Horizontal and Vertical
BONE AUGMENTATION
for Dental Implant Therapy

Horizontal and Vertical BONE AUGMENTATION for Dental Implant Therapy

EDITED BY

CRAIG M. MISCH, DDS, MDS

Adjunct Clinical Professor
University of Michigan School of Dentistry
Ann Arbor, Michigan

Private Practice in Oral and Maxillofacial Surgery
Sarasota, Florida

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PREFACE

The field of implant dentistry continues to evolve and improve. One constant that has not changed is the need for sufficient bone volume at the site of implant placement to facilitate osseointegration and continued bone support over time. Bone augmentation is often required to accomplish this important goal. Many books on implant dentistry reflect an author's approach to a specific clinical problem—a "this is how I do it" book. I have always had a passion for research and teaching, and my goal for this text was to explain not only how I do it but also *why* and *when* we do it.

The first six chapters provide the reader fundamental knowledge of the science of bone augmentation, and chapters 7 to 10 cover the diagnosis and planning for bone augmentation surgery. The centerpiece of the text is the Michigan Classification for horizontal and vertical bone augmentation. Dr Hom-Lay Wang and I developed the Michigan Classification to offer clinicians an evidence-based decision tree for managing different clinical situations. This classification focuses on the treatment of bone defects and deficiencies outside the bony contour. The current research on outcomes using various methods of bone augmentation and biomaterials was evaluated to construct parameters and guidelines. Finally, chapters 11 to 18 discuss the various techniques for horizontal and vertical bone augmentation.

For this text I invited the most knowledgeable clinicians and researchers in their specific areas of expertise to coauthor the chapters. As such, it reflects a collective body of work rather than one author's preference or opinion. My goal was to provide a comprehensive source of authoritative information on the topic of bone augmentation. I also wanted to establish guidelines for students, clinicians, and researchers on predictable approaches to bone regeneration for dental implant therapy.

Technology has improved our ability to diagnose, plan, and execute treatment; using CBCT, we can create a virtual patient for prosthetic guided bone augmentation. Customized scaffolds for bone regeneration can be fabricated based on the specific needs of each patient. Recombinant growth factors can be used to improve the regenerative capacity of osteoconductive biomaterials. Further advancements will undoubtedly improve outcomes. Surgeons should consider the advantages and disadvantages of each material and technique for the clinical situation and choose the approach with manageable costs, low morbidity, and the greatest chance for success. This text offers the reader a better understanding of how to accomplish these goals and improve the lives of their patients.

Acknowledgments

The first person I wish to thank is my loving wife, Katie. We have been married for over 30 years and raised three intelligent and beautiful daughters: Maggie, Angela, and Rachel. Katie and I also practice together in the same office, Misch Implant Dentistry. We have just added Maggie Misch-Haring to the team as our periodontist and her husband, Harry Haring, as another prosthodontist. Throughout our marriage, Katie has supported my professional goals and helped me achieve a successful career. I could not have done it without her. I have always had a great interest in bone regeneration and dental implant therapy; Katie knew I always wanted to write a book on this topic and that my bucket list would not be complete until this was done. I realize it has not been easy putting our lives on hold while working on this project, but she continued to be supportive, and I am exceedingly grateful.

I also want to acknowledge my brother, Carl, for encouraging my interest in dentistry and fostering my education in dental implants. We worked together in Michigan for 3 years and thereafter did our prosthodontic

PREFACE

residency training at the University of Pittsburgh. Carl also inspired me to become active in professional organizations and to teach, write, and lecture.

Following my prosthodontic residency and implantology fellowship, I stayed on as faculty at the University of Pittsburgh. My program director, Dr Chester Chorazy, took a chance on accepting a prosthodontist into an oral and maxillofacial surgical residency. This opportunity was the missing piece of the puzzle in my training and professional career. Dr Chorazy was like a father to us and mentored our education and surgical training.

I also want to thank Dr Hom-Lay Wang for his continued support and friendship. Dr Wang helped immensely with writing and editing this text. Although he is extremely busy, he was always available to help. To all the coauthors in this text, I appreciate your expertise, dedication, and willingness to contribute and share your knowledge for this publication.

Last but not least, I would like to thank the Quintessence Publishing staff, including Leah Huffman (Editorial Director), Bryn Grisham (Publishing Director), and William Hartman (Executive Vice President and Director). With so many contributors, it was a challenge meeting timelines, but with dedication, persistence, and patience, our task was completed. I hope you enjoy the finished product.

CONTRIBUTORS

Tara Aghaloo, DDS, MD, PhD
Professor of Oral and Maxillofacial Surgery
UCLA School of Dentistry
Los Angeles, California

Carlo Barausse, DDS, PhD
Department of Biomedical and Neuromotor Sciences
University of Bologna
Bologna, Italy

Chia-Yu Chen, DDS, DMSc
Division of Periodontology
Department of Oral Medicine, Infection, and Immunity
Harvard School of Dental Medicine
Boston, Massachusetts

Matteo Chiapasco, MD
Professor, Unit of Oral Surgery
Department of Biomedical, Surgical, and Dental Sciences
University of Milan
Milan, Italy

Benjamin R. Coyac, DDS, PhD
Department of Periodontology and Laboratory for Bone Repair
School of Graduate Dentistry
Rambam Health Care Campus
Haifa, Israel

Alessandro Cucchi, DDS, MSClin, PhD
Private Practice
Bologna, Italy

Dan Cullum, DDS
Private Practice in Oral and Maxillofacial Surgery
Coeur d'Alene, Idaho

Pietro Felice, MD, DDS, PhD
Department of Biomedical and Neuromotor Sciences
University of Bologna
Bologna, Italy

Matthew Fien, DDS
Private Practice in Periodontics
Fort Lauderdale, Florida

William V. Giannobile, DDS, MS, DMSc
Dean and A. Lee Loomis, Jr, Professor of Oral Medicine, Infection, and Immunity
Harvard School of Dental Medicine
Boston, Massachusetts

Howard Gluckman, BDS, MChD, PhD
Private Practice in Periodontics and Implant Dentistry
Cape Town, South Africa

Adjunct Assistant Professor
University of Pennsylvania School of Dental Medicine
Philadelphia, Pennsylvania

Adjunct Professor
University of the Western Cape
Cape Town, South Africa

Jill A. Helms, DDS, PhD
Professor and Vice Chair, DEI
Department of Surgery
Stanford School of Medicine
Stanford University
Palo Alto, California

Ole Jensen, DDS, MS
Adjunct Professor
University of Utah School of Dentistry
Salt Lake City, Utah

CONTRIBUTORS

David Kim, DDS, DMSc
Associate Professor
Division of Periodontology
Harvard School of Dental Medicine
Boston, Massachusetts

Jessica Latimer, DDS
Division of Periodontology
Department of Oral Medicine, Infection, and Immunity
Harvard School of Dental Medicine
Boston, Massachusetts

Bach Le, DDS, MD
Clinical Associate Professor
Department of Oral & Maxillofacial Surgery
The Herman Ostrow School of Dentistry
University of Southern California
Los Angeles, California

Private Practice in Oral and Maxillofacial Surgery
Whittier, California

Mark Ludlow, DMD, MS
Section Head of Implant Dentistry, Digital Dentistry, and Removable Prosthodontics
University of Utah School of Dentistry
Salt Lake City, Utah

Shogo Maekawa, DDS, PhD
Department of Periodontology
Graduate School of Medical and Dental Sciences
Tokyo Medical and Dental University
Tokyo, Japan

Richard J. Miron, DDS, BMSc, MSc, PhD, Dr med dent
Department of Periodontology
School of Dental Medicine
University of Bern
Bern, Switzerland

Craig M. Misch, DDS, MDS
Adjunct Clinical Professor
University of Michigan School of Dentistry
Ann Arbor, Michigan

Private Practice in Oral and Maxillofacial Surgery
Sarasota, Florida

Maggie Misch-Haring, DMD, MS
Private Practice in Periodontics and Implant Surgery
Sarasota, Florida

Alberto Monje, DDS, MS, PhD
Department of Periodontology
University of Michigan School of Dentistry
Ann Arbor, Michigan

Adjunct Professor, Department of Periodontology
UIC Barcelona
Barcelona, Spain

Rodrigo Neiva, DDS, MS
Chair and Clinical Professor of Periodontics
Penn Dental Medicine
University of Pennsylvania
Philadelphia, Pennsylvania

Lorenzo Tavelli, DDS, MS, PhD
Division of Periodontology
Department of Oral Medicine, Infection, and Immunity
Harvard School of Dental Medicine
Boston, Massachusetts

Istvan A. Urban, MD, DMD, PhD
Urban Regeneration Institute
Budapest, Hungary

Hom-Lay Wang, DDS, MDS, PhD
Professor and Director of Graduate Periodontics
University of Michigan School of Dentistry
Ann Arbor, Michigan

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BONE VOLUME FOR DENTAL IMPLANT PLACEMENT

Craig M. Misch | Hom-Lay Wang | Maggie Misch-Haring

The replacement of missing or failing teeth with dental implants has revolutionized the field of dentistry and improved the quality of our patients' lives. High success rates and excellent predictability of dental implant therapy have been demonstrated in numerous clinical studies and a variety of indications. A number of factors important for the long-term survival and/or success of implants and implant-supported prostheses have been identified. One critical prerequisite is a sufficient volume of bone at the site of implant placement to facilitate osseointegration and continued bone support over time. In a prosthetic-driven approach to treatment, the planned prosthesis guides the number and 3D position of the implants. If the preferred implant locations have inadequate available bone, then bone augmentation may be required so that the implant can be placed in the ideal position for esthetics, prosthetic support, and long-term function.

Bone Volume

The volume of bone in the edentulous site planned for implant placement is measured in 3D in terms of width, height, and angulation.

Bone width

The minimum bone width is dependent on the preferred implant diameter and location. A minimum 2.0-mm facial bone thickness has been recommended around implants in the esthetic zone to avoid crest resorption and gingival recession.[1,2] However, this recommendation was based on 1.4-mm horizontal bone loss found around external hex connection implants[3] (Fig 1-1). Tissue-level, conical-connection, and platform-switching implants are associated with less bone resorption.[4–6] A clinical study found that the horizontal component of bone loss around platform-switching implants measured only 0.6 mm.[7] Therefore, using implant designs with a conical seal, medialized connection, or absence of a microgap, such as a tissue-level implant, may reduce the ridge width requirement to 1.0 to 1.5 mm of facial and palatal/lingual bone (Fig 1-2). In addition, the edentulous ridge typically widens apically from the crest, so vertical bone reduction may be an alternative to bone augmentation in areas where esthetics is not a concern. However, in some cases the facial and palatal/lingual cortices may show minimal divergence.

Another alternative to bone augmentation of the atrophic ridge with deficient width is to use a narrow-diameter implant (NDI; Fig 1-3). A recent systematic review and meta-analysis found that implant diameters of 3.0 to 3.5 mm showed no difference in implant survival compared to standard-diameter implants (> 3.5 mm).[8] Additional systematic reviews and meta-analyses of studies have also found that NDIs are an effective alternative to standard-diameter implants due to similar survival and success rates, marginal bone loss, and mechanical

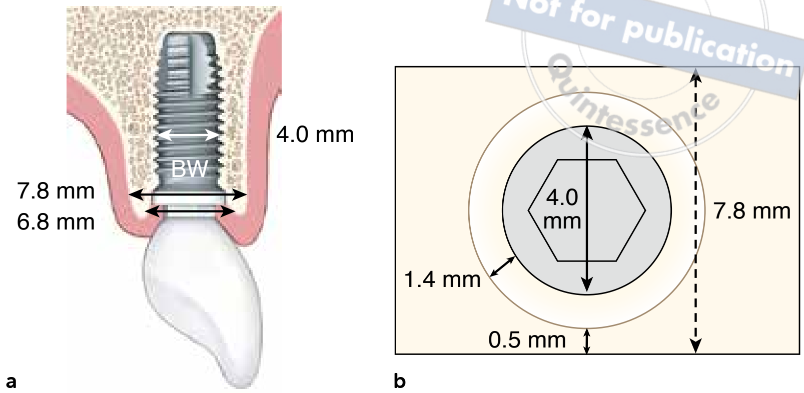

FIG 1-1 Cross-sectional *(a)* and occlusal *(b)* views of horizontal bone loss around an external hex implant. A minimum ridge width of 7.8 mm would be needed for placement of a 4.0-mm-diameter implant.

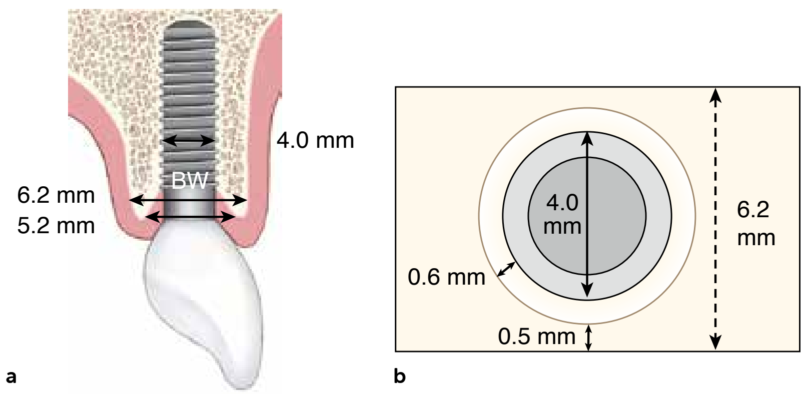

FIG 1-2 Cross-sectional *(a)* and occlusal *(b)* views of horizontal bone loss around a conical-connection implant. A minimum ridge width of 6.2 mm would be needed for placement of a 4.0-mm-diameter implant.

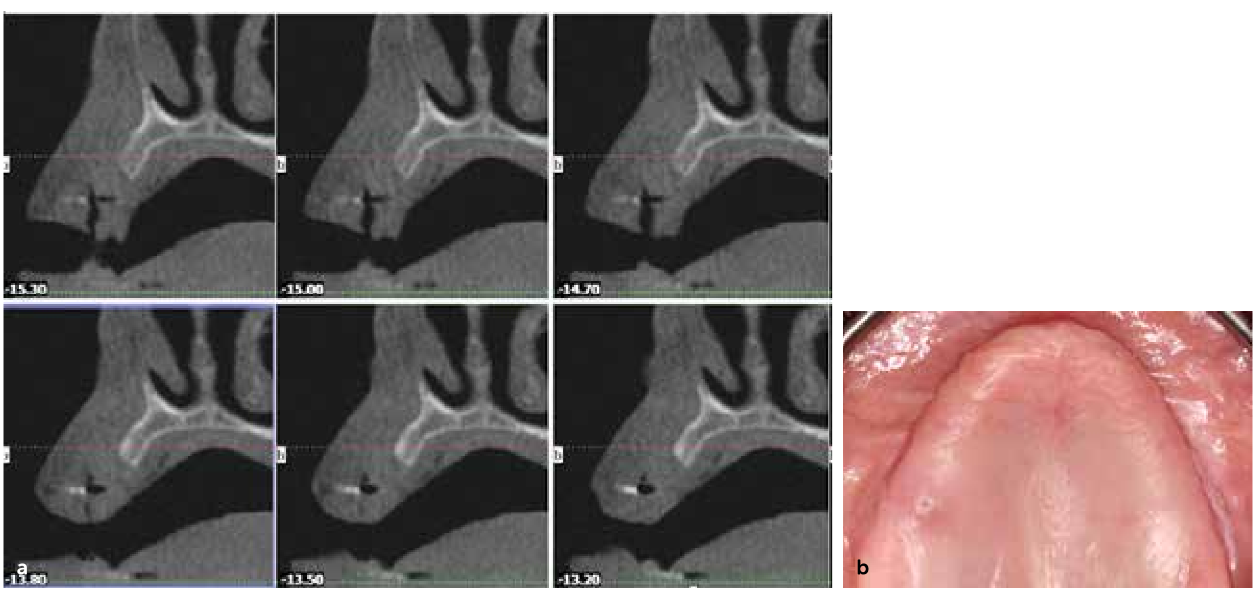

FIG 1-3 *(a)* A preoperative CT scan reveals a narrow ridge in the edentulous maxilla. *(b)* Preoperative occlusal view of the atrophic maxilla.

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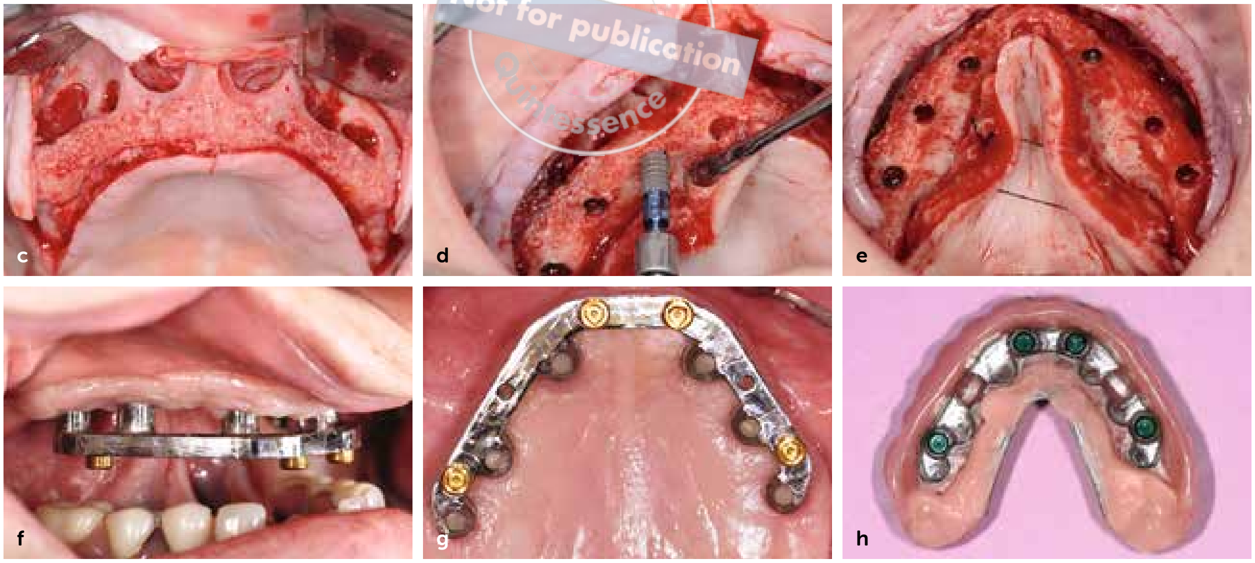


FIG 1-3 *(cont) (c)* Surgical view of the atrophic maxilla. The nasal and sinus floors were identified, and the mucosa was reflected superiorly. (Surgery performed by Dr Maggie Misch-Haring.) *(d)* Placement of an NDI (3.3 × 8.0 mm) with a nasal lift. *(e)* Six NDIs (3.3 × 8.0 mm) were placed in the atrophic maxilla. *(f)* The implants were restored with an implant-connecting bar. *(g)* Occlusal view of the implant-connecting bar. Note the medial position of the implants due to maxillary atrophy. *(h)* Intaglio view of the maxillary overdenture with attachments. *(i)* Clinical view of the maxillary overdenture.

and biologic complication rates.[9,10] Stronger metals, such as titanium-zirconium or titanium alloy, may reduce the risk of implant fracture when NDIs are used. Systematic reviews on titanium-zirconium NDIs have found implant success and survival rates to be similar to those of standard-diameter titanium implants with no increase in fractures.[11,12] However, long-term survival and data on the possible risk of technical complications with wide-platform restorations on NDIs are lacking. As such, a standard- or wide-diameter implant for single molar replacement may be prudent.

Bone height

The minimum bone height for implant placement is dependent on several factors. One consideration is the anatomical region. In the posterior maxilla, the floor of the sinus can limit the available bone height. However, the sinus floor is an anatomical boundary that can be encroached upon or manipulated via an internal or lateral sinus elevation. Many studies have shown that the survival of short implants (< 8 mm in length) is the same as that of longer implants placed into grafted sinuses.[13,14] Although there is no definitive bone dimension needed before considering sinus bone grafting, 6.0 to 8.0 mm inferior to the sinus floor appears to be sufficient (Fig 1-4). In the posterior mandible, the mandibular canal and lingual cortex can limit implant length. A common rule is to allow for at least a 2.0-mm distance from the mandibular canal for implant placement to account for potential inaccuracies in radiographic measurements, drilling depth, and implant placement.[15] As mandibular bone is usually of better quality, extra-short implants (6.0 mm in length) have been shown to be effective[16] (Fig 1-5). As such, 8.0 mm of available bone height superior to the canal is needed to place extra-short implants in the posterior mandible (Fig 1-6).

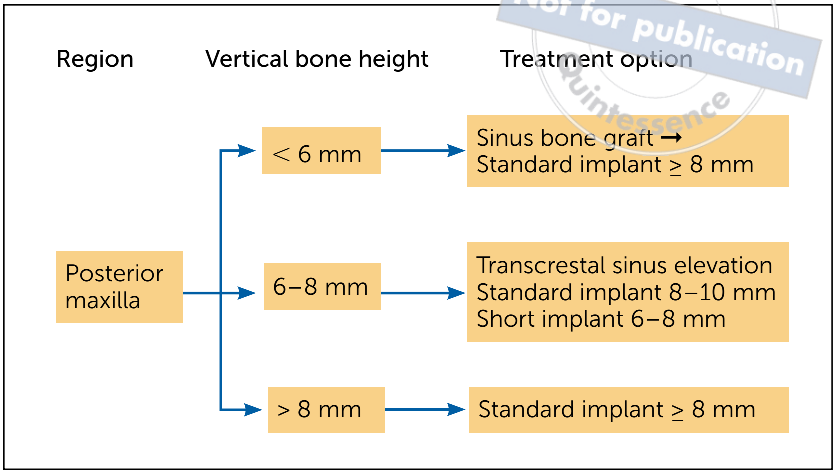


FIG 1-4 Vertical bone height requirements in the posterior maxilla.

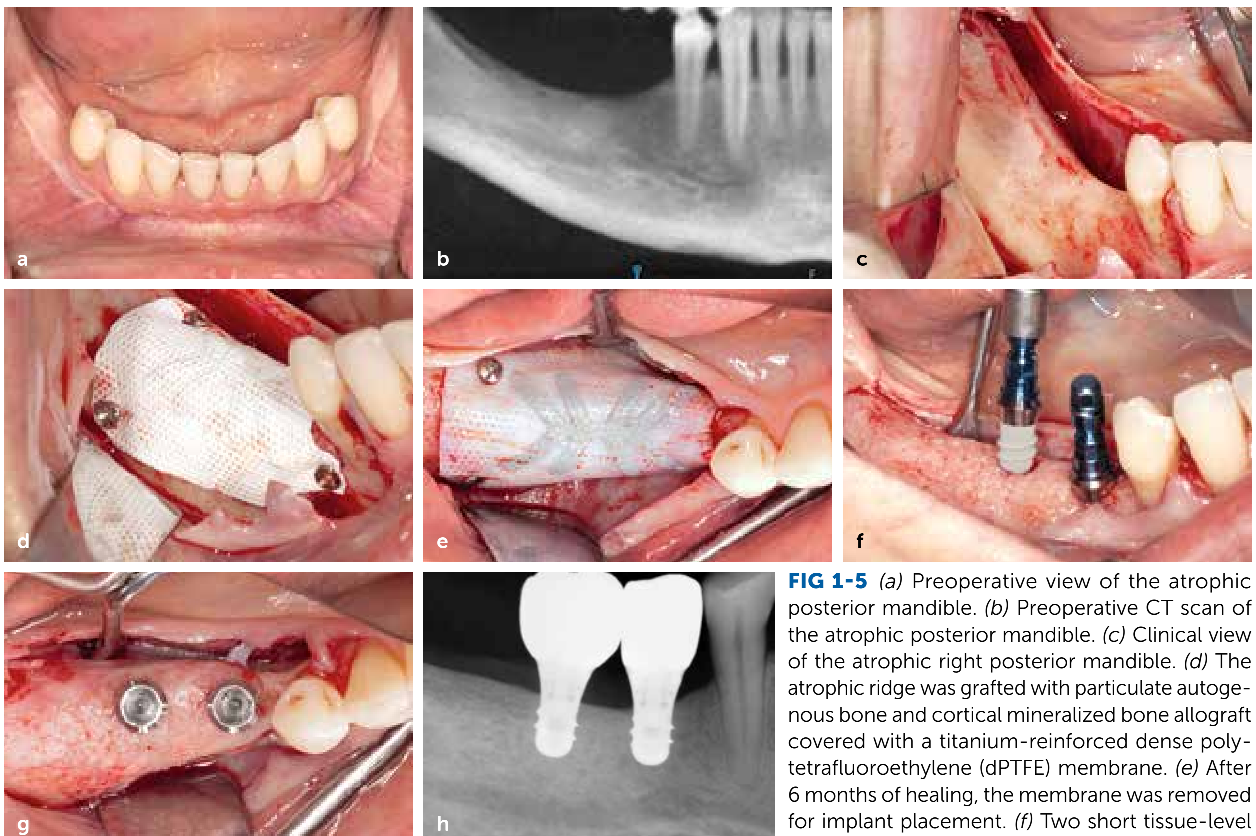


FIG 1-5 *(a)* Preoperative view of the atrophic posterior mandible. *(b)* Preoperative CT scan of the atrophic posterior mandible. *(c)* Clinical view of the atrophic right posterior mandible. *(d)* The atrophic ridge was grafted with particulate autogenous bone and cortical mineralized bone allograft covered with a titanium-reinforced dense polytetrafluoroethylene (dPTFE) membrane. *(e)* After 6 months of healing, the membrane was removed for implant placement. *(f)* Two short tissue-level implants (4.1 × 6.0 mm) were placed into the grafted mandible. *(g)* Occlusal view of the two short tissue-level implants in the right posterior mandible. *(h)* The implants were restored with individual screw-retained crowns.

The amount of bone resorption following the loss of teeth determines the crown height or prosthetic space. *Implant crown–abutment height space* is defined as the distance from the occlusal plane to the platform of the implant(s). The available restorative space will influence the type of prosthesis, material choices, and surgical techniques. It also has esthetic and biomechanical implications. In the esthetic zone, the decision needs to be made

FIG 1-6 Vertical bone height requirements in the posterior mandible.

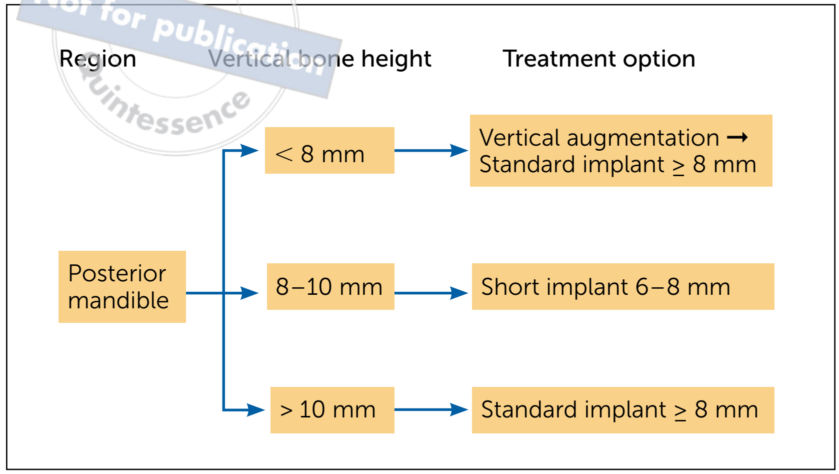
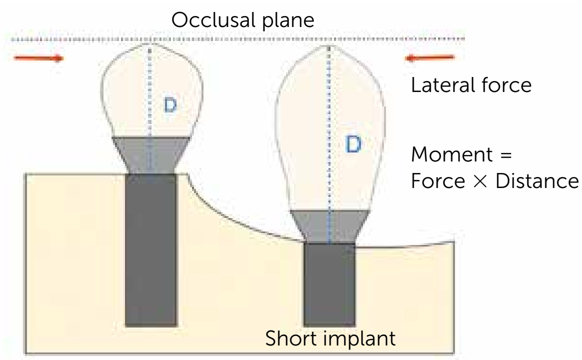


FIG 1-7 Using short implants in an atrophic ridge increases the crown–abutment height space. Placing a short implant into an atrophic ridge will result in greater crown-abutment height (D). Because moment = force × distance, a greater distance (D) will increase the moment or torque on the implant-abutment connection.



regarding whether to reconstruct a vertical bone defect in an attempt to replicate normal anatomy or to replace the missing hard and soft tissue with the prosthesis. As vertical bone augmentation is more technically difficult, a prosthetic solution may provide a more predictable and straightforward approach in some cases. When crown–abutment height space is excessive, the resultant load on the prosthetic connection increases (Fig 1-7). This can result in a greater risk of technical complications such as abutment screw loosening and component fracture. When the crown–abutment height space becomes greater, the implant crowns may be splinted to decrease the risk of mechanical complications. However, systematic reviews have found that marginal bone loss and implant survival do not appear to be influenced by the crown-to-implant ratio.[17–19]

Ridge angulation

In some cases, the angulation of the ridge in the edentulous site may not allow for the ideal implant trajectory. This problem is most often encountered in the atrophic maxilla. As the facial bone resorbs following extraction, the long axis of the ridge can become more tilted facially in line with the palatal contour (Fig 1-8). If the implant is placed in a more vertical orientation, the facial bone may be too thin or the apex may perforate the buccal cortex. This issue may be a more significant problem with single-tooth implants and small-span implant-supported partial dentures in the anterior maxilla. Bone augmentation may be needed to restore the ridge contour and allow for a better implant trajectory. An alternative approach is to place the implant at an angle within the bone and

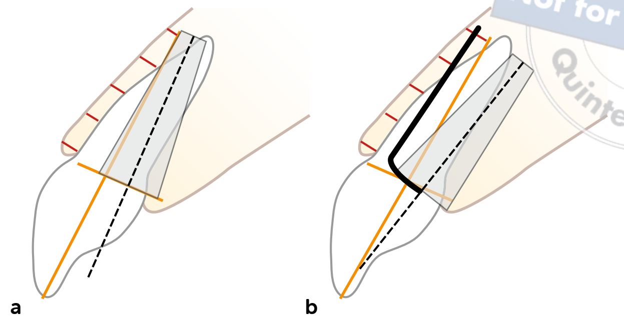


FIG 1-8 Facial bone resorption following tooth loss requires a more facial implant inclination. Note the difference between the position of an implant placed upon extraction of a maxillary incisor *(a)* versus implant placement after extraction and bone remodeling at the expense of the facial *(b, black line* represents facial contour of the resorbed ridge). The implant needs to be inclined more buccally.

use an angulated abutment to alter the path of prosthetic attachment or use an angulated screw channel. Although in the past there was concern regarding off-axis loading of dental implants, more recent studies have found no decrease in implant survival or higher marginal bone loss with tilted implants.[20]

Soft Tissue Thickness

Another important factor for stability of the peri-implant bone is vertical soft tissue thickness. Several studies have suggested that approximately 4.0 mm of supracrestal soft tissue height is required to allow the formation of a biologic seal.[21,22] A more accurate term may be *supracrestal tissue adhesion* due to horizontal fiber orientation around the dental implant.[22] Thin tissue may induce bone remodeling around the implant neck to obtain adequate biologic width.[23–26] When managing a deficient ridge with a thin phenotype, it may be necessary to plan for soft tissue as well as hard tissue augmentation.

The Consequences of Tooth Loss

Insufficient bone for dental implant placement can be a consequence of periodontitis, infection, trauma, pathology, tooth loss, jaw atrophy, congenital absence of teeth, or previous dental implant failure. Following tooth loss, the bundle bone lining the socket is rapidly resorbed. The greatest amount of alveolar bone loss occurs on the facial aspect due to the limited thickness of the buccal cortex compared to the lingual/palatal aspects of the socket walls.[27] The thickness of the facial cortex in the crestal area of teeth in the anterior maxilla has been shown to be thin (< 1 mm) in approximately 90% of patients.[28,29] Sockets that have thin facial bone are prone to more resorption following tooth loss. Although this results in more horizontal resorption, there is also loss of vertical ridge height, which has been reported to be most pronounced on the buccal aspect.[30] A CBCT study found that thin facial wall thickness (< 1 mm) was associated with significant vertical bone resorption, with a median vertical bone loss of 7.5 mm, as compared with thicker socket walls (> 1 mm), which showed vertical bone resorption of only 1.1 mm after 8 weeks of healing.[31] Human studies on alveolar bone resorption following extraction have shown horizontal bone loss of 29% to 63% and vertical bone loss of 11% to 22% after 6 months of healing.[32] These studies demonstrated rapid reductions in the first 3 to 6 months, followed by a gradual reduction in dimensions thereafter, when remodeling of the ridge begins to plateau. However, longitudinal studies have found a continued reduction of the residual ridge in patients wearing soft tissue–borne removable prostheses.[33,34]

Bone resorption following tooth loss can compromise the bone volume for implant placement and may also have a deleterious effect on the implant position. In the maxilla, there is a greater loss of facial bone initially, so the residual ridge loses width and moves in a medial direction. As a consequence, the long axis of the ridge for implant placement tilts more to the facial (see Fig 1-8). With additional resorption, there is a loss of bone height and continued palatal shift of the ridge crest (Fig 1-9a). This can compromise implant positioning as the restorations need to be facial to the ridge crest. In the mandible, the initial loss of facial bone also results in a loss of ridge width as the residual ridge moves in a medial direction. However, with continued atrophy and loss of bone height, the lingual inclination of the mandible leads to a gradual inferior and lateral shift of the ridge crest (see Fig 1-9a). In the sagittal plane, the anterior maxilla

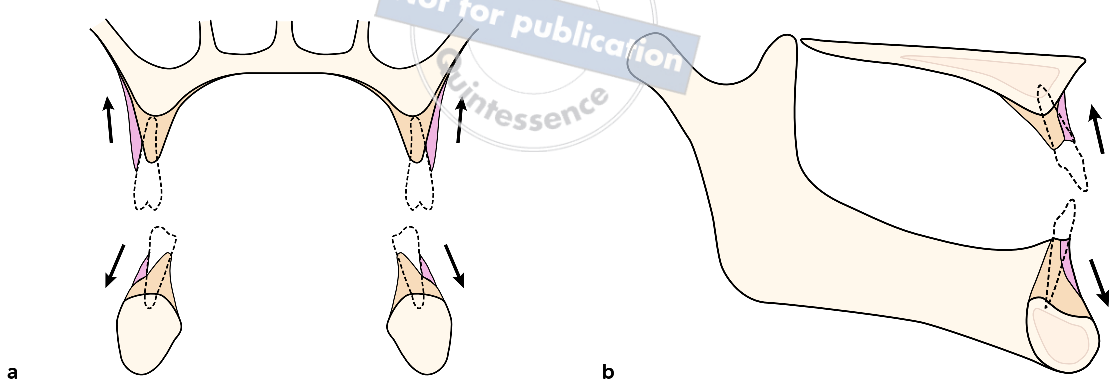


FIG 1-9 *(a)* In the posterior region, the maxilla resorbs in a medial direction. The mandible initially resorbs medially, but with vertical loss it becomes wider. *(b)* The sagittal view shows that the anterior maxilla resorbs in a palatal direction, while the anterior mandible initially resorbs medially, but with vertical loss it moves in a facial direction.

resorbs in a superior and posterior direction while the anterior mandible resorbs in an inferior and anterior direction (Fig 1-9b). In the edentulous patient who has experienced moderate to severe ridge resorption in both the maxilla and mandible, a resultant skeletal Class III relationship occurs along with a prognathic appearance. Such bone atrophy can cause compromised interarch relationships in the vertical, transverse, and sagittal planes, which may complicate dental implant placement from a functional and esthetic perspective.

Bone loss and soft tissue alterations following tooth loss in the anterior maxilla can have a significant impact on the esthetic outcome of implant-supported restorations. To restore ridge contour and provide adequate bone volume for implant placement, bone and soft tissue augmentation is often a prerequisite to achieving a satisfactory esthetic result. These cases can be especially challenging when lip mobility exposes the maxillary gingiva or vertical bone augmentation is needed.

As bone loss following tooth extraction can negatively influence bone volume for implant placement and position, esthetics, and biomechanics, it is prudent to consider measures to maintain alveolar bone. The use of alveolar ridge preservation (ARP) can minimize dimensional changes following tooth extraction to provide adequate bone volume for dental implant placement. Extraction sites treated with socket bone grafts (ARP) have been shown to have significantly less dimensional change both vertically and horizontally when compared with controls not treated with ARP procedures.[35] In conjunction with minimally traumatic tooth extraction, this may reduce the need for subsequent bone augmentation procedures or decrease the amount of bone gain required for future dental implant placement.

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