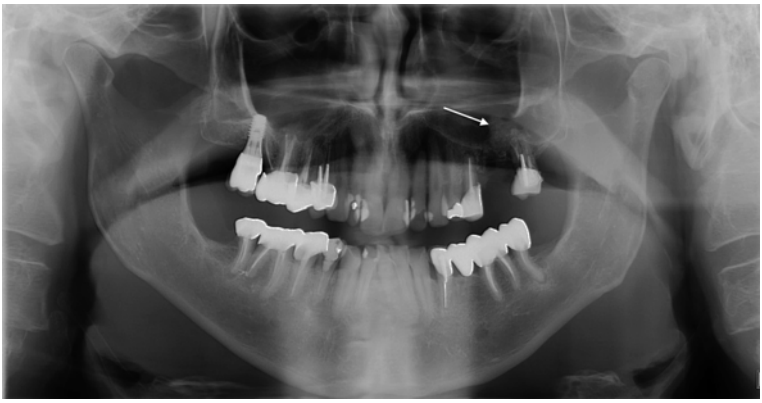


Fig. 8.1 Biomaterial leakage in the maxillary sinus lumen due to an undetected membrane perforation

examination with a periapical X-ray, a panoramic radiography, or a CBCT can be helpful after the surgery to check if there is a leakage of the biomaterial or if it is compact. Leakage means that the membrane is perforated and the biomaterial flowed into the sinus cavity (Fig. 8.1). It is not recommended to search with an instrument for a perforation, but rather to inspect visually the membrane through the window. If blood clot forming in the sinus interferes with the visibility, we can remove the clot using wet gauze or a special suction tip. Gently rinsing the sinus floor with saline allows better visual inspection and permits to detect a perforation if the amount of liquid flowing through the sinus is important. Endoscopically assessed sinus grafting is useful for detecting precisely any membrane perforation, but this technique is more invasive and time-consuming and necessitates two surgeons (Garbacea et al 2012). It is important to discover any potential perforation; even a small undetected and untreated perforation can pose a postoperative risk.

Direct visual inspection is the best way to detect a perforation.

The movement of the elevated membrane movement while the patient is breathing from his nose gives an idea if the membrane is perforated.

Postoperative radiologic examination with a periapical X-ray, a panoramic radiography, or a CBCT can be helpful after the surgery to check if there is a leakage of the biomaterial.

8.2.1.3 Timing of the Perforation

During *the surgery a perforation could appear at any of these stages.* During bone window trepanation if the bur passes through the bone and reaches the membrane, it can either perforate it or injure it. The use of a diamond bur when approaching to the membrane lessens this risk. The piezoelectric device has been proven to be safer

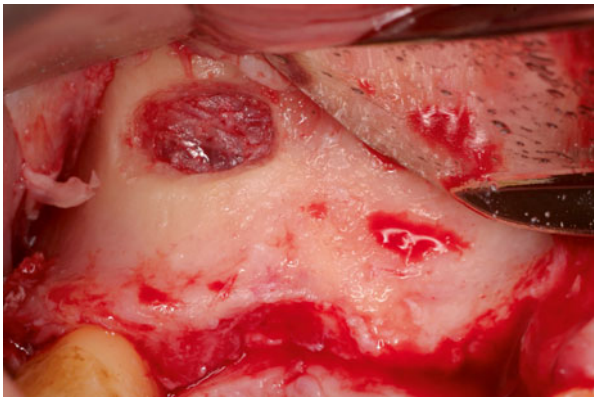


Fig. 8.2 A small lateral window has the advantage to be more conservative for the surrounding bone but allows restricted visual access to the elevated membrane

(Wallace et al. 2007), considering that the diamond-coated tips do not harm the soft tissue. Following osteotomy if the bony window is to be removed, care should be taken not to tear the membrane when detaching it. Moreover, perforations can be associated with the use of air-driven high-speed rotary instruments. Anyway, dental turbines, which are always air-driven, should not be used in surgery also because of their risk of subcutaneous air emphysema. According to some authors, perforations occur more frequently during osteotomy than during the reflection of the membrane (Vlassis and Fugazzotto 1999). Reflecting the sinus membrane remains a delicate step of sinus floor elevation. The tension applied by the instrument on the sinus membrane, the buccopalatal depth of the sinus cavity, the ease of access, the thickness of the membrane, and especially the presence of septa are all factors that can complicate membrane reflection. A very delicate pressure is applied on the membrane, and without resistance the movement is repeated with small amplitude and slowly progressed. In sinuses with important buccopalatal width, the access to the medial or palatonasal wall is difficult, long neck curettes must be used, and it is crucial to keep the instrument in tight contact with the bone to prevent membrane tearing. Incomplete elevation of the sinus membrane from the medial wall is considered unfavorable for bone revascularization and remodeling.

The size of the window is a factor to be considered. If it is too small (Fig. 8.2) in order to be tissue conservative, the visual and mechanical access to the sinus is restricted, the movements of the curette are more limited, and the identification of a perforation is difficult. Sinus septa are the major cause for membrane perforation and will be discussed later. Under general anesthesia, the airways are under positive pressure, the sinus membrane is inflated, more care must be taken, and the risk of piercing seems more probable than under local anesthesia.

If simultaneous implant placement is planned, drilling the residual alveolar crest must be done with care in order not to perforate the membrane when the drill passes the sinus floor. A curette can be helpful to maintain the membrane high and far from the drill.

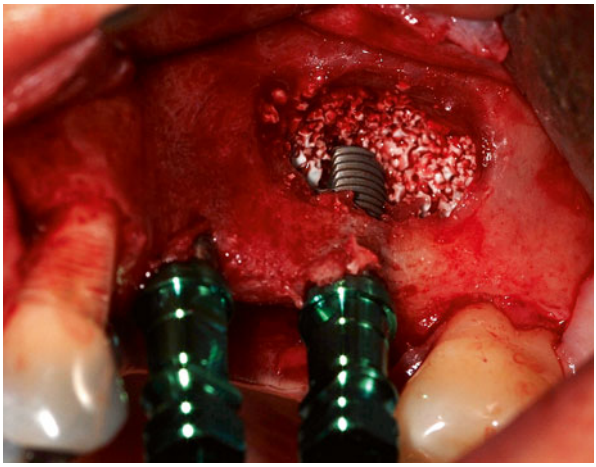


Fig. 8.3 Bone grafting the palatal side before implant placement

When the bone substitutes are introduced inside the sinus, there is a risk of microlacerating the membrane especially if the edges of the biomaterial are sharp. If the quantity of biomaterial filled in the cavity is very important while the surface of the elevated membrane is small, the pressure applied on the membrane can fragilize it or tear it.

If simultaneous implantation is planned, the sinus is first partially grafted by bone substitutes at the palatal side followed by implant placement before completing the grafting procedure (Fig. 8.3). Otherwise the implant insertion after complete bone substitute filling will augment the risk of tension on the membrane and perforate it intra- or postoperatively.

Membrane perforations occur during osteotomy and the reflection of the membrane.

Keep the instrument in tight contact with the bone to prevent membrane tearing.

Factors that can increase the risk of membrane perforation are (Becker et al. 2008):

- Septa
- Thin membrane
- Soft tissue adhesion
- Previous entrance into the sinus
- Cyst/sinus pathology
- Operator error
- Overfilling with the graft material

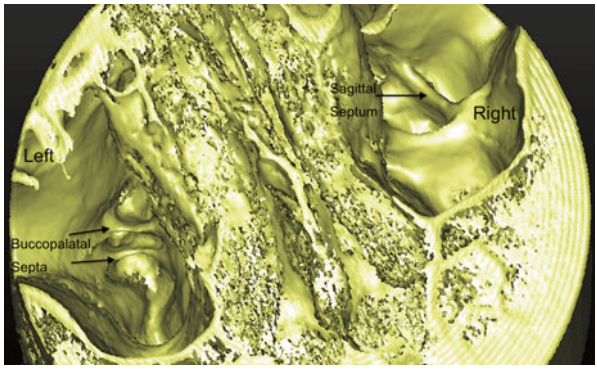


Fig. 8.4 3D reconstruction of a CT scan. Upper view of the two maxillary sinuses. Presence of two transverse (buccopalatal) septa in the left sinus and a sagittal septum in the right sinus

8.2.1.4 Septa

The anatomy of the maxillary sinus cavity is variable. On the internal walls, we often observe a bone crest in relation to dental roots, acute angles, or especially septa. These irregularities are considered to be a real challenge during sinus grafting. The thorough preoperative examination of anatomical structures is always vital to prevent intraoperative or postoperative sinus complications. Antral septa were first analyzed and studied by the anatomist Arthur S. Underwood in 1910. Considered insignificant by clinicians for decades, they have gained importance since the beginnings of sinus floor grafting. Krennmair et al. (1999) classified septa into primary and secondary. The primary septa arise from the development of the maxilla and tooth eruption and are congenital, whereas the secondary septa are said to arise from the irregular pneumatization of the sinus floor following tooth loss and are acquired. Secondary bony septa can be considered residues between two zones of different resorption rate. Therefore, it can be said that the septa above the teeth are primary and the septa above an edentulous ridge are primary or secondary.

Septa prevalence is significantly higher in edentulous ridges compared with dentate ridges (Pommer et al. 2012). 28.4 % of sinuses contain at least one septum. No gender difference could be observed. The most frequent location (54.6 %) of septa is apical to first or second maxillary molar regions. It is very rare (0.3 %) to have a complete septum that divide completely the sinus into two separate cavities. Most of septa are incomplete and their mean height is 7.5 mm.

For a clinical purpose, it is extremely important to explore the orientation of the septum in order to decide how it will be managed during sinus floor grafting. Septa could be transverse (buccopalatal) in 87.6 %, sagittal (mesiodistal) in 11.1 %, or horizontal (parallel to the sinus floor) in 1.3 % (Fig. 8.4).

The use of 2D radiography for sinus examination and septa diagnosis prior to sinus floor augmentation is insufficient and give incorrect interpretations. Sagittal septa are not diagnosable on panoramic radiographs. The position, inclination, and height of the transverse septa are inaccurate on panoramic radiographs (Fig. 8.5). In order to have a complete knowledge of the anatomy of the sinus and to reduce complications related to septa, 3D radiography must be done (Fig. 8.4). The precise

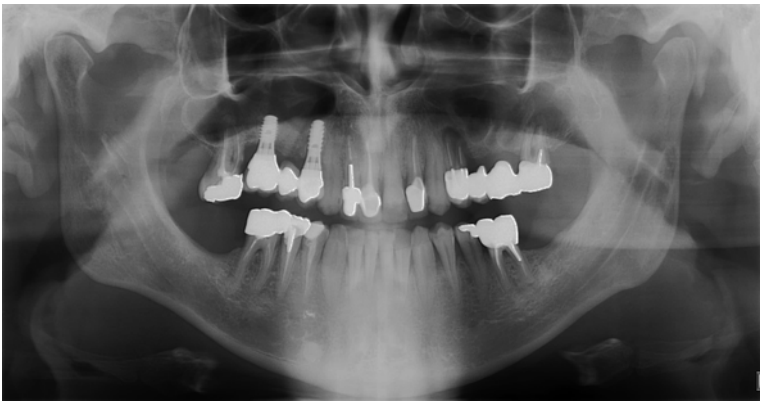


Fig. 8.5 Same patient of Fig. 8.4. On the panoramic radiograph, the sagittal septum in the right sinus cannot be seen and the buccopalatal septa in the left sinus are visible

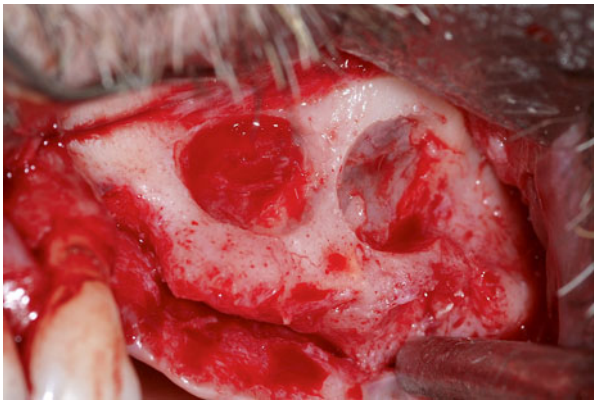


Fig. 8.6 In the presence of a septum, two lateral windows could be necessary

study of the coronal and Panorex reconstructed images allows the operator to conduct correctly the grafting procedure.

Once the septa presence and configuration are well underlined, the surgical access strategy can be adopted. In presence of a transverse septum, the buccal window design is modified: two windows can be made (Fig. 8.6), one anterior and one posterior to the septum, and the membrane elevated till the tip of the septum but not lifted among its cranial part. If the septum is low, one W-shaped window can be made, and the membrane must be elevated from the cranial part of the septum. When septa are present, it is advised not to invert the buccal bone plate. Luxation of the window into the sinus and lifting of the membrane can tear the membrane stuck between the different bone borders. Cutting the septa with a chisel or a piezoelectric device and removing it with forceps can be done in order to eliminate this obstacle, but during this manipulation, a membrane perforation is very likely.

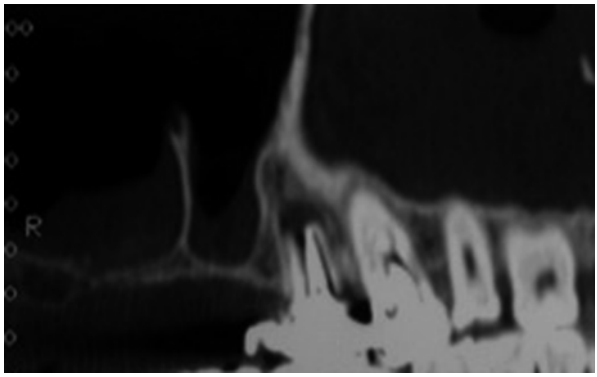


Fig. 8.7 Presence of a high septum

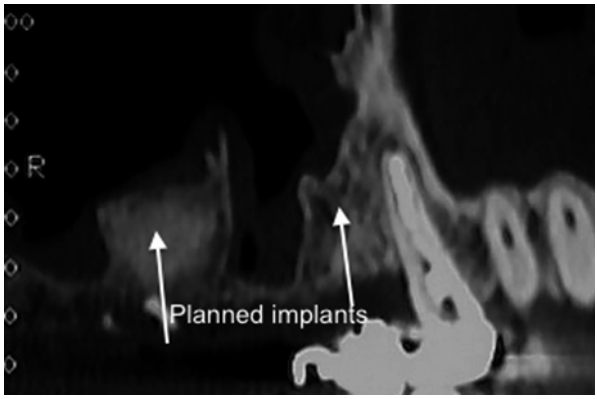


Fig. 8.8 The sinus was grafted distally to the septum and the implants will be placed in this grafted site (first molar) and the first premolar site. The two implants support a three-unit fixed prosthesis.

If the septum is high and sagittal, grafting only the lateral portion of the sinus cavity (laterally to the septum), as if the sinus anatomy is internally narrow, will be the safer therapeutic approach, and the implants will have to be placed more buccally. In case of short sagittal septum, a large window will allow access and membrane elevation to both parts, lateral and medial part of the sinus. It is very delicate to overpass the cranial part of the septa.

Some septa might be too difficult to manage during sinus floor augmentation, so we must take into consideration to change implant positions, avoiding some sites and therefore avoiding the sinus grafting on these sites (Figs. 8.7 and 8.8). In other cases grafting is aborted due to septa positions, so alternatives for sinus floor augmentation are chosen.

The membrane perforation risk is higher when antral septa exist because of the technical difficulty to overpass the cranial border of the septa and especially because the Schneiderian membrane is always thinner over the septa. In fact Binali et al. (2013) found a negative relationship between the membrane thickness and the presence of septa.

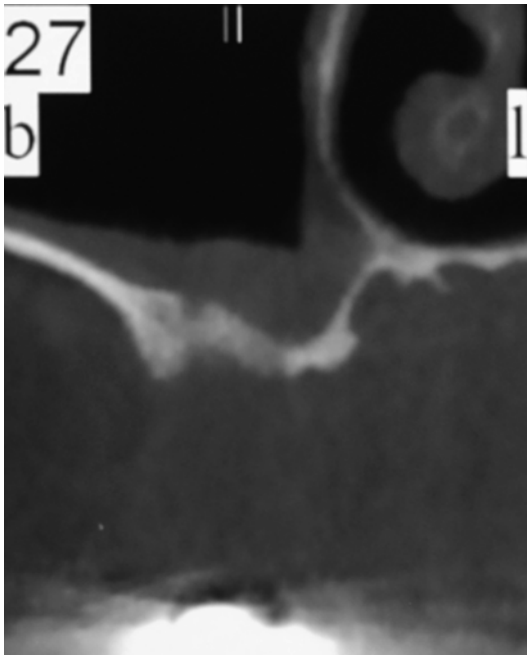


Fig. 8.9 Radiographic view of a thick Schneiderian mucosa lining the sinus floor

Explore the orientation and morphology of the septum on 3D radiography in order to know how to manage it.

Two windows or W-shaped window allows access to sinus when the septum is high and transverse.

Graft only the lateral portion of the sinus cavity when the septum is high and sagittal.

Schneiderian membrane is always thinner over the septa.

8.2.1.5 Membrane Thickness

Lacerations are most likely to occur if the sinus membrane is thin (Van der Bergh et al. 2000). The incidence of perforation is greater when the thickness is less than 1.5 mm. Preoperative *membrane thickness* evaluation through clinical and radiological evaluation is possible (Figs. 8.9 and 8.10). Authors have found positive correlation between periodontal phenotype and sinus mucosal thickness. Subjects with thick gingival architecture are likely to have a thick (>1.26 mm) sinus mucosa. Gingival thickness seems to be a reliable parameter to predict sinus membrane thickness.

Variations in the thickness of the Schneiderian membrane are due to the connective tissue layer. The epithelial lining contains two cell layers and is uniformly thick. Studies have found that thickness was higher in male than in female

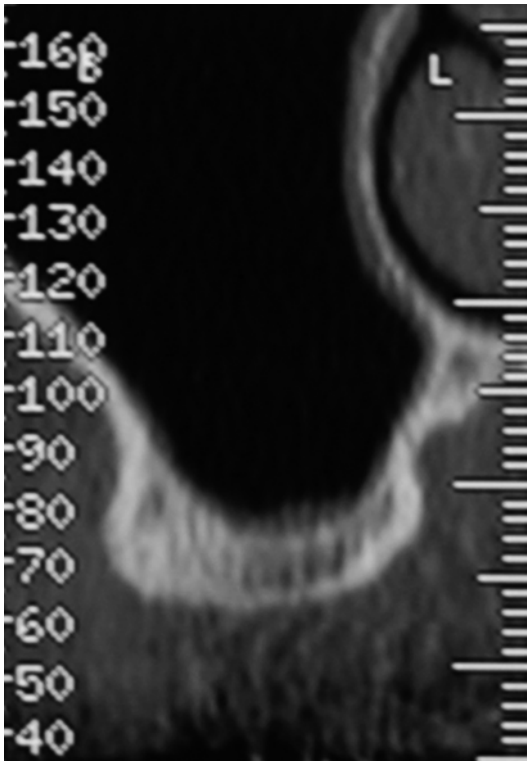


Fig. 8.10 Radiographic view of a thin sinus mucosa

patients and that only slight differences were assessed intraindividually (Havas et al. 1988).

Sinuses that already received a surgical entrance might have a membrane that is fused with the inner portion of the buccal flap (Figs. 8.10, 8.11, 8.12, 8.13, 8.14, and 8.15). The membrane can also clinically be hardened and thickened, with some portions containing residual graft particles (Fig. 8.16). Removal of the incorporated graft is almost impossible because the membrane and the residual graft had fused together. The sinus membrane must be separated from the inner portion of the flap by sharp dissection with the blade to the detriment of the buccal mucosa. The stiffened sinus membrane is then carefully elevated. Manipulation of the mucosa in these cases seems easier.

8.2.1.6 Perforations Management

Vlassis and Fugazzotto (1999) have classified perforations based on their size or on their location, and in 2003 they published a new classification based on the difficulty to repair. We will describe the most adapted ways to manage such complications.

When a perforation is detected, it is essential to evaluate the width of the bone window, and when necessary the outline of this window will be extended in order to reach intact membrane from where elevation can be initiated. The membrane

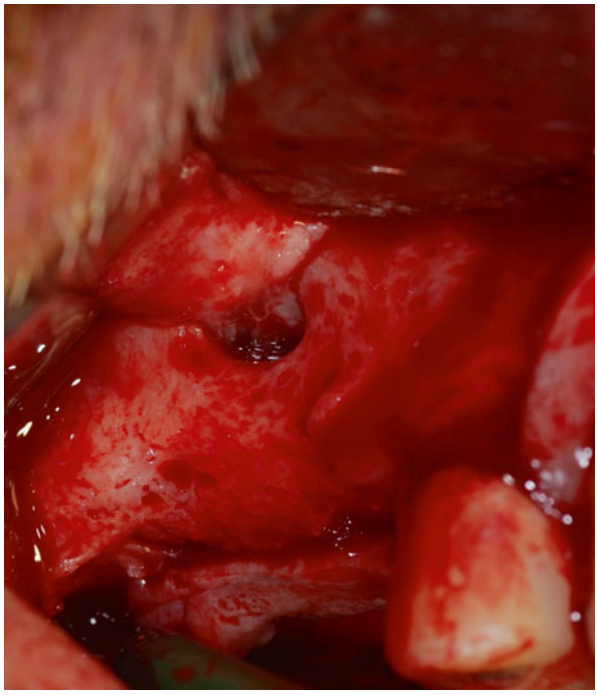


Fig. 8.11 The sinus and buccal mucosas are fused secondary to a gap in the maxillary bone. The origin of this gap is a previous periapical infection

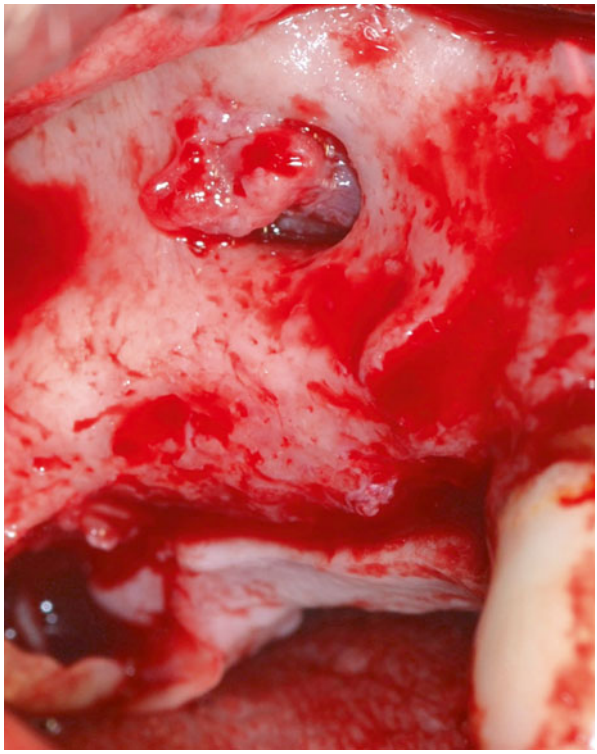


Fig. 8.12 Separation of the fusion with a blade to the detriment of the buccal mucosa. Care is taken not to cut the sinus membrane

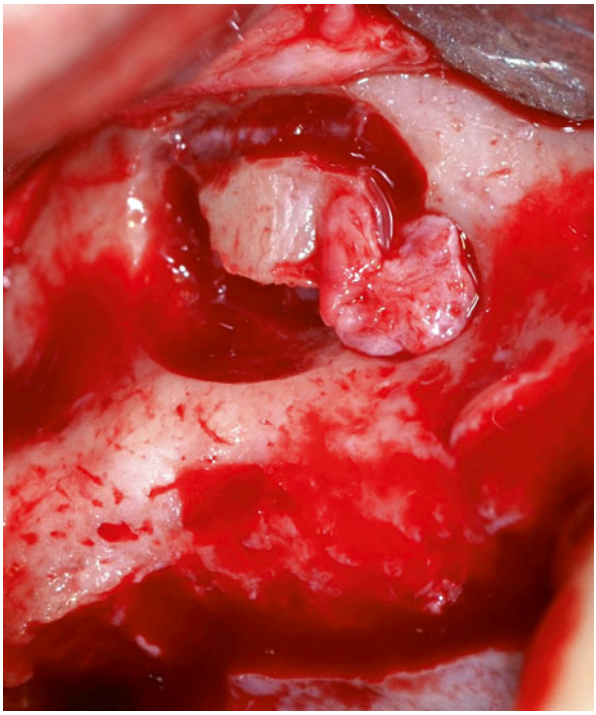


Fig. 8.13 Osteotomy of the lateral wall starts from the maxillary bone gap

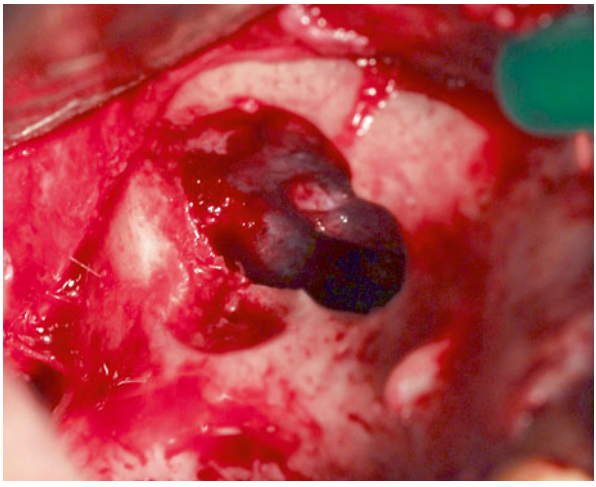


Fig. 8.14 After removal of the lateral window, the elevation of the stiffened sinus mucosa is completed

surrounding the perforation is delicately dissected with a blunt instrument. This elevation must be started far from the perforation in an attempt to relieve the tension on the tissue of the perforated area.

In *small* perforations (<5 mm), the membrane will fold on itself during the elevation. After complete elevation, an absorbable collagen wound dressing (photo CollaTape, Zimmer Dental Inc., Carlsbad, USA) is applied on the antral mucosa as reinforcement. Its adhesive properties make it easy to handle and to apply on the perforated membrane (Figs. 8.17 and 8.20). A platelet-rich fibrin membrane can

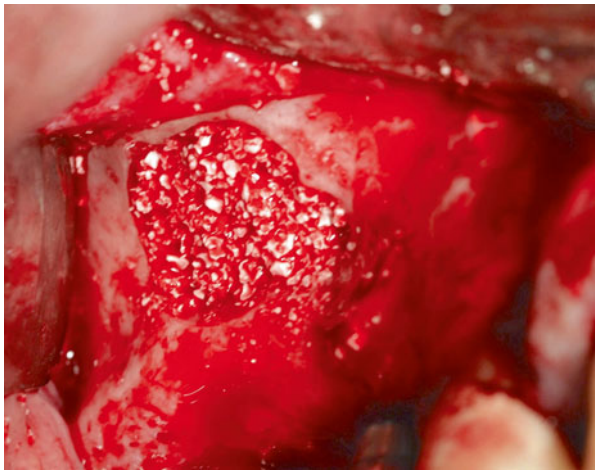


Fig. 8.15 Filling of the sinus floor with synthetic hydroxyapatite (Ingenios Zimmer Dental Inc., Carlsbad, USA)

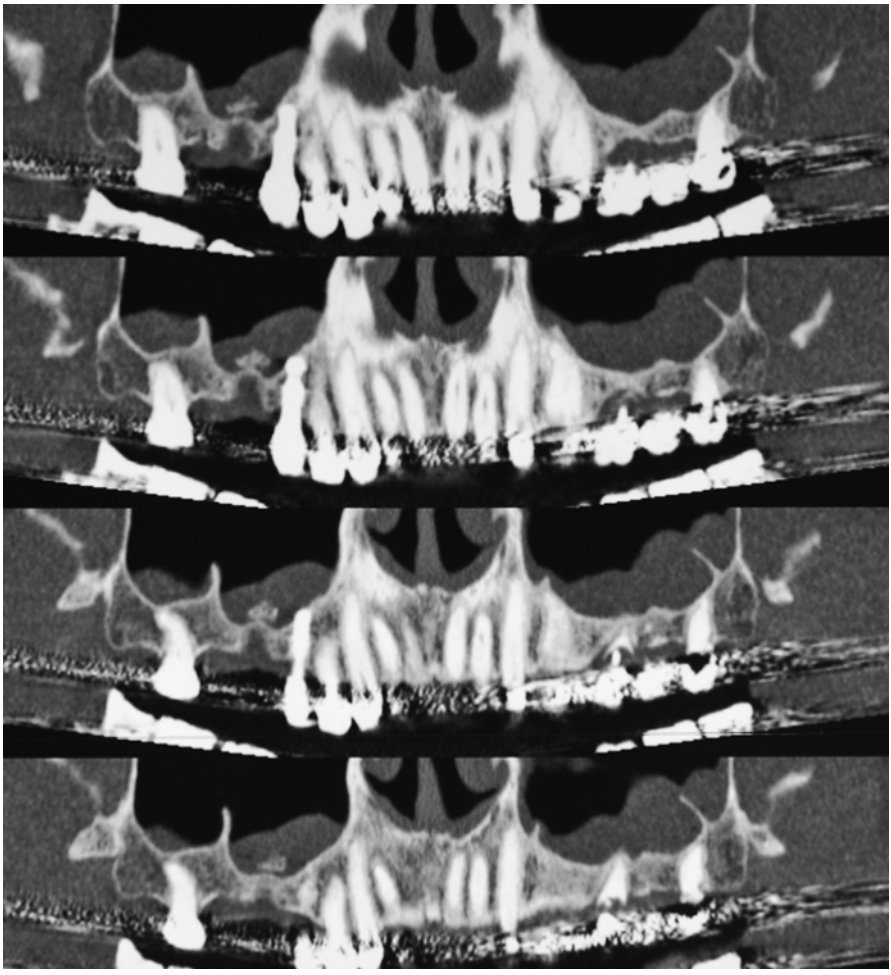


Fig. 8.16 Biomaterial particles incorporated in the sinus membrane secondary to a failed grafting attempt

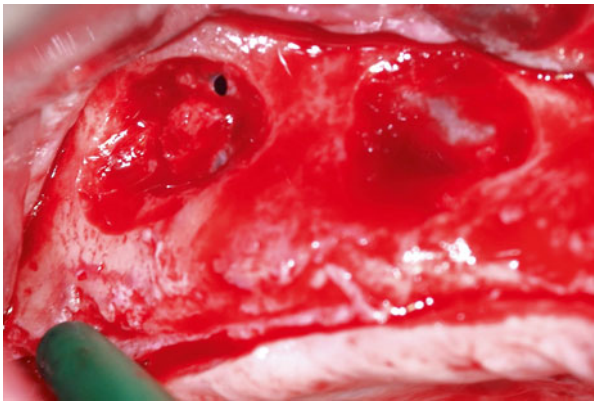


Fig. 8.17 A small perforation occurred during the osteotomy procedure

Fig. 8.18 CollaTape wound dressing (Zimmer Dental Inc., Carlsbad, USA)

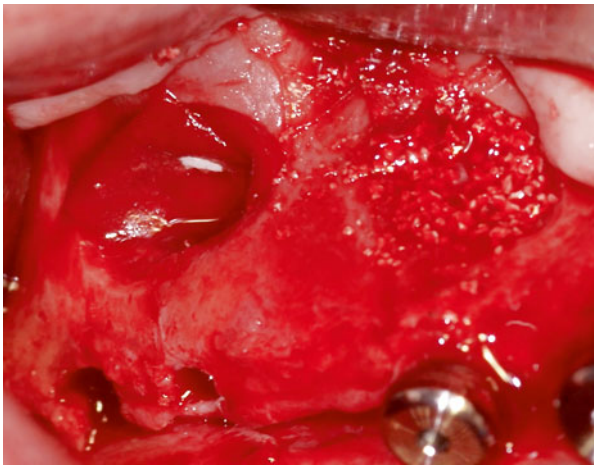


Fig. 8.19 The wound dressing covering the perforation after membrane elevation

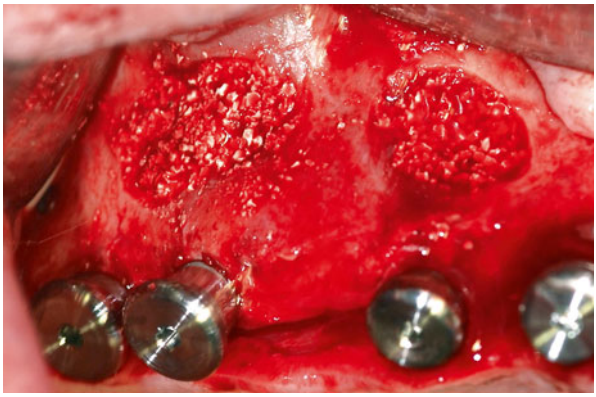


Fig. 8.20 Filling of the sinus floor and simultaneous implant placement

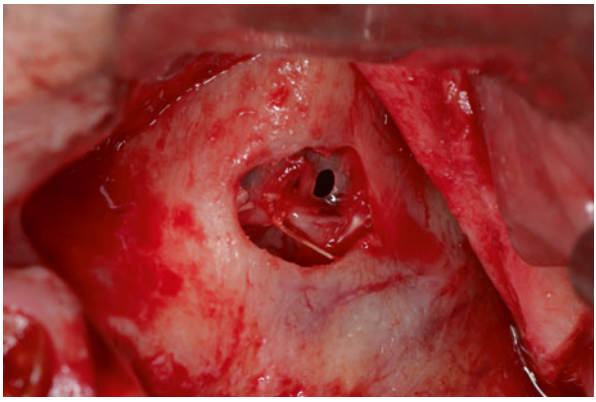


Fig. 8.21 Attempt to suture the perforated membrane

also be used in this same indication. Bone filling can then be continued. The use of a fibrin adhesive to seal a small perforation has been suggested by authors to be efficient (Choi et al. (2006)).

In *larger* perforations (5–10 mm), if after elevation of the membrane the perforation is still apparent, we can place an absorbable collagen membrane underneath the elevated sinus membrane to create a superior barrier to confine the grafts.

Suturing the perforation with a 6/0 Vicryl (Ethicon, Norderstedt, Germany) is a very difficult manipulation because of the inaccessibility and the mechanical proprieties of the mucosa lining that has tendency to dilaceration and subsequently to enlarge or create new perforations (Fig. 8.21).

Complete Tear. In the event of a large dilaceration, again the use of a large resorbable collagen membrane allows proper reparation.

This membrane will be placed on the medial wall of the sinus and then folded on the borders of the bone window from the upper and lower part as a new roof and floor. This pouch surrounds and isolates the bone graft (Proussaefs and Lozada 2003).

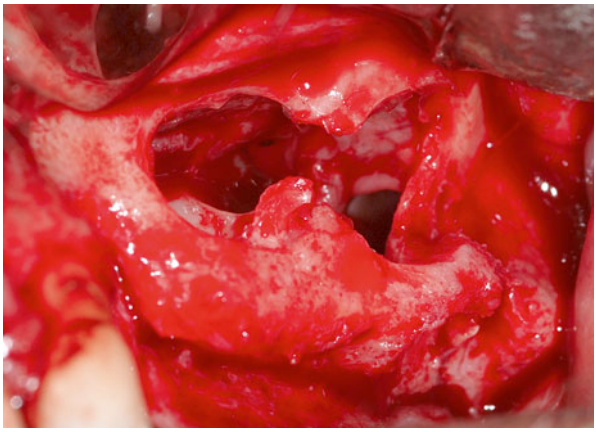


Fig. 8.22 The same patient in Fig. 8.4. During membrane elevation between the two sagittal septa, a large dilaceration of the membrane occurred

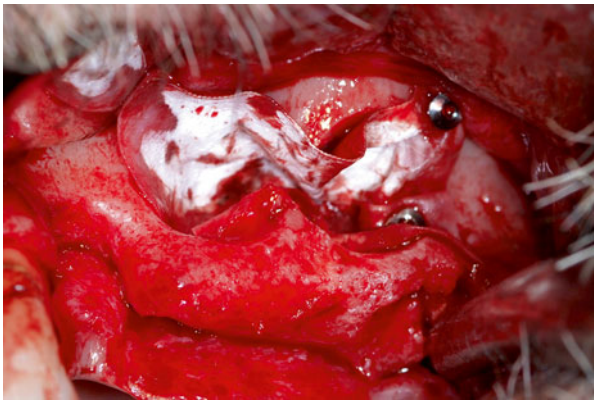


Fig. 8.23 A large resorbable collagen membrane (Copios Pericardium 30×40 mm, Zimmer Dental Inc., Carlsbad, USA) is placed on the medial wall of the sinus and then folded on the borders and stabilized with fixing pins

It is sometimes necessary to stabilize this membrane on the surrounding bone using fixing pins or resorbable sutures. However, this isolation using the pouch might have an adverse effect on the neovascularization and the remodeling of the graft (Figs. 8.22, 8.23, 8.24, and 8.25).

Otherwise a bone block harvested from the symphysis or the retromolar area can be placed and fixated as a roof for the graft. The major inconvenience is the additional time and surgical site that were not planned and unexpected by the patient. A pedicled buccal fat pad can also be used to restore the defect. It can be harvested quickly but meticulously from the infratemporal fossa through an incision of the periosteum. After blunt dissection of the buccinator muscle with a Metzenbaum scissors, the buccal fat pad is drawn out with Kelly forceps and placed against the membrane. It will isolate the sinus cavity from the graft material packed underneath it.

For all sinus grafting candidates and especially for those who had a perforation repaired, it is extremely important to emphasize on the postoperative care: not to blow their noses and to sneeze opening the mouth for 2 weeks after surgery (no scuba diving, no flying).

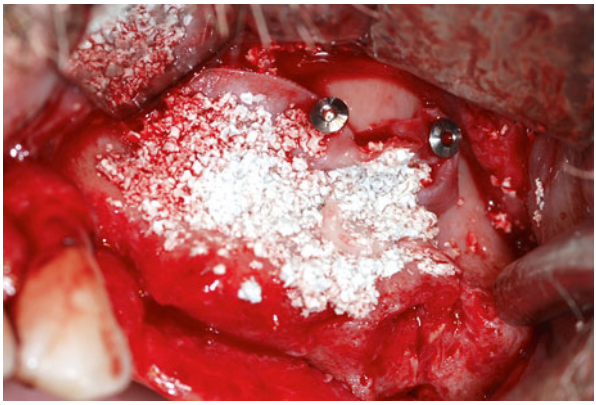


Fig. 8.24 Biomaterial filling in the pouch

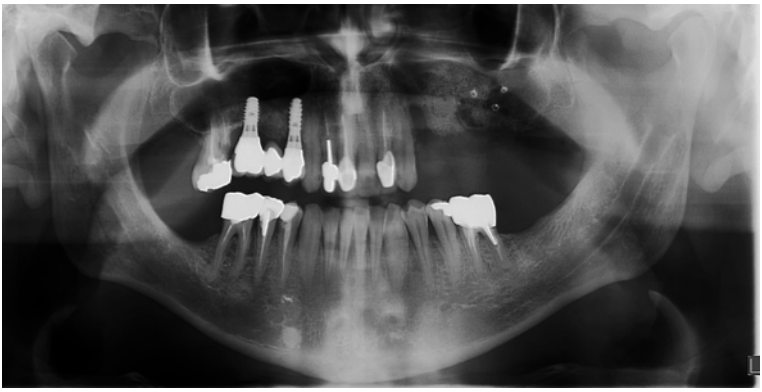


Fig. 8.25 Postoperative panoramic radiography showing the graft left maxillary sinus

At last the interruption of the procedure is recommended when the repair of a perforation seems difficult. Some authors (Schwartz-Arad et al. 2004; Pikos 2008; Lee et al. 2013) have postulated that there is no need to abort a sinus augmentation procedure in the event of a complete tear and that properly repaired sinus membrane perforation did not cause subsequent implant failure. In some cases, it is much easier and safer to abort grafting and program reentry at least six weeks later, in order to obtain a healed membrane.

8.2.1.7 Outcome

Considering its prevalence (20 %), perforation is a frequent complication; it is all the more important to evaluate *the outcome of sinus grafting after a perforation.*

Membrane perforation can be associated with the appearance of:

- Graft dislodgement into the sinus
- Obstruction of the osteomeatal apparatus
- Disruption of the normal sinus physiology

- Bacterial invasion
- Secondary acute or chronic infection
- Graft loss and/or failure
- Disturbance of the vascularization of the membrane and consequently of the neovascularization of the graft mass

Disrupted mucociliary apparatus function and loss of the biologic barrier owing to perforation of the membrane can increase sinus bacteria invasion and infection. The first step in managing infection is drainage and switching antibiotic regimens (to clindamycin or pristinamycin). If the infection persists, surgical debridement of infected bone and granulation tissue has to be performed.

The clinical significance of sinus membrane perforation is controversial. Multiple studies have shown an association between membrane perforation and acute sinusitis or graft infection or failure (Proussaefs et al. 2004; Schwartz-Arad et al. 2004; Jensen et al. 1998, Khoury et al. 1999), whereas others have shown no association between membrane integrity and infection or graft failure (Bornstein et al. 2008; Raghoebar et al. 2001; Becker et al. 2008; Jensen 1997). Repaired perforations have often an uneventful healing. Complete graft removal and drainage are seldom necessary because of acute postoperative infection. Due to infection a partial graft loss can be observed, but the remaining bone can be sufficient for implant placement. Patients can also report graft particle evacuation from the nasal fossae.

Data (Proussaefs and Lozada 2003; Khoury 1999) in the literature showed that in perforated membrane cases, the implant failure was significantly higher and vital bone formation lower. In contrast in other studies, there was no association between membrane perforations and implant survival rate (Schwartz-Arad et al. 2004; Fugazzotto and Vlassis 2003; Nkenke et al. 2002; Shlomi et al. 2004). However, extreme care should be taken when managing perforations, and close follow-up should be established in order to make an early diagnosis. When reparation seems difficult or impossible, the procedure should be abandoned in order to avoid serious postoperative complications.

Repaired perforations have often an uneventful healing.

Extreme care is taken when managing perforations and close follow-up is primordial. When reparation is impossible, the procedure is aborted. Reentry is planned after 3 months.

8.2.2 Hemorrhage/Bleeding

The second most frequent complication that could occur during sinus grafting is bleeding.

This bleeding can originate from the *spongious bone* of a thick lateral wall of the maxillary sinus. In this case, the bleeding is weak and do not generate any

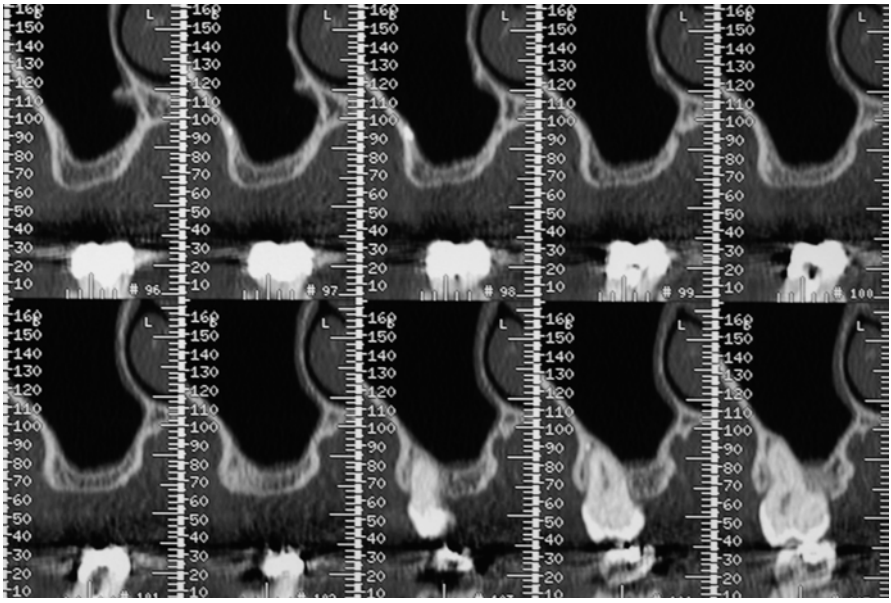


Fig. 8.26 This alveoloantral artery runs in the mucosa and cannot be seen on the CT scan

discomfort. It can impair visibility during the beginning of the surgery; then once the vasoconstriction due the local anesthesia is established, the surgery can be continued comfortably.

The *arterial bleeding* from the alveoloantral artery (AAA) is potentially a source of stress and complications for the practitioner and the patient.

The posterosuperior alveolar artery (PSAA) is responsible of the vascularization of the posterior maxilla, the posterior teeth, and adjacent soft tissues. It gives off two branches, the lateral one for the soft tissues (mucogingival artery, MGA) running outside the buccal bone under the periosteum and the medial one (alveoloantral artery, AAA) that penetrates the lateral wall of the maxillary bone in the molar region. This AAA runs till the anterior wall of the maxilla to anastomose with the infraorbital artery (IOA) (Solar et al. 1999; Hur et al. 2009; Yoshida et al. 2010). The AAA is the main blood supply for the lateral wall of the maxillary sinus (Ella et al. 2008). The AAA is constantly present and visible on all anatomic specimens.

8.2.2.1 AAA Trajectory

During its path the *AAA has two possible trajectories*:

A. It can be completely inside the maxillary sinus, in the thickness of the mucosa (Fig. 8.26 and 8.27).
B. Or it can have a partial intraosseous trajectory, invaginated in the lateral wall of the sinus, in its thickness (Figs 8.28 and 8.29).

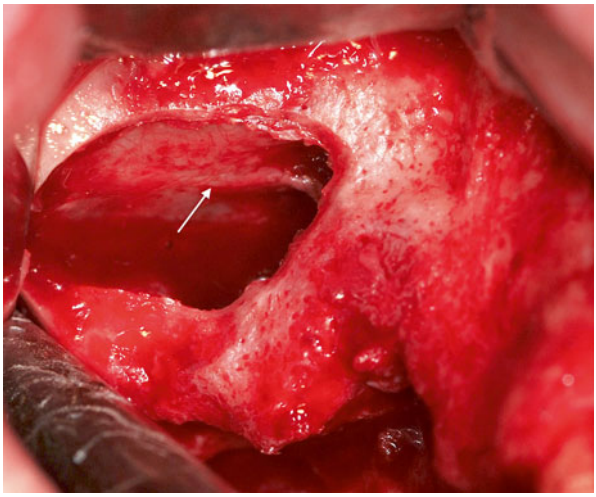


Fig. 8.27 This alveoloantral artery runs in the mucosa and is elevated safely within the mucosa

The trajectory of the AAA has a direct impact on the clinical management:

A. If the AAA is in the Schneiderian membrane, it cannot be seen on 3D radiography (Fig. 8.26) (computerized tomography (CT) scan or cone beam computerized tomography (CBCT)). Its position is in the membrane, so when elevating the membrane the artery will also be elevated without risk of severing it. It goes unnoticed clinically and radiologically, which means that even if we do not see the artery on the CBCT, this artery exists, but does not represent a risk of hemorrhage. The risk of severing the AAA when it is completely in the mucosa is almost impossible during the sinus lift grafting (Fig. 8.27).
B. When its trajectory is inside or invaginated in the lateral wall bone, the artery can be seen on CT scan or CBCT. We can follow its localization on the coronal planes or transversal views (Fig. 8.28), although it is rare to image a continuous canal from the maxillary tuberosity to the anterior part of the maxilla (Ella et al. 2008). While doing the osteotomy in order to access to the sinus cavity, there is a risk of lacerating the arterial wall. Cutting the artery will result in a significant, pulsatile bleeding.

If the AAA is in the Schneiderian membrane, it is not seen on CT scan, and it will be elevated without risk.

If the AAA is inside or invaginated in the lateral wall bone, it will be seen on CT scan, and there is a risk of injuring the arterial wall during the osteotomy.

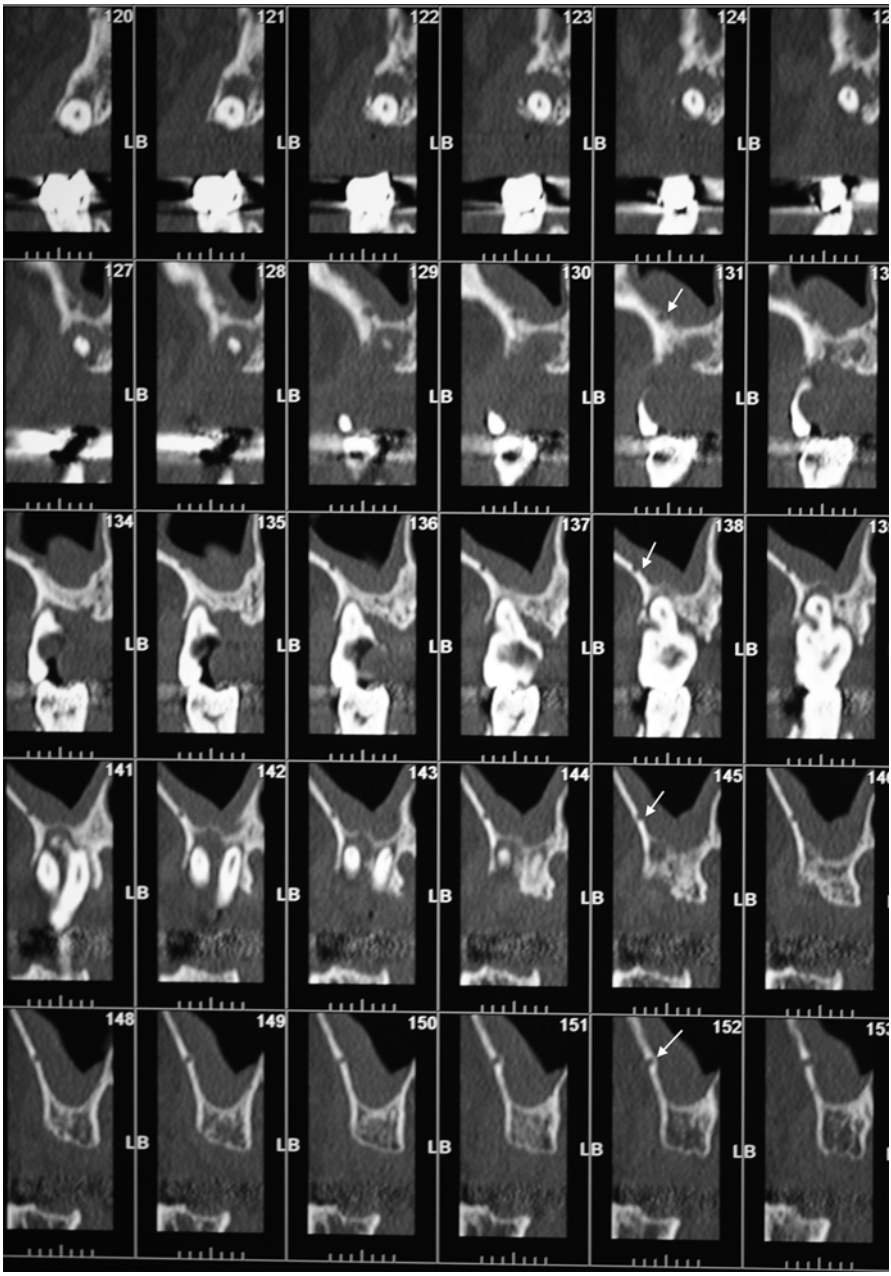


Fig. 8.28 This alveoloantral artery runs in the lateral wall bone and its path is clearly seen on the CT scan

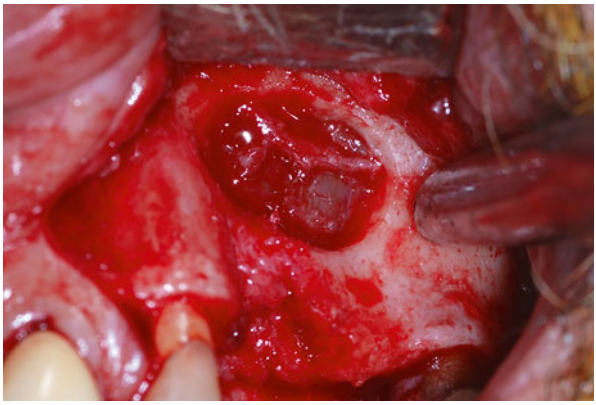


Fig. 8.29 This alveoloantral artery runs in the lateral wall bone. The bone around the alveoloantral artery is trimmed in order to reflect the mucosa freely

8.2.2.2 Artery Vertical Position

The *distance* of this artery was studied in cadaveric and radiographic publications. Its mean distance from the residual alveolar ridge in the first molar area (Elian et al. 2005; Mardinger et al. 2007) varies from 14.0 to 17.5 mm. Other authors measured the distance of the AAA from the sinus floor. These two measurements are directly influenced by factors as the presence or absence of teeth, the resorption rate, and the pneumatization of the sinus. The artery is closer to the ridge when the edentation is older. When the edentation is old, the bone resorption and the maxillary sinus pneumatization lead to a more crestal situation of this artery in which case it will be more difficult to avoid. The more the alveolar ridge is resorbed, the higher is the risk of severing the vessel during trepanation. The most caudal situation on the course of the AAA is in the first molar region where it coincides with the zygomatic process of the maxillary bone. And it is in this same area that the bone window is usually trepanated. The same studies have shown that 80 % of the AAA are located more than 15 mm from the alveolar crest. The osteotomy is generally made lower than 15 mm which lessens the probability of vascular complication.

8.2.2.3 Artery Diameter

The diameter of the canal in which the AAA runs was also studied.

This same canal contains also nerves, which means that the diameter of the artery is a bit narrower than the canal's diameter itself. The mean diameter range from 0.9 to 1.30 mm (Ella et al. 2008; Solar et al. 1999; Hur et al 2009). A diameter equal or greater than 2.0 mm is relatively rare, 4 to 7 % in the literature (Mardinger et al. 2007). Bleeding of a small artery (<2.0 mm) is usually resolved spontaneously. The limited size of the artery and the reactive vasoconstriction lower the blood flow. And the bleeding stops progressively. When the diameter exceeds 2.0 mm, there is a higher risk of hemorrhage, because the vasoconstriction itself isn't enough when the artery has a large diameter. However, this bleeding is not life-threatening. It can cause fright and stress for the surgeon, making it difficult to conduct the surgery. The visual impairment can cause a membrane perforation and can interfere with

placement of the graft material. Bleeding, if not well stabilized, will exaggerate the postoperative swelling and hematoma, create a hemosinus, or flush out the graft material.

Bleeding of a small artery (<2.0 mm) resolves spontaneously.
When the diameter exceeds 2.0 mm, there is a higher risk of hemorrhage.

8.2.2.4 Surgical Guidelines to Avoid and Manage an AAA

The best way to manage an AAA is to avoid it. During the treatment planning, the radiological examination is a crucial step. On the coronal and transversal planes, the artery is looked for on the lateral wall of the sinus. When it is identified, its position is measured in order to prepare the bony window below it as often as possible. The estimation of the diameter allows an evaluation of the bleeding amount. If the diameter of the artery is really large (>2 mm) and the experience of the practician limited in oral surgery, the sinus graft must be aborted and referred to an experienced surgeon. Pulsatile bleeding under local anesthesia in the dental office might frighten the surgeon. When the canal is not observed, this can be related to the fact that the canal is very small and is beyond the resolution of the device (Elian et al. 2005; Mardinger et al. 2007) or to the fact that the artery is completely adherent to the sinus membrane. In this last situation, there is no risk of severing it. So generally before the surgery and thanks to the 3D radiography, the risk of hemorrhage is predicted and measures are taken to manage it. A piezoelectric instrument can be utilized to trim bone around the intraosseous artery in order to free the artery from the canal without injuring the arterial walls (Fig. 8.29). If a bur touches an artery, it lacerates it, causing a significant bleeding. Head elevation and direct firm pressure must be the first reaction of the surgeon. The compression is applied with a compress soaked with tranexamic acid, a periodontal probe can also be used and inserted in the canal, and finally the placement of a bone wax or even the particulate grafting material into the AAA canal can stop bleeding. Once the bleeding is controlled, the membrane elevation can be continued, and the cavity filled. After 15 min the compression can be loosened (Flanagan 2005). Usually, the filling material exerts enough pressure to maintain the artery's walls sealed. If bleeding continues or if there is a doubt about the hemostasis, then another manipulation is necessary to ensure an enduring hemostasis. This is done by electrocauterization or direct ligation. The bipolar electrocoagulation is done directly on the artery in the canal and repeated until the bleeding is completely stopped. If not available, the electrocauterization will be substituted by ligation of the artery prior to the laceration. The ligature with a slow resorbable suture will go around the artery through small perforations made in the lateral wall bone above and below the canal with a thin bur. Once tightened, the ligature must stop the bleeding; this method is not very reliable because the artery is surrounded by bone. In order not to tear the sinus membrane ligature, an electrocauterization must be done, whenever it is possible, after the elevation is completed.

Authors agree that severing the AAA will not result in a life-threatening hemorrhage and is well managed by experienced oral surgeons on patients with normal hemostasis. The main inconvenience remains the alteration of the visibility. It is assumed that the outcome from a severed artery can be an incomplete vascularization and insufficient bone remodeling. If the hemorrhage is not well controlled, postoperative delayed secondary vasodilatation will result in important bleeding leading to hematoma, hemosinus, and even flushing out of the graft. Hemosinus can affect the sinus clearance which might provoke sinusitis and compromise the graft outcome.

After radiographic visualization of the AAA, the bony window is prepared below its trajectory.

When inevitable, the bone around the intraosseous artery is trimmed in order to free the artery from the canal.

In case of bleeding, head elevation and direct firm pressure must be applied with a compress soaked with tranexamic acid during 15 min.

Bone wax or grafting material into the AAA canal stops the bleeding.

Electrocauterization or direct ligation is helpful in case of important hemorrhage.

8.2.3 Buccal Bone Fracture

While placing the implants simultaneously to a lateral sinus elevation, the buccal bone is weakened by the lateral window and the drilling of the implant site (Fig. 8.3).

Implant insertion can provoke fractures of the residual buccal bone plate. These fractures are vertical and most frequently non-displaced. The bone cracks but maintains its stability. No additional treatment is necessary (Fig. 8.30). In some cases, the fracture is displaced, bone parts brake, and they are not lined up straight. In these cases the mobilized buccal bone can be resorbed, exposing the implant surface; it is recommended to cover it with biomaterial and a membrane to let it heal properly. There is also a risk of losing the implant's primary stability. The implant should be removed and replaced after healing.

In some patients, lateral wall is extremely thin and can be crushed if the pressure applied by the retractor is important.

8.2.4 Nonachievement of Primary Stability

Simultaneous implant placement is possible whenever there is a residual crest height of 3 to 4 mm. No higher failure rate was found in the literature (Wallace and Froum 2003; Del Fabbro et al. 2004). Undersizing the implant site enhances primary stability, especially in bone with poor density. The use of osteotomes to condense laterally the recipient site, augmenting bone density, improves the primary

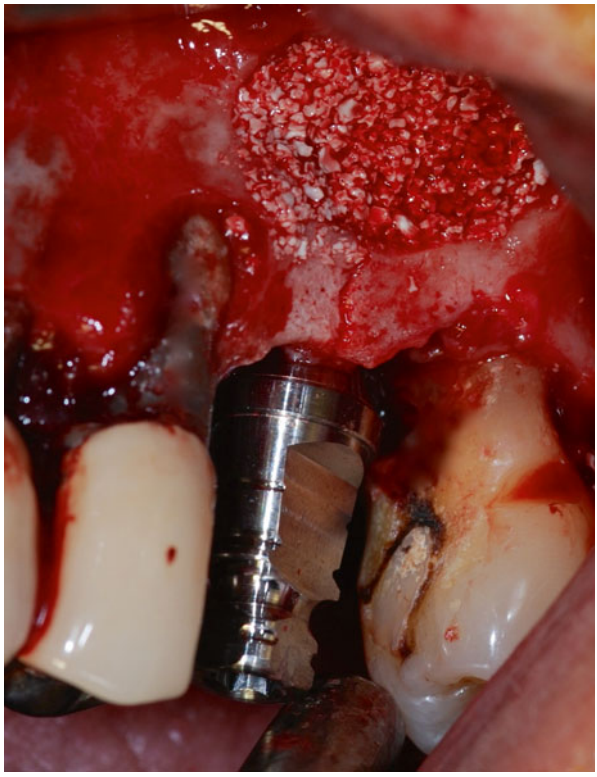


Fig. 8.30 Buccal bone fracture after implant insertion, the implant, and the bone borders are stable. Tapered implants with multiple threads are preferable when simultaneous implantation is planned because of their enhanced primary stability (AdVent Implant, Zimmer Dental Inc., Carlsbad, USA)

stability. The primary stability is also affected by the implant's geometry, surface, and threads. When placing the implants simultaneously, it is recommended to use adapted implants. If this cannot be achieved, implant placement should be abandoned and done in a second-stage surgery. Poor primary stability can be an origin for non-osseointegration or implant dislocation through the maxillary sinus.

8.2.5 Infraorbital Nerve Injury

The infraorbital nerve emerges at approximately 10 mm beneath the inferior border of the orbit, on the arterial wall of the maxillary sinus. Its innervation area extends vertically from the inferior eyelid to the superior lip, laterally from the ala of the nose to the anterior part of the cheek, sagittally from the periosteum till the skin. Nerve branches run in the nasolabial fold. These nerves can inadvertently be cut if a high incision release is made in the canine region or be damaged if periosteal elevation is done very high till the infraorbital foramina, or even by the squeeze of the retractor. Release incisions in the canine region should not be very vertical, but rather oblique anteriorly in order to avoid these fibers. During flap reflection, there is no need to reach the infraorbital foramina. A trapezoidal flap allows a good visual

access of the surgical site. Making a full-thickness flap and positioning the retractor on the bone surface help avoid damaging the soft tissues and especially nervous fibers.

8.3 Postoperative Complications

8.3.1 Bleeding Complications

A postoperative sinus hemorrhage is observed in case of perforation of the sinus mucosa or involvement of intraosseous alveolar artery anastomoses of a diameter greater than 1.5 mm (Mardinger et al. 2007). This sinus hemorrhage is drained into the nasal cavity and is reflected by an epistaxis of variable duration, from a few hours to a few days, and is rarely abundant enough to require endonasal wicking. Only sinuses with prior obstruction of the ostiomeatal complex expose their sinus hemorrhages to superinfection.

8.3.2 Graft Leak

8.3.2.1 Endosinus Graft Leak

This is the result of an unnoticed perforation of the sinus mucosa (crestal filling) or one that is inadequately repaired. The evolution of grafts extruded into the sinus depends on the quantity of grafts in question, their size, and the possibility of sinus drainage.

In most cases, extruded grafts alter the drainage function of the mucosa and lead to a reaction sinusitis or even confined sinusitis in case of deposit and ostial obstruction by these grafts. More rarely, some extruded grafts may be positioned in contact with the sinus mucosa, without alteration of the sinus physiology, and do not require ablation (Fig. 8.31).

8.3.2.2 Vestibular Graft Leak

Only vestibular suture dehiscences with complete disruption (4 % of the series; Baccar et al. 2005) are associated with graft extrusion by the flap of the osteotomy, requiring regular local care (antiseptic instillation) under cover of oral antibiotics, to guide the directed reepithelialization, while screening for incipient infection of the grafts (Fig. 8.32). The patient should be informed of a possible re-intervention to address excessive leaking of the grafts.

8.3.3 Wound Opening

Wound opening after lateral sinus elevation is a rare complication when no other augmentations (crestal or onlay grafting) are associated. Because the external volume of the crest remains unchanged, no difficulty for passive flap closure is

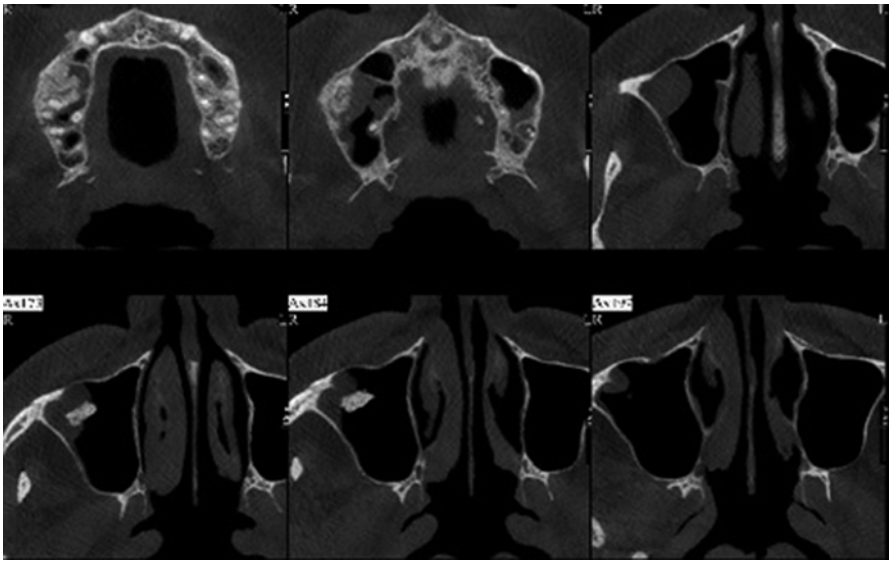


Fig. 8.31 Axial CT scan. Small penetration of bony fragments

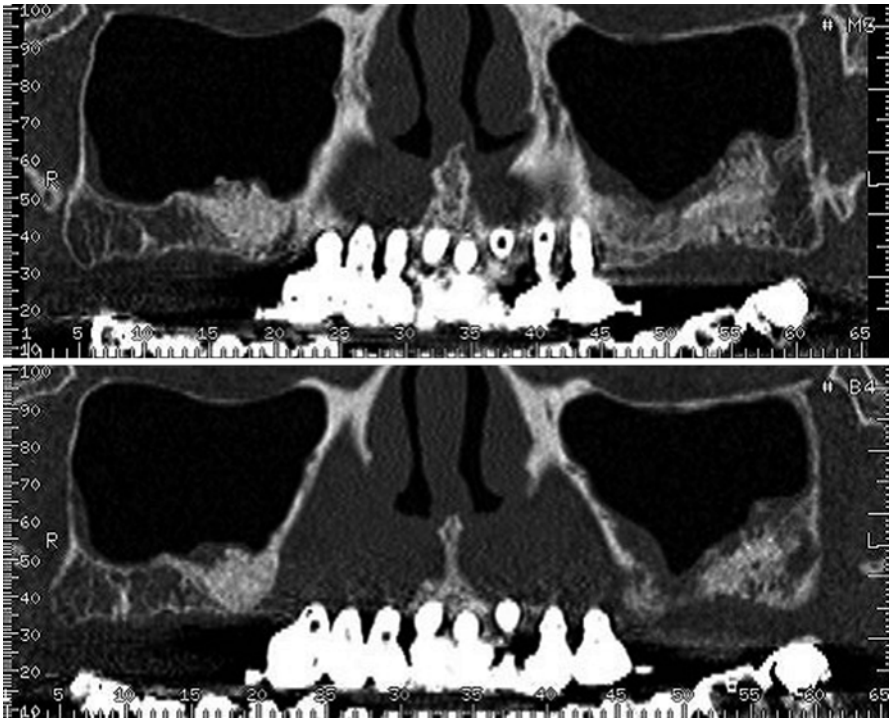


Fig. 8.32 Dentascan loss of bone graft after dehiscence of surgical wound

encountered. A good flap design, correct suturing technique, passive flap closure, and avoidance of trauma from a removable prosthetic are important factors to avoid such a complication (Jovanovic et al. 1992; Greenstein et al. 2008). Local antiseptic and systemic antibiotic are prescribed in case of margin opening. If the wound is larger, attempting to close is problematic, and bone trimming or elimination should be considered in order to improve gingival migration and reepithelialization (Greenstein et al. 2008).

8.3.4 Infections Complications

8.3.4.1 Early Acute Sinusitis

Acute sinusitis on the 8th day is the least common sinusitis and that with the fastest resolution, so long as the maxillary sinus is physiologically healthy. Often related to perioperative anaerobic contamination, favored by a superinfection of an insufficiently drained hematoma, or inadequate antibiotic coverage, it is left to medical treatment and involves prescription of a combination of amoxicillin/clavulanic acid, or prescription of Synergistin, at a dose of 1 gram twice per day for 10 days.

Its prevention is based on strict aseptic conditions, on the use by some authors of bone grafts impregnated with metronidazole (Bhattacharyya 1999), and on appropriate antibiotic coverage, to begin in the preoperative phase or immediately postoperative. In case of sinusitis confirmed, it will be necessary to confirm the cure of the infectious episode on the fifteenth day via endonasal endoscopy, supplemented in case of any doubt by a sinus CT.

8.3.4.2 Long-Lasting Sinusitis

Present in 15 % of the series, long-lasting sinusitis appears around the 3rd week and brings complications involving the implant plan, in the absence of early detection of infectious episode (Bhattacharyya 1999). It is linked to four possible mechanisms, all responsible for a confined sinusitis of the maxillary sinus, without the possibility of drainage of the purulent secretions, due to obstruction of the drainage orifice (obstruction of the ostium) (Fig. 8.33). Preventing confined sinusitis requires an understanding of each mechanism, presented in order of decreasing frequency (Timmenga et al 1997).

- Decompensation of an initially pathological ostiomeatal complex:
  The authors (Timmenga et al. 1997) report a prevalence rate of 40 % of confined sinusitis, in case of lateral sinus filling performed in a patient with unknown sinonasal disease. Prevention of this complication involves the oral surgeon detecting the population with a sinonasal history when taking the medical history in order to provide them with a pre-implant ENT evaluation.
- Obstruction of the ostium by bone grafts
  Bone grafts extruded into the sinus are responsible for an alteration in the physiological drainage of the maxillary sinus, preventing sinus ventilation, in the case of ostial incarceration of biomaterials consisting of granules less than 1.5 mm in

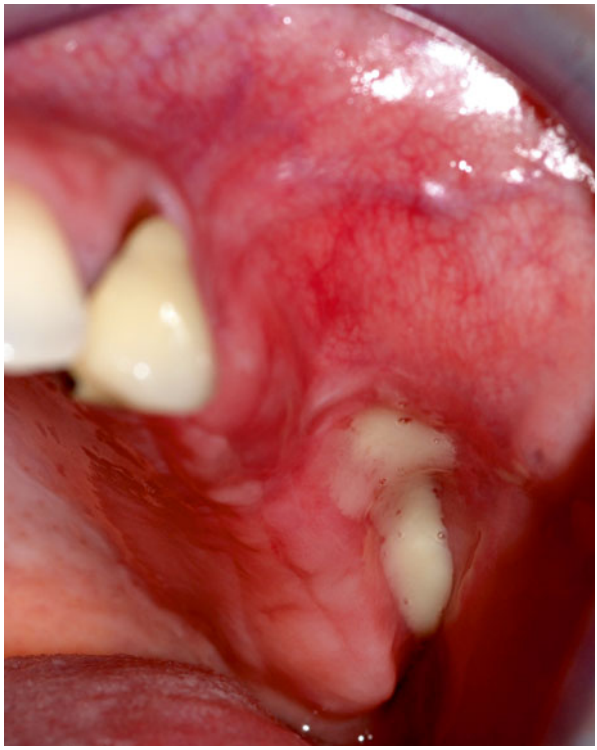


Fig. 8.33 Sinusitis at the third week after sinus grafting. The obstruction of the ostium extruded the pus from a buccal fistula

diameter (Hunter et al. 2009) (Figs. 8.34, 8.35, and 8.36). Prevention is through good quality repair of perforations of the endosinus mucosa and the prohibition of filling in case of extensive tearing of the mucosa.

- Sinus enhancement beyond 16 mm
  This type of enhancement may result in the blockage of the ostium, in the case of original anatomical situation of the ostium less than 20 mm from the sinus floor. Prevention lies in not exceeding a filling height of 16 mm, even for complex reconstruction (Fig. 8.37).
- Polypoid opacity of the floor impacted in the ostium
  Prevention involves obtaining images showing the middle meatus, to ensure a sufficiently safe height between the ostium and the top of the polypoid opacity.

8.3.4.3 Treatment of Confined Sinusitis

This will be suspected in the presence of putrid unilateral purulent nasal secretions with facial pain, cough, and variably a fever. Guided by protected bacteriological sampling of the middle meatus, treatment consists of dual antibiotic therapy, based on the combination of amoxicillin/clavulanic acid (or Synergistin) and levofloxacin for 15 days, combined with a corticosteroid at a dose 1 mg/kg/day for 8 days and nasal disinfection. Endonasal endoscopic control will be performed on the 15th day and a sinus CT systematically on 21st day. In case of non-sterilization of the sinusitis

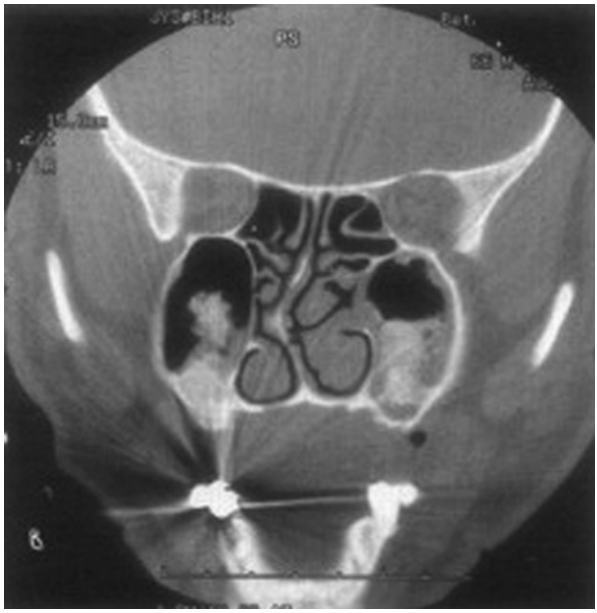


Fig. 8.34 Coronal CT scan penetration of bony fragments into the sinus lumen

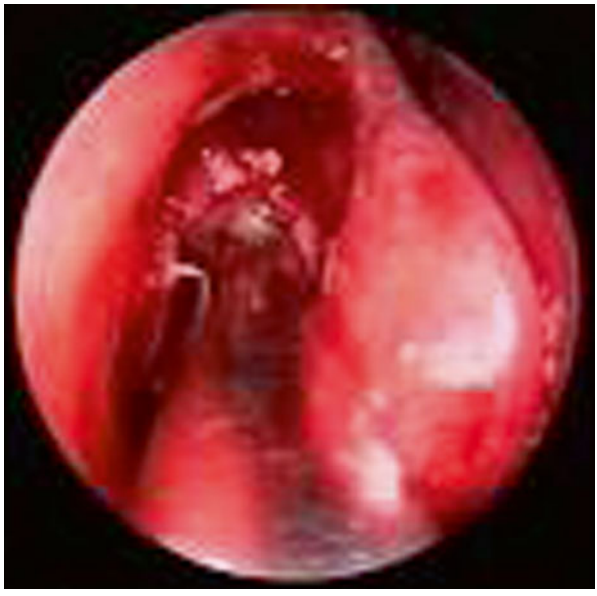


Fig. 8.35 Endoscopic view of penetration of bony fragments into the sinus lumen

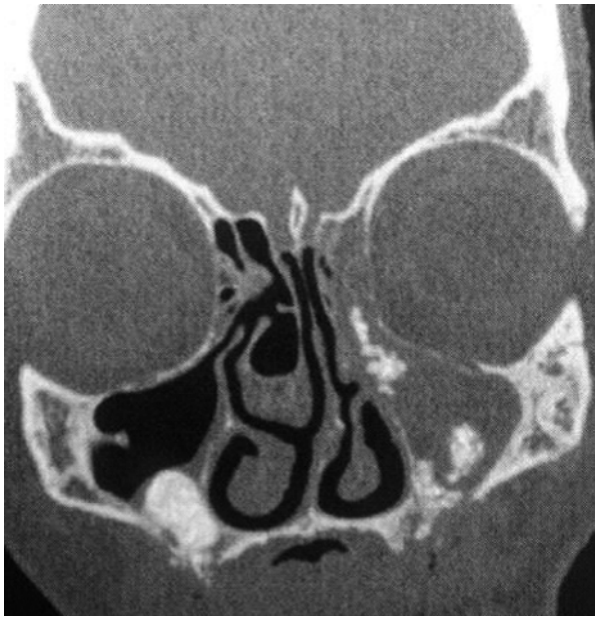


Fig. 8.36 Coronal CT scan. Ostial obstruction by fragments floating into the sinus

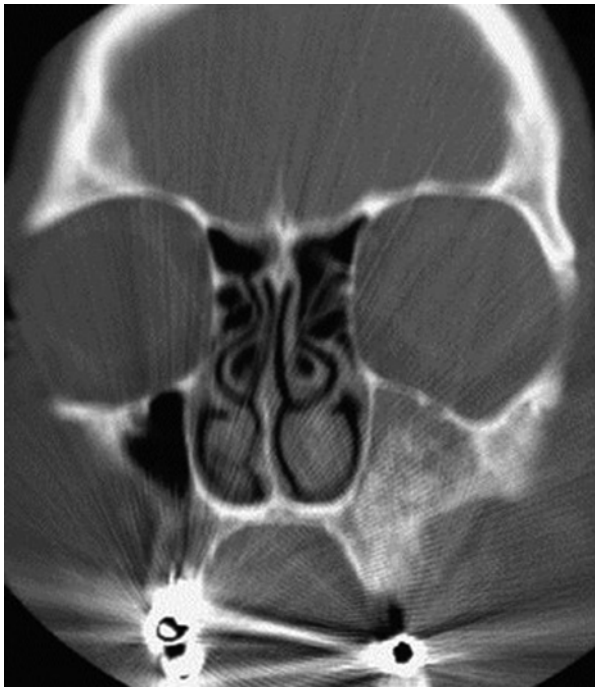


Fig. 8.37 Coronal CT scan. Excess of height of sinus elevation

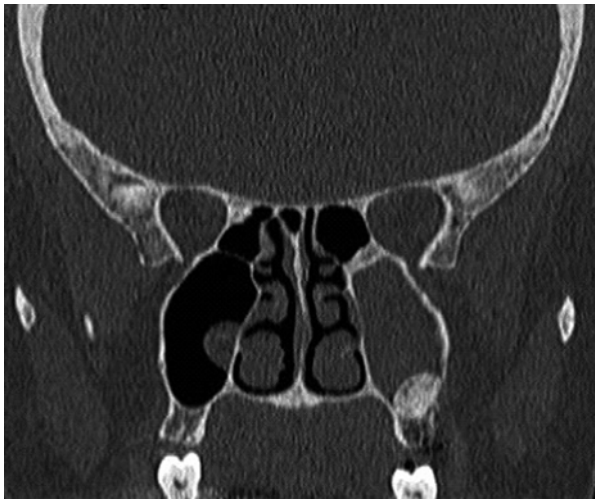


Fig. 8.38 Coronal CT scan. Left maxillary sinusitis without graft osteitis

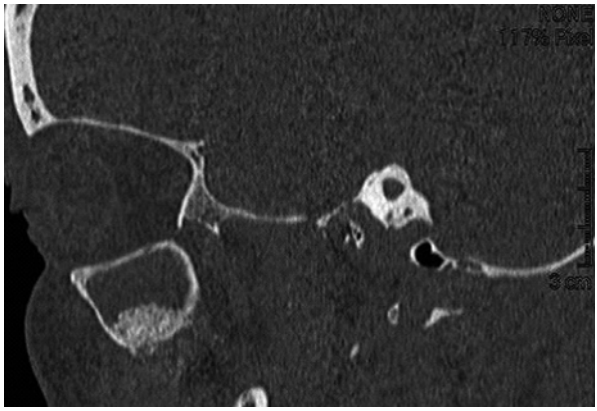


Fig. 8.39 Sagittal CT scan. Left maxillary sinusitis without graft osteitis

in endoscopy, or in CT, it will be necessary to offer the patient surgery (endonasal middle meatotomy) to prevent infection of the grafts (Zimbler et al. 1998).

The middle meatotomy must be adapted to the mechanism responsible for the sinusitis and will involve, as applicable, a simple drainage of endosinus collections (respecting bone grafts protected by endosinus mucosa) (Figs. 8.38 and 8.39) or will involve, if necessary, the removal of the grafts extruded into the sinus.

8.3.4.4 Graft Osteitis

This is a significantly serious complication.

- Circumstances of discovery

It presents in the form of a long-lasting sinusitis masked by inadequate medical treatment or in a more advanced form, with extension of maxillary sinusitis to the

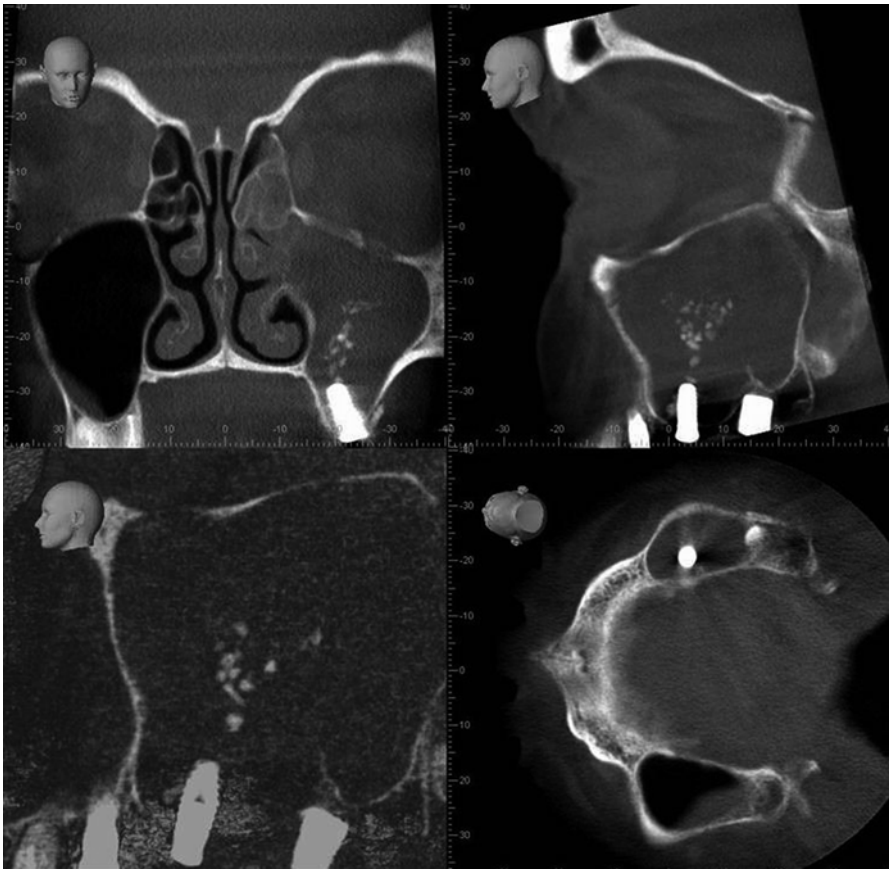


Fig. 8.40 Cone beam. Osteitis of maxillary sinus floor

other sinuses of the face (anterior pansinusitis) with osteitis of the walls of the maxillary sinus, vestibular cellulite with dehiscence of sutures, extrusion of bone grafts opposite crestal and alveolar oroantral fistula, and mobilization of the implants placed in the filling (Figs. 8.40 and 8.41).

- Therapeutic management

This clinical picture requires treatment based on parenteral antibiotics guided by bacteriological samples, associated with a middle meatotomy (often associated with a Caldwell-Luc approach) with complete removal of the bone grafts, curettage of the mucosa, and removal of the implants (Felisati et al. 2008). In contrast to that advocated by some authors, we prefer not to treat oroantral fistulas during the same procedure. We believe that the flaps should be aimed at sinus walls free of osteitis and the eradication of infected areas associated with the middle meatotomy usually results in spontaneous closure of oroantral fistulas.

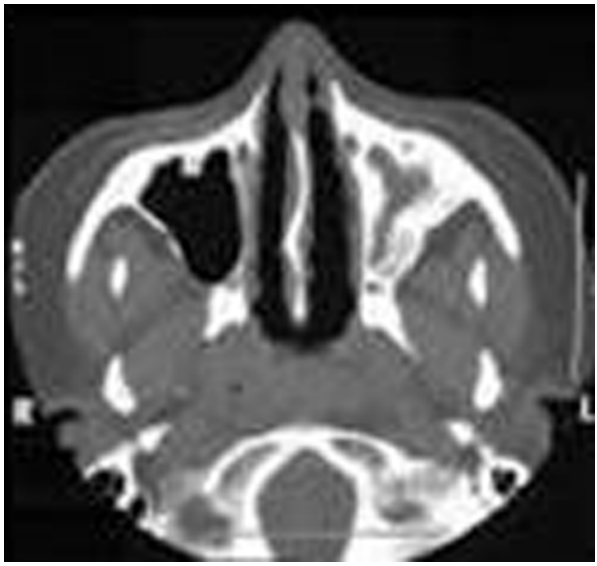


Fig. 8.41 Axial CT scan. Osteitis of the left maxillary sinus

8.3.5 Endosinus Extrusion of the Implant

Rarely immediate, expulsion of an implant into the sinus is not an exceptional situation in our personal experience, but remains undisclosed upon reading the various authors (Galindo-Moreno et al. 2012). Without urgency, radiologic examination (CT scan) then extraction of the implant is performed under endoscopic guidance through middle meatotomy (for an implant located in the upper 2/3 of the sinus) (Fig. 8.42), through lower meatotomy or vestibular approach if the implant is situated lower (Figs. 8.43, 8.44, 8.45, and 8.46). Its extraction is made difficult in the case of a sinus anatomically modified by a preexisting bone filling. It is primordial to have a direct vision or through endoscopic guidance to avoid injuring the orbital floor.

8.3.6 Modification of the Sinus Mucosa

Changes in the mucosa after bone filling translate into a polypoid mucosal hypertrophy improperly referred to as "mucocele" in the literature. In contrast with a mucocele, which is an active lesion with its own wall lysing the bone walls (Fig. 8.47), the polypoid reaction is secondary to a folding of the mucosa, nonprogressive and

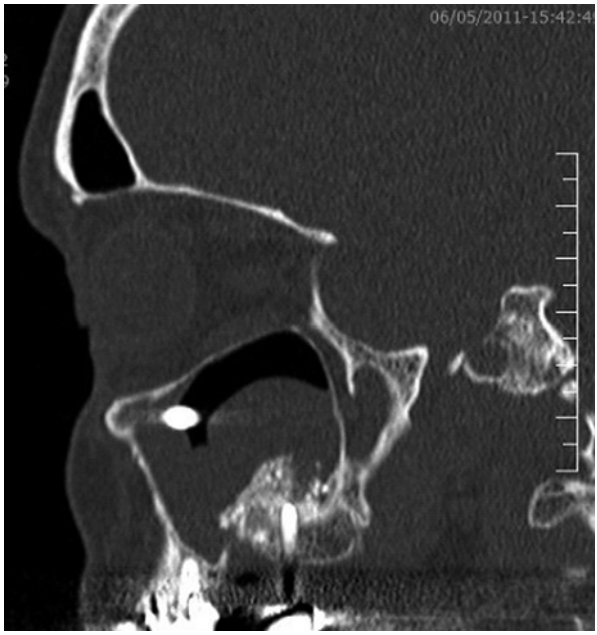


Fig. 8.42 Sagittal CT scan. Displacement of dental implants inside the maxillary sinus

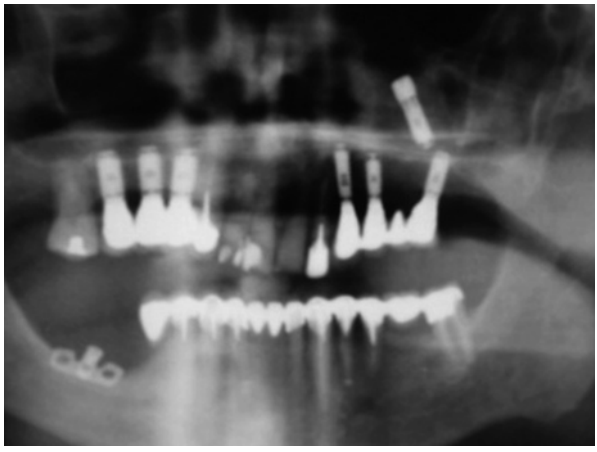


Fig. 8.43 Extruded implant in the left maxillary sinus

non-osteolytic, not requiring any treatment of its own (Fig. 8.48). The description of a true "mucocele" in the long-term evolution cannot be formally eliminated, as reported on multiple occasions after Caldwell-Luc surgery for chronic maxillary sinusitis.

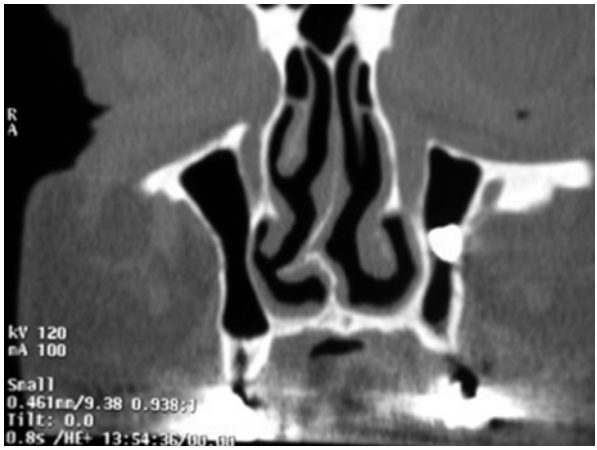


Fig. 8.44 Coronal CT scan reveals an anteroinferior localization of the implant

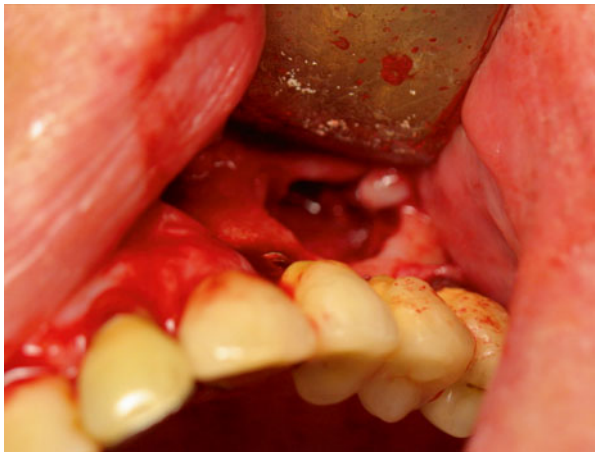


Fig. 8.45 Vestibular antrostomy

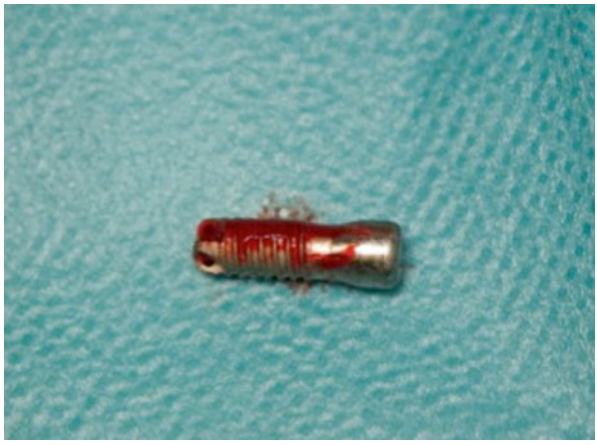


Fig. 8.46 Implant removal from the sinus

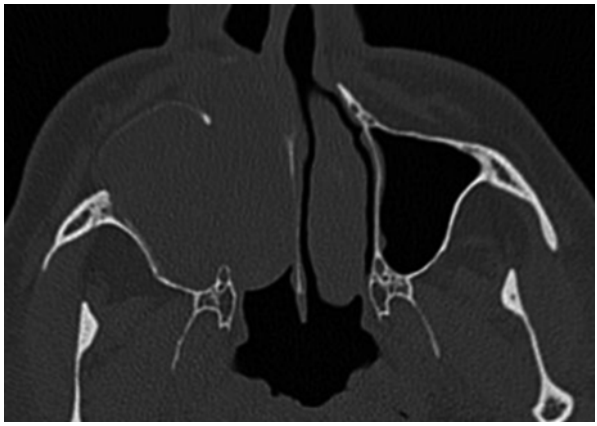


Fig. 8.47 Axial CT scan. Right maxillary sinus showing the presence of a mucocele

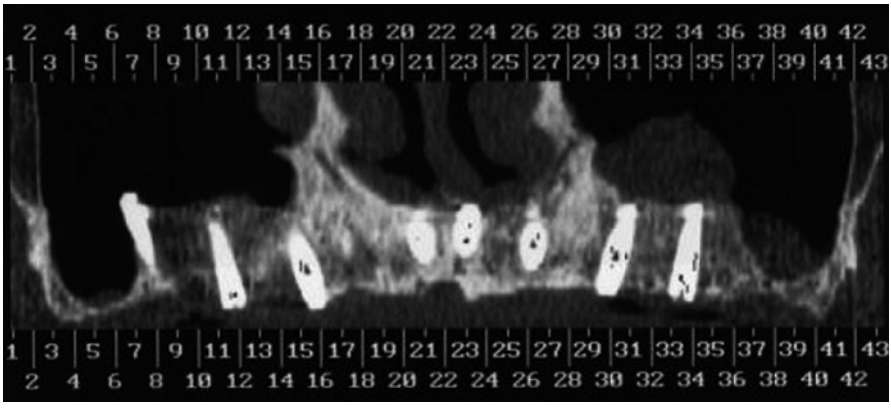


Fig. 8.48 Dentascan. Note the presence of pseudopolyps in the left maxillary sinus at 6 months after sinus floor elevation

Conclusion

Prevention of endosinus complications requires a well-controlled surgical technique and a good understanding of the antral pathophysiology. It is based on pre-implant screening of patients with a sinonasal history, precise radiological examination, good knowledge of the anatomy, and performing an appropriate repair of membrane perforations. Early detection of infectious episodes and close and prolonged monitoring, with ENT examination and CT scan, help prevent complications leading to failure of the implant program.

References

Baccar MN, Laure B, Chabut A, Bonin B, Romieux G, Goga D (2005) Stabilité du greffon et des implants après greffe osseuse du sinus maxillaire: Étude rétrospective de 44 cas. Rev Stomatol Chir Maxillofac 106:153–156

Becker ST, Terheyden H, Steinriede A, Behrens E, Springer I, Wiltfang J (2008) Prospective observation of 41 perforations of the Schneiderian membrane during sinus floor elevation. Clin Oral Implants Res 19:1285–1289

Bhattacharyya N (1999) Bilateral chronic maxillary sinusitis after the sinus-lift procedure. Am J Otolaryngol 20:133–135

Binali C, Sumbulu MA, Durna D (2013) Relationship among Schneiderian membrane, Underwood's septa, and the maxillary sinus inferior border. Clin Implant Dent Relat Res 15:83–87

Bornstein MM, Chappuis V, von Arx T (2008) Performance of dental implants after staged sinus floor elevation procedures: 5-Year results of a prospective study in partially edentulous patients. Clin Oral Implants Res 19:1034–1041

Choi BH, Zhu SJ, Jung JH, Lee SH, Huh JY (2006) The use of autologous fibrin glue closing sinus membrane perforations during sinus lifts. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101:150–154

Del Fabbro M, Testori T, Francetti L, Weinstein R (2004) Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 24:565–577

Elian N, Wallace S, Cho SC, Jalbout ZN, Froum S (2005) Distribution of the maxillary artery as it relates to sinus floor augmentation. Int J Oral Maxillofac Implants 20:784–787

Ella B, Sédarat C, Noble RDC, Normand E, Lauverjat Y, Siberchicot F, Caix P, Zwetyenga N (2008) Vascular connections of the lateral wall of the sinus: surgical effect in sinus augmentation. Int J Oral Maxillofac Implants 23:1047–1052

Felisati G, Borloni R, Maccari A, Mele V, Chiapasco M (2008) Endoscopic removal of alloplastic sinus graft material via a wide middle antrotomy. Int J Oral Maxillofac Surg 37:858–861

Flanagan D (2005) Arterial supply of maxillary sinus and potential for bleeding complication during lateral approach sinus elevation. Implant Dent 14:336–338

Fugazzotto PA, Vlassis J (2003) A simplified classification and repair system for sinus membrane perforations. J Periodontol 74:1534–1541

Galindo-Moreno P, Padial-Molina M, Avila G, Rios HF, Wang HL (2012) Complications associated with implant migration into the maxillary sinus cavity. Clin Oral Implants Res 23:1152–1160

Garbacea A, Lozada JL, Church CA, Al-Ardah AJ, Seiberling KA, Naylor WP, Chen JW (2012) The incidence of maxillary sinus membrane perforation during endoscopically assessed crestal sinus floor elevation: a pilot study. J Oral Implantol 38:345–359

Greenstein G, Cavallaro J, Romanos G, Tarnow D (2008) Clinical recommendations for avoiding and managing surgical complications associated with implant dentistry: A review. J Periodontol 79:1317–1329

Havas TE, Motbey JA, Gullane PJ (1988) Prevalence of incidental abnormalities on computed tomographic scans of the paranasal sinuses. Arch Otolaryngol Head Neck Surg 114:856–859

Hunter WL, Bradrick JP, Houser SM, Patel JB, Sawady J (2009) Maxillary sinusitis resulting from ostium plugging by dislodged bone graft: case report. J Oral Maxillofac Surg 67:1495–1498

Hur MS, Kim JK, Hu KS, Bae HE, Park HS, Kim HJ (2009) Clinical implications of the topography and distribution of the posterior superior alveolar artery. J Craniofac Surg 20:551–554

Jensen OT (1997) Maxillary sinus function after sinus lifts for the insertion of dental implants. J Oral Maxillofac Surg 55:940–945

Jensen OT, Shulman LB, Block MS (1998) Report of the sinus consensus conference of 1996. Int J Oral Maxillofac Implants 13:11–17

Jovanovic SA, Spiekermann H, Richter EJ (1992) Bone regeneration around titanium dental implants in dehisced defect sites: a clinical study. Int J Oral Maxillofac Implants 7:233–245

Khoury F (1999) Augmentation of the sinus floor with mandibular bone block and simultaneous implantation: A 6-year clinical investigation. Int J Oral Maxillofac Implants 14:557–564
Krennmair G, Ulm CW, Lugmayr H, Solar P (1999) The incidence, location, and height of maxillary sinus septa in the edentulous and dentate maxilla. J Oral Maxillofac Surg 57:667–671
Lee HW, Lin WS, Morton D (2013) A retrospective study of complications associated with 100 consecutive maxillary sinus augmentations via the lateral window approach. Int J Oral Maxillofac Implants 28:860–868
Mardinger O, Abba M, Hirshberg A, Schwartz-Arad D (2007) Prevalence, diameter and course of the maxillary intraosseous vascular canal with relation to sinus augmentation procedure: a radiographic study. Int J Oral Maxillofac Surg 36:735–738
Nkenke E, Schlegel A, Schultze-Mosgau S, Neukam FW, Wiltfang J (2002) The endoscopically controlled osteotome sinus floor elevation: a preliminary prospective study. Int J Oral Maxillofac Implants 17:557–566
Pikos MA (2008) Maxillary sinus membrane repair: update on technique for large and complete perforations. Implant Dent 17:24–31
Pommer B, Ulm C, Lorenzoni M, Palmer R, Watzek G, Zechner W (2012) Prevalence, location and morphology of maxillary sinus septa: systematic review and meta- analysis. J Clin Periodontol 39:769–773
Proussaefs P, Lozada J (2003) The “Loma Linda pouch”: a technique for repairing the perforated sinus membrane. Int J Periodontics Restorative Dent 23:593–597
Proussaefs P, Lozada J, Kim J, Rohrer MD (2004) Repair of the perforated sinus membrane with a resorbable collagen membrane: a human study. Int J Oral Maxillofac Implants 19:413–420
Raghoebar GM, Timmenga NM, Reintsema H (2001) Maxillary bone grafting for insertion of endosseous implants: results after 12-124 months. Clin Oral Implants Res 12:279–284
Schwartz-Arad D, Herzberg R, Dolev E (2004) The prevalence of surgical complications of the sinus graft procedure and their impact on implant survival rate. J Periodontol 75:511–516
Shlomi B, Horowitz I, Kahn A, Dobriyan A, Chaushu G (2004) The effect of sinus membrane perforation and repair with Lambone on the outcome of maxillary sinus floor augmentation: a radiographic assessment. Int J Oral Maxillofac Implants 19:559–562
Solar P, Geyerhofer U, Traxler H, Windisch A, Ulm C, Watzek G (1999) Blood supply to the maxillary sinus relevant to sinus floor elevation procedures. Clin Oral Implants Res 10:34–44
Timmenga NM, Raghoebar GM, Boering G, Van Weissenbruch R (1997) Maxillary sinus function after sinus lifts for the insertion of dental implants. J Oral Maxillofac Surg 55:936–939
Toscano NJ, Holtzclaw D, Rosen PS (2010) The effect of piezoelectric use on open sinus lift perforation: a retrospective evaluation of 56 consecutively treated cases from private practices. J Periodontol 81:167–171
Underwood AS (1910) An inquiry into the anatomy and pathology of the maxillary sinus. J Anat Physiol 44:354–369
Van der Bergh JP, Ten Bruggenkate CM, Disch FJ, Tuinzing DB (2000) Anatomical aspects of sinus floor elevations. Clin Oral Implants Res 11:256–265
Vlassis JM, Fugazzotto PA (1999) A classification system for sinus membrane perforations during augmentation procedures with options for repair. J Periodontol 70:692–699
Wallace SS, Froum SJ (2003) Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol 8:328–343
Wallace SS, Mazor Z, Froum SJ, Cho SC, Tarnow DP (2007) Schneiderian membrane perforation rate during sinus elevation using piezosurgery: clinical results of 100 consecutive cases. Int J Periodontics Restorative Dent 27:413–419
Wiltfang J, Schultze-Mosgau S, Merten HA, Kessler P, Ludwig A, Engelke W (2000) Endoscopic and ultrasonographic evaluation of the maxillary sinus after combined sinus floor augmentation and implant insertion. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89:288–291
Yoshida S, Kawai T, Asaumi R, Miwa Y, Imura K, Koseki H, Sunohara M, Yosue T, Sato I (2010) Evaluation of the blood and nerve supply patterns in the molar region of the maxillary sinus in Japanese cadavers. Okajimas Folia Anat Jpn 87:129–133
Zimbler MS, Lbowitz RA, Glikman RA, Brecht LE, Jacobs JB (1998) Antral augmentation, osseointegration and sinusitis: the otolaryngologist’s perspective. Am J Rhinol 12:311–316

9 Current State, Treatment Modalities, and Future Perspectives of Sinus Floor Elevation (SFE)

Ronald Younes, Georges Khoury, and Nabih Nader

Contents

Nowadays, more than half (54.2 %) of the implant rehabilitations in the edentulous posterior maxilla are involved with an SFE procedure prior to implant placement (Seong et al. 2013).

Moreover, SFE has been proven to be the most predictable of the maxillary bone augmentation techniques used to enhance bone volume for the placement of dental implants in compromised sites (Del Fabbro et al. 2013; Aghaloo and Moy 2007). It is also interesting to note that the implant survival rate (ISR) in the grafted posterior maxillary sinus appears to be better than that in the posterior maxilla with a bone of poor quality but adequate quantity for implant placement (Tong et al. 1998).

R. Younes, DDS, PhD (✉)
Department of Oral Surgery, Faculty of Dentistry, St. Joseph University, Beirut, Lebanon
e-mail: ronald.younes@usj.edu.lb, ronald.younes@hotmail.com

G. Khoury, DDS, MSc
Department of implantology and bone reconstruction,
Paris-Diderot University, Paris, France
e-mail: dr.georges.khoury@gmail.com

N. Nader, DDS
Department of Oral and Maxillofacial Surgery,
School of Dentistry, Lebanese University, Beirut, Lebanon
e-mail: nabih.nader@gmail.com

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4_9

Multiple evidence-based reviews have demonstrated that SFE results in an overall ISR well beyond 90 % (Wallace and Froum 2003; Del Fabbro et al. 2004; Graziani et al. 2004; Pjetursson et al. 2008; Esposito et al. 2010; Nkenke and Stelzle 2009; Jensen et al. 1998a).

The challenge facing clinicians today is not the ability to achieve a conventional SFE procedure successfully. Rather, it is to select the most appropriate SFE approach depending on the initial clinical situation because the variety of treatment is influenced by several parameters including the anatomy of the area, the residual bone height (RBH), the residual bone width (RBW), the residual bone quality as well as a number of other factors such as the extent of the edentulous sector, etc. (Tan et al. 2008).

Evidence available today indicates that both lateral and crestal SFE techniques are predictable and safe with successful outcome in the means of grafting technique and long-term ISR (Esposito et al. 2010, 2014; Cannizzaro et al. 2013).

However, despite that the crestal SFE approach is considered to be more conservative than the lateral approach, the main drawback is that the crestal SFE is usually performed blindly due to the impossibility to visualize the sinus floor (Tan et al. 2008), with a risk of membrane perforation while performing transalveolar SFE (Nkenke et al. 2002; Berengo et al. 2004), leading to anarchic spreading of bone particles in the sinus cavity, which presumably results in a unsuccessful outcome of SFE. In spite of this limitation, numerous studies reported that membrane perforation is less frequent in the osteotome-mediated procedure than in the lateral approach (Del Fabbro et al. 2012; Katranji et al. 2008; Chanavaz 1990). Moreover, an endoscopic study revealed that the sinus floor might be elevated up to 5 mm without perforating the sinus membrane (Engelke and Deckwer 1997). This implies that the osteotome technique has to be used when the required bone augmentation does not exceed 5 mm (Sendyk and Sendyk 2002). For this reason, as for lateral SFE approach, an osteotome-staged crestal approach with delayed implant insertion has been proposed with encouraging results in case of a reduced RBH (<4 mm).

However, practically, the crestal approach cannot be extended to all cases since it requires a minimal ridge *width* of 6 mm, allowing the placement of a convenient implant diameter, particularly in multiple edentulous cases. In this case, a lateral approach should be performed, combined to either an onlay graft or a GBR procedure in order to widen the deficient ridge.

On the other hand, SFE treatment planning should not only be based on the RBH but also related to the tridimensional bone loss in the sinus based on Cawood and Howell's classification (1988). In fact, an insufficient RBH may be due to either as a sinus pneumatization or a vertical ridge resorption, or a combination of both factors.

In the first situation, an SFE may be indicated, whereas in the second one (vertical atrophy), it may happen that the sinus does not need to be grafted. Instead, a vertical reconstruction to recreate an adequate interarch distance may be the treatment of choice.

Furthermore, bone resorption of the edentulous ridge may lead to a horizontal discrepancy between the maxilla and the mandible. If an SFE alone is performed,

implants will be placed in a palatal position, with a less than ideal prosthetic rehabilitation. Therefore, the atrophic posterior maxilla should be evaluated and classified not only as far as the RBH and width is concerned but also as far as vertical and horizontal intermaxillary relationships are concerned. Consequently, SFE may represent only a part of the reconstruction necessary to reestablish adequate bone volumes and intermaxillary relationships, in order to optimize implant placement and the final prosthetic results from a functional and esthetic point of view.

9.1 Graft Materials

From the analysis of the literature, it is usually recognized that the "gold standard" for SFE procedures remains AB (Jensen et al. 1998); the histomorphometric outcome of total bone volume (TBV) after SFE using various bone substitutes, allogenic, xenogenic, and alloplastic graft materials or combinations, resulted in a significant lower TBV compared to AB grafting (Klijn et al. 2010). However, with sound surgical technique, appropriate patient selection, and proper postoperative care, the survival rates identified in numerous reviews indicate that BS alone or in combination with AB is able to achieve similar ISR and an adequate support for endosseous implants with a decreased risk of graft resorption. Presumably, with the recent developments and the venue of bioactive BS and adjunctives (growth factors etc.), it will be possible to obtain in the near future some innovative high-performance BS specifically adapted to bone remodeling, achieving a complete regeneration combined to long-term bone graft stability.

9.2 Technique's Selection Decisive Criteria

Although SFE is considered to be a highly predictable augmentation procedure achieving high ISR, the technique's success should be based on an accurate radiographic and clinical diagnosis in order to select the most appropriate SFE procedure to various clinical situations:

- The use of a *lateral or a crestal approach* to access the sinus cavity
- The decision to perform either a *simultaneous or delayed implant* placement

9.3 One-Stage Versus Two-Stage SFE Approach

According to current available data, the two techniques are comparable (Jang et al. 2010; Felice et al. 2014).

Two-stage SFE appears safe and predictable with minimal complications that can be managed successfully without a negative effect on clinical outcomes. However, a one-stage approach demonstrated similar ISR (Jensen et al. 1998;

Wallace and Froum 2003; Del Fabbro et al. 2008; Chao et al. 2010; Peleg et al. 1998, 1999) and is timesaving with less morbidity to the patient.

The decision to apply either *simultaneous or delayed SFE* approach should rely on several parameters including:

- *The residual bone height* (*RBH*) considered as a decisive parameter since it will enable the primary implant stability (Peleg et al. 1998, 1999; Del Fabbro et al. 2004, 2008). A two-step procedure is recommended in cases of severe atrophy with reduced RBH in which primary implant stability cannot be guaranteed (Del Fabbro et al. 2008; Kang 2008; Felice et al. 2014)
- *The residual bone quality*, another essential parameter that will favor or not initial implant stability.

9.4 Lateral Versus Crestal SFE Approach

In addition to the above factors, the decision to apply a lateral or a crestal approach depends on several additional factors including:

- The residual bone width (RBW): in case of severe horizontal ridge atrophy, then lateral approach should be performed with an onlay block graft (or a GBR procedure).
- The extent of the edentulism: the surgeon should differentiate these two situations (refer to Tables 9.2 and 9.3). A larger edentulous sector will be in favor of a lateral SFE.
- The presence of septa: it is fundamental to evaluate this since they are considered an important obstacle with a magnified risk of membrane tearing that should be avoided (refer to Tables 9.2 and 9.3); moreover, their precise location plays a decisive role in technique selection.
- Bucco-palatal intrasinus distance (width): the lateral approach is more recommended in cases with low RBH and a large maxillary sinus volume (Peleg et al. 1998; Weingart et al. 2005; Jang et al. 2010).
- The lateral approach is more recommended in the molar area combining reduced RBH with large sinus volume, while the crestal approach seems more appropriate in the premolar area (more RBH and narrower sinus volume).

Although technique selection depends as described above on several parameters, lateral or crestal SFE should be also chosen according to the preference of the surgeon.

9.5 Classifications

Numerous authors attempted to propose classifications that may help the practitioner in selecting the most appropriate technique for a given clinical situation. These classifications were based on several parameters such as the RBH, the ridge

width, the distance between the top of the bone crest and the cemento-enamel junction, etc.

- Jensen (1994) and Misch and Judy (1987) described the first classifications according to residual bone height of the atrophic ridge (RBH). At that time, lateral SFE was the only treatment option. Moreover, short implants were not available yet: lateral SFE was performed in the presence of an RBH of 10 mm, which seems nowadays inappropriate.
- Zitzmann and Schärer (1998) introduced the crestal approach for the first time in their classification also based on the RBH.
- Misch included in his 1999 classification, in addition to RBH, the sinus (crest) width parameter with smaller-width sinuses allowing reduced healing periods than larger-width (>15 mm) sinuses, resulting in faster bone formation.
- Simion (2004) added the distance between the top of the crest and the CEJ (of the adjacent teeth) as a new parameter (see the Classification Table 9.1 below).
- Fugazzotto (2003) proposed a hierarchy of treatment selection of simultaneous vs. delayed implant placement associated to SFE (see Table 6.2).

Below Table 9.1 including the main classifications proposed in the past 30 years to plan the appropriate SFE procedure.

The above classifications excluded two interesting parameters that we consider beneficial to include in an SFE treatment plan.

- The aim of the guide-chart table below (Tables 9.2 and 9.3) is to present a new classification proposing well-defined surgical protocols for the correction of the defects areas according to preoperative residual bone volume. Moreover, the interest of this classification is due to the introduction of two new parameters in addition to the residual bone height (RBH): These factors are:
  1. *The extent of the edentulism*: single or multiple edentulous sector, considering that a single edentulism will privilege the crestal approach for two main reasons: First is due to the difficulty to achieve a lateral approach in the presence of neighboring roots that will interfere with a convenient window osteotomy. The second reason is related to a faster bone healing that is more favorable with crestal approach in the presence of "U shape" defect with mesial and distal walls (due the presence of the teeth) and a limited risk of sinus membrane tearing.
  2. *The presence and the location of the septa*: considered as another important decisive factor: A septum located apically to the desired augmentation site (future implant position) will result in a risky situation when performing a crestal approach due to the uncontrolled risk of membrane tearing. It would be more appropriate to use a lateral approach with a visual access. On the contrary, a "lateral septum", in offset position from the implant site, will be beneficial for an enhanced bone healing when using a crestal approach

Table 9.1 Overview of the SFE main classifications: treatment selection based on different parameters

	Jensen (1994)	Zitzmann (1998)	Misch (1999)	Fugazzotto (2003)	Simion et al. (2004)	Chiapasco et al. (2008)	Wang and Katranji (2008)	Stern and Green (2012)
IIP			SA-1	cl. A	cl.A		cl.A	
			H ≥ 12	H = 10	H >6		H ≥10	
			W >5		BC-CEJ: 3		BC-CEJ ≤3	
							W ≥ 5	
C + SI		H≥ 6	SA-2	cl. B			cl.B	H >8 (single)
			H: 10–12	H: 7–9			H:6–9	
			W >5				BC-CEJ ≤3	
							W ≥5	
C +/−GBR+/−SI							cl. Bh	
							H:6–9	
							BC-CEJ ≤3	
							W <5	
C + onlay+/− expansion + SI			SA-2-B					
			H:10–12					
			W: 2.5–5					
C + GBR + DI							cl. Bv	
							H:6–9	
							BC-CEJ >3	
							W ≥5	
C + GBR/ onlay + DI							cl. Bc	
							H: 6–9	
							BC-CEJ >3	
							W <5	
L + SI	cl.A & B	H: 4–6				cl.A H 4–8		H: 5–10
	H: 7–10					W >5		H >5 (single)
						BC-CEJ ++		

L+SI+onlay								cl. B H:4–8 W <5 BC-CEJ++						
L+/−SI	cl.C H: 4–6		SA-3 H ≥5		cl. C H: 4–6						cl. C H ≤5 BC-CEJ ≤3 W ≥5			
L+DI	cl.D H <4	H ≤4	SA-4 H <5		cl. D H: 1–3		cl. B H <6 BC-CEJ: 3		cl.C H <4 W >5 BC-CEJ ++					H ≤4
L+GBR/ onlay+DI									cl.D H <4 W <5 BC-CEJ ++		cl. Ch H ≤5 BC-CEJ ≤3 W <5			
L+GBR+/− onlay+DI											cl. Cv & Cc H ≤5 BC-CEJ >3			
VRA							cl.C H >6 BC-CEJ >3							
L+VRA							cl.D H <6 BC-CEJ >3		Cl. E H: 4–8 W >5 BC-CEJ – –					
L+onlay+VRA									cl. F H:4–8 W <5					

SFE sinus floor elevation; IIP immediate implant placement without a need for SFE; *C* crestal SFE, *L* lateral SFE, *SI* simultaneous implant placement, *DI* delayed implant placement, *GBR* guided bone regeneration, *VRA* vertical ridge augmentation, *W* width of the crest, *BC-CEJ* distance between the top of the bone crest and the Cemento-enamel junction

Table 9.2 SFE Technique selection in case of single edentulism

Parameters	Single edentulism	
Residual bone height	≥4 mm	<4 mm
No septum	Crestal + SI	**Crestal + DI**
		Lateral + DI
Apical septum	**Lateral ± SI**	Lateral + DI
	Short implant	
Lateral septum	Crestal + SI	**Lateral + DI**
		Crestal + DI

Bold is used for the preferred technique
An apical septum emerges apically to the region needing an SFE
A lateral septum is located laterally to the region to be grafted: it is considered as an additional bony wall, considered as an added value in SFE following the principle of guided bone regeneration
DI delayed implant placement, *SI* simultaneous implant placement

Table 9.3 SFE Technique selection in case of multiple edentulism

Parameters	Multiple edentulism	
Residual bone height	≥4 mm	<4 mm
No septum	**Lateral ± SI**	Lateral + DI
	Crestal ± SI	
Apical septum	Lateral ± SI	Lateral + DI
Lateral septum	Crestal ± SI	**Lateral + DI**
		Crestal + DI (2 entries)

Bold is used for the preferred technique
An apical septum emerges apically to the region needing an SFE
A lateral septum is located laterally to the region to be grafted: it is considered as an additional bony wall, considered as an added value in SFE following the principle of guided bone regeneration
DI delayed implant placement, *SI* simultaneous implant placement

since the additional bony wall of the septum will help in containing the particulate BS combined to a better tenting effect of the sinus membrane, thus optimizing the osteoconduction.

This new classification is simple without excluding the previous existing classifications. For example, the crest width parameter follows these previous classifications with the indication to augment the horizontal defect through an onlay graft or a GBR procedure if needed (Tables 9.2 and 9.3).

9.6 Future Perspectives

Numerous issues remain unclear regarding the long-term prognosis of SFE. Moreover, it is still unclear when these augmentations are really needed.

- Although their long-term prognosis is still unknown, the recent successful utilization of short implants (4–6 mm) will probably decrease the need for SFE in the near future (Esposito et al. 2014).

- The predictability of short implants would promote the use of a graftless approach with no need for additional bone substitutes; even in the presence of a reduced RBH, an increase of 2 mm is considered to be achievable through a graftless SFE and would be a viable alternative to the augmentation using a grafting material without compromising proper implant rehabilitation.
- Moreover, the growing tendency to opt for short implants would favor the less "invasive" crestal approach over the current widespread use of lateral SFE procedure.

Meta-analysis studies (Esposito et al. 2010, 2014) have demonstrated that the use of crestal SFE approach in conjunction with a short implant leads to fewer complications than a lateral SFE combined with longer implant placement (10–12 mm).

Nowadays, there is still controversy regarding the appropriate indications of crestal versus lateral SFE approach and whether to use a delayed or a simultaneous implant placement. In fact, the delayed placement is either indicated as a primary objective when implant primary stability is difficult to achieve or as a secondary objective when the surgeon fails to get primary implant stability on the day of implant placement.

Practically speaking, the pre-operative assessment of the RBH should always be associated with a per-operative evaluation of the residual bone quality in order to guarantee primary implant stability in case of simultaneous implant placement.

Furthermore, the crestal SFE approach is no longer restricted by a minimal RBH (>5 mm), but rather extended to more advanced cases, with no prerequisite for simultaneous implant placement, as is the case for the lateral SFE approach.

Finally, it is difficult to provide clear indications with respect to whether the crestal or lateral SFE procedure should be adopted first. Ultimately, the decision is determined by the surgeon's judgment based on his experience and each clinical situation, with priority given to surgical interventions that are simpler, less invasive, with less risk of complications, and ultimately attaining goals within the shortest time frame.

References

Aghaloo TL, Moy PK (2007) Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 22 Suppl:49–70

Berengo M, Sivolella S, Majzoub Z, Cordioli G (2004) Endoscopic evaluation of the bone-added osteotome sinus floor elevation procedure. Int J Oral Maxillofac Surg 33:189–194. doi:10.1054/ijom.2002.0459

Cannizzaro G, Felice P, Minciarelli AF, Leone M, Viola P, Esposito M (2013) Early implant loading in the artrophic posterior maxilla: 1-stage lateral versus crestal sinus lift and 8 mm Hydroxyapatite-Coated implants. A 5-year randomised controlled trial. European Journal of Oral Implantology. 6(1):13–25

Cawood JI, Howell RA (1988) A classification of the edentulous jaws. Int J Oral Maxillofac Surg 17:232–236

Chanavaz M (1990) Maxillary sinus: anatomy, physiology, surgery, and bone grafting related to implantology – eleven years of surgical experience (1979–1990). J Oral Implantol 16:199–209

Chao Y-L, Chen H-H, Mei C-C, Tu Y-K, Lu H-K (2010) Meta-regression analysis of the initial bone height for predicting implant survival rates of two sinus elevation procedures. J Clin Periodontol 37:456–465. doi:10.1111/j.1600-051X.2010.01555.x

Chiapasco M, Zaniboni M, Rimondini L (2008) Dental implants placed in grafted maxillary sinuses: a retrospective analysis of clinical outcome according to the initial clinical situation and a proposal of defect classification. Clinical Oral Implants Research 19(4):416–428. doi:10.1111/j.1600-0501.2007.01489.x

Del Fabbro M, Corbella S, Weinstein T, Ceresoli V, Taschieri S (2012) Implant survival rates after osteotome-mediated maxillary sinus augmentation: a systematic review. Clin Implant Dent Relat Res 14(Suppl 1):e159–e168. doi:10.1111/j.1708-8208.2011.00399.x

Del Fabbro M, Rosano G, Taschieri S (2008) Implant survival rates after maxillary sinus augmentation. Eur J Oral Sci 116:497–506. doi:10.1111/j.1600-0722.2008.00571.x

Del Fabbro M, Testori T, Francetti L, Weinstein R (2004) Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 24:565–577

Del Fabbro M, Wallace SS, Testori T (2013) Long-term implant survival in the grafted maxillary sinus: a systematic review. Int J Periodontics Restorative Dent 33:773–783

Engelke W, Deckwer I (1997) Endoscopically controlled sinus floor augmentation. A preliminary report. Clin Oral Implants Res 8:527–531

Esposito M, Felice P, Worthington HV (2014) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev 13(5):CD008397. doi:10.1002/14651858.CD008397

Esposito M, Grusovin MG, Rees J, Karasoulos D, Felice P, Alissa R, Worthington HV, Coulthard P (2010) Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev (3):CD008397. doi:10.1002/14651858.CD008397

Felice P, Pistilli R, Piattelli M, Soardi E, Barausse C, Esposito M (2014) 1-Stage versus 2-Stage lateral sinus lift procedures: 1-Year post-loading results of a multicentre randomised controlled trail. European Journal of Oral Implantology 7(1):65–75

Fugazzotto PA (2003) Augmentation of the posterior maxilla: a proposed hierarchy of treatment selection. Journal of Periodontology 74(11):1682–1691. doi:10.1902/jop.2003.74.11.1682

Graziani F, Donos N, Needleman I, Gabriele M, Tonetti M (2004) Comparison of implant survival following sinus floor augmentation procedures with implants placed in pristine posterior maxillary bone: a systematic review. Clin Oral Implants Res 15:677–682. doi:10.1111/j.1600-0501.2004.01116.x

Jang H-Y, Kim H-C, Lee S-C, Lee J-Y (2010) Choice of graft material in relation to maxillary sinus width in internal sinus floor augmentation. J Oral Maxillofac Surg 68:1859–1868. doi:10.1016/j.joms.2009.09.093

Jensen OT (1994) Guided bone graft augmentation. In: Buser D, Dahlin C, Schenk RK, eds. Guided bone regeneration in implant dentistry. 1st edition. Chicago: Quintessence Publishing Co. Inc; pp. 235–264

Jensen OT, Shulman LB, Block MS, Iacono VJ (1998) Report of the sinus consensus conference of 1996. Int J Oral Maxillofac Implants 13 Suppl:11–45

Kang T (2008) Sinus elevation using a staged osteotome technique for site development prior to implant placement in sites with less than 5 mm of native bone: a case report. Int J Periodontics Restorative Dent 28:73–81

Katranji A, Fotek P, Wang H-L (2008) Sinus augmentation complications: etiology and treatment. Implant Dent 17:339–349. doi:10.1097/ID.0b013e3181815660

Klijn RJ, Meijer GJ, Bronkhorst EM, Jansen JA (2010) A meta-analysis of histomorphometric results and graft healing time of various biomaterials compared to autologous bone used as sinus floor augmentation material in humans. Tissue Eng Part B Rev 16:493–507. doi:10.1089/ten.TEB.2010.0035

Misch, Carl E. (c. 1999). 2nd. ed., Contemporary Implant Dentistry. St. Louis: Mosby. pp. xviii, 684 p

Misch CE, Judy KW (1987) Classification of partially edentulous arches for implant dentistry. Int J Oral Implantol 4:7–13

Nkenke E, Schlegel A, Schultze-Mosgau S, Neukam FW, Wiltfang J (2002) The endoscopically controlled osteotome sinus floor elevation: a preliminary prospective study. Int J Oral Maxillofac Implants 17:557–566

Nkenke E, Stelzle F (2009) Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. Clin Oral Implants Res 20(Suppl 4):124–133. doi:10.1111/j.1600-0501.2009.01776.x

Peleg M, Mazor Z, Chaushu G, Garg AK (1998) Sinus floor augmentation with simultaneous implant placement in the severely atrophic maxilla. J Periodontol 69:1397–1403. doi:10.1902/jop.1998.69.12.1397

Peleg M, Mazor Z, Garg AK (1999) Augmentation grafting of the maxillary sinus and simultaneous implant placement in patients with 3 to 5 mm of residual alveolar bone height. Int J Oral Maxillofac Implants 14:549–556

Pjetursson BE, Tan WC, Zwahlen M, Lang NP (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. J Clin Periodontol 35:216–240. doi:10.1111/j.1600-051X.2008.01272.x

Seong W-J, Barczak M, Jung J, Basu S, Olin PS, Conrad HJ (2013) Prevalence of sinus augmentation associated with maxillary posterior implants. J Oral Implantol 39:680–688. doi:10.1563/AAID-JOI-D-10-00122

Sendyk WR. Sendyk CL (2002) Reconstrução óssea por meio do levantamento do assoalho do seio maxilar. In: Gomes LA. Implantes osseointegrados – Técnica e Arte. São Paulo: Ed. Santos. p. 109–122

Simion M, Fontana F, Rasperini G, Maiorana C (2004) Long-term evaluation of osseointegrated implants placed in sites augmented with sinus floor elevation associated with vertical ridge augmentation: a retrospective study of 38 consecutive implants with 1- to 7-year follow-up. The International Journal of Periodontics and Restorative Dentistry 24(3):208–221

Stern A, Green J (2012) Sinus lift procedures: an overview of current techniques. Dental Clinics of North America 56(1):219–233, x. doi:10.1016/j.cden.2011.09.003

Tan WC, Lang NP, Zwahlen M, Pjetursson BE (2008) A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II: transalveolar technique. J Clin Periodontol 35:241–254. doi:10.1111/j.1600-051X.2008.01273.x

Tong DC, Rioux K, Drangsholt M, Beirne OR (1998) A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 13:175–182

Wallace SS, Froum SJ (2003) Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol Am Acad Periodontol 8:328–343. doi:10.1902/annals.2003.8.1.328

Wang HL, Katranji A (2008) ABC sinus augmentation classification. The International Journal of Periodontics and Restorative Dentistry 28(4):383–389

Weingart D, Bublitz R, Petrin G, Kälber J, Ingimarsson S (2005) Combined sinus lift procedure and lateral augmentation. A treatment concept for the surgical and prosthodontic rehabilitation of the extremely atrophic maxilla. Mund Kiefer Gesichtschir 9:317–323. doi:10.1007/s10006-005-0627-3

Zitzmann NU, Schärer P (1998) Sinus elevation procedures in the resorbed posterior maxilla. Comparison of the crestal and lateral approaches. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:8–17

Index

R. Younes et al. (eds.), *Sinus Grafting Techniques: A Step-by-Step Guide*,
DOI 10.1007/978-3-319-11448-4