This book is dedicated to my wife, Marina, for her sacrifices and unlimited love, and our children, Deana and Antony, who provided the light and drive to make this book possible.
Vertical Alveolar Ridge Augmentation in Implant Dentistry
A Surgical Manual

Edited by

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Preface

“Education is not a learning of facts, but training of the mind to think.”

Albert Einstein.

“Anatomy is destiny,”

Sigmund Freud.

Implant Dentistry (Oral Implantology) is a constantly evolving dental and surgical clinical practice and science. There are a variety of books that come out every year on different aspects of this surgical–restorative discipline. Large hardcover textbooks with a name containing at least two words implant and dentistry heavily dominate shelves of medical/dental bookstores of many publishing companies and subsequently homes of many dentists who are happy to dedicate themselves to a lifelong learning. For different reasons, these expensive and authoritative books are often not top sellers. These books often become "shelf-bound", collecting dust but more importantly providing little practical use in spite of their original intent.

During my professional dental graduate and oral and maxillofacial surgery postgraduate studies in three universities, I have always enjoyed more practical books – clinical manuals. These usually smaller medical, surgical, and dental books in a hard or soft cover were my mobile knowledge friends that I could take with me anywhere and study "on the go" in any setting. Arguably, these friendly manuals are preferred by most medical and dental students, residents, and doctors alike.

A good example of this type of clinically relevant practical book for me has always been Rapid Interpretation of EKG’s by Dale Dubin, MD. This is by far one of the most widely read and studied medical books by any medical or dental practitioner who had to learn about electrocardiography (EKG). This outstanding book is now in its successful 6th Edition and has always been a No.1 Best Seller. Why? I believe this is not only because it is a brilliantly written book accompanied by easy to follow photos, graphs, and tables, as well as quizzes and interactive courses, but also because of the book’s immense practicality and relevance for any health science student or practitioner or often a lay reader/learner.

The book that you are holding in your hands is an attempt to write this sort of book, a very clinically relevant surgical manual, a practical guide on the WHY and HOW of the alveolar bone augmentation in implant dentistry, a "take to the operative room" book full of clinically oriented chapters that can be easily understood and followed.

In the middle of writing this book, due to an enormous amount of accumulated techniques for the alveolar ridge augmentation, Dr. Ole Jensen (whom I consider my mentor and who wrote an Introduction for this book) suggested that it would be an impossible and confusing task to demonstrate to doctors, residents, and students all these amazing surgical techniques in a single book volume. The size of this book would be enormous and practicality of having something very relevant with you and being able to "carry it around" would be a daunting task. That is how slowly the concept of two volumes (two books, really) evolved where horizontal and vertical ridge augmentation techniques in a style of a surgical manual-atlas full of case reports and illustrative photos are described in separate books.

The first book (Book I) contains multiple surgical techniques intended for mainly width-deficient alveolar ridges and thus the book is, in general, about the horizontal ridge augmentation; the second book, Vertical Alveolar Ridge Augmentation in Implant Dentistry: A Surgical Manual (Book II) contains a variety of surgical procedures designed for height (and volume) deficient alveolar ridges and therefore is about vertical and three-dimensional ridge augmentation. Both books do not claim to be a complete all-inclusive dissertation of all alveolar bone augmentation techniques. That would be impossible and impractical. Many surgical techniques are being proposed almost daily on the pages of peer-review oral surgical, periodontal, implant, and general dental journals and other publications. They are also often modified from the original versions with the discovery of new instrumentation and advances in computer technology. Two books approach was a logical (we thought) attempt to “split” the presented material into horizontal and vertical surgical techniques for the sake of learning.

Our goal with these two intrinsically linked books was to present a variety of commonly used and sometimes less known surgical techniques from a different point of view in a clear and concise manner with photographs and illustrations, and supplemented by case reports. Each book starts with the applied surgical anatomy and embryology of the jaws, move through diagnosis and treatment planning, which includes a team approach with restorative practitioner (prosthetic chapter) and often an orthodontic colleague (orthodontic implant side development chapter), and then move to a variety of hard (and even soft) tissue augmentation techniques. Each book ends with a glance into the future (quickly becoming a present-day reality), like tissue engineering, stem-cell technology, and organ regeneration. All these chapters were written by top-notch surgical specialists (surgeons–researchers–lecturers) from around the globe in the area of their particular expertise.

A reader of any skill or knowledge- a surgical resident or a new dental practitioner, an experienced periodontist or an oral and...
maxillofacial surgeon- pay a special attention to the following three surgical concepts presented in these books:

1. Soft tissue versus hard tissue augmentation, or a combined hard–soft tissue augmentation approach that is often needed in the esthetic zone.

2. Static versus dynamic bone augmentation of the alveolar ridge (block graft versus distraction osteogenesis, or ridge-split versus orthodontic forced eruption, or guided bone regeneration (GBR) versus periosteal expansion osteogenesis).

3. Two-dimensional versus three-dimensional versus four-dimensional (predicting future bone changes associated with aging) bone augmentation.

As the editor and one of many contributors of these two surgical manuals, I hoped to accomplish the intended goal of these two books - to present a clinically relevant surgical material that would be read and re-read many times during your career and, therefore, would undoubtedly benefit your patients. If this will happen, I will consider myself a happy man.

Len Tolstunov
Acknowledgments

I would like to express my sincere gratitude to all 70 individuals from around the globe (from 10 countries) who became contributors to these two books (65 chapters in total) for their unselfish sharing of their knowledge, expertise, talent, and time. This was a volunteer army of top-notch professionals who sacrificed their own personal time to contribute to these books and thus to dental and medical education. In the process of book writing and production, many of them have become my friends and genuine collaborators whom I admire and look up to.

I especially would like to acknowledge my wife, Marina, who had to occupy her life with new hobbies and interests to fill the gap that her husband created for two full years by not being around all the time and spending numerous hours in the office occupied with this project. Marina is the love of my life and I would be remiss forgetting her sacrifices, which are numerous. My kids, Deana and Antony, were a daily part of my comfort zone that I needed so much in order to express myself clearly, genuinely, and completely on the pages of this book.

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I am also very grateful to my dear staff at our Van Ness Oral and Maxillofacial Surgery Center in San Francisco, who helped me to run my full-time surgical practice simultaneously with full-time book writing without major distress. They are Vilma Mejia, Liliya Kaganovsky, Marina Tolstunov, and Ann Siebert.

Many professional teachers and colleagues have unknowingly contributed to this book through the education they have provided to me. They include teachers and oral surgeons at the Moscow Medical Stomatological Institute in Moscow, Russia, the University of the Pacific in San Francisco, and the University of California San Francisco.
In modern implant-driven oral rehabilitation, alveolar bone deficiency is defined by what is necessary for successful dental implant osseointegration. This need for adequate quantity and quality of bone has led to the development of several innovative methods for alveolar ridge augmentation. At the same time, improved implant technology, like computer-guided implant placement methods, have lessened the need for complex augmentation procedures. The practitioner may ask what is needed for a specified treatment without regard to full regeneration of hard tissue. Where once large-scale reconstruction was considered, now minimally invasive surgical procedures are employed. The clinician then may ask what kind of minimally invasive procedures can and should be performed to support a restoratively driven implant treatment plan. This book will attempt to answer this question.

In addition to osseointegration, there are other factors to consider, including regaining alveolar form and associated esthetic gingival contour – effects termed orthoalveolar form. Orthoalveolar form, however, implies that the alveolar process and associated soft tissues are restored to ideal form and function with alveolar arches in functional occlusal relationship, including alveolar width and height and gingival drape essential for osseointegration and subsequent long-term function of dental implants. This means that the alveolus is not only restored to its original form but also often increased in bone mass and quality of soft tissue to accommodate dental implants. It is important to be familiar with a variety of surgical procedures in order to achieve an orthoalveolar form. This book will attempt to demonstrate these techniques.

Practitioners sometimes lose sight of what they need to accomplish. Completion of a surgical grafting procedure may not be needed for the prescribed implant procedure. Final restoratively driven surgical outcome according to a precise implant treatment plan helps to keep the whole dental team on track of what is needed to accomplish in each particular case. The surgeon must visualize where implant elements need to be placed, decide if the bone mass is needed there to support implants, and graft accordingly. This requires preprosthetic planning, which may include the use of surgical guide or navigation. The plan may prescribe staged or simultaneous grafting, even secondary grafting after implant placement. Whatever the plan, surgical efforts should attempt to gain added bone stock within the envelope of function, choosing a surgical method that has a biological basis for success. This book will attempt to illustrate these methods.

The surgical method of grafting is judged by early and late healing events but include the concepts of consolidation, functional remodeling, resistance to resorption, and bioactive capability for osseointegration. An ideal bone graft should therefore be well consolidated, undergo remodeling without significant resorption, and be well vascularized. Bone graft substitutes, like alloplasts, xenografts, and possibly allografts, may not fully integrate with native bone. Various forms of autografts, recombinant biomimetics, and autologous cell-based therapies may have an improved biological basis but require advanced surgical skills and technical support. This book will attempt to describe these therapies.

The quest for ideal bone graft is continuing. New techniques are constantly being introduced to simplify, improve, or expand indications for alveolar reconstruction. Currently, surgical techniques for implant-driven alveolar ridge augmentation can be classified into four broad categories. These would include: (1) guided tissue and bone regeneration (with or without titanium-reinforced devices), (2) block grafting (extraoral and intraoral), (3) ridge-split with formation of osteoperiosteal (pedicled) flaps, and (4) distraction osteogenesis. Alveolar ridge deficiency can also be classified according to defect morphology such as vertical defects, horizontal defects, combination defects, and complete absence of bone. Science and practice of alveolar ridge reconstruction is still a descriptive surgical discipline with numerous variables to consider, not the least of which is the “patient factor” that includes the patient’s general medical condition, patient’s wishes and desires (wants and needs), and patient’s cooperation. This book will attempt to address these factors of importance.

Another factor to consider in any surgery is the healing capacity of the host’s recipient site being grafted. In many cases, it can be more important than the type of material used for grafting. If the site is well vascularized and the grafting procedure is done well, complete incorporation of the bone graft may occur. Interestingly, in 1668, the very first bone graft (harvested from a dog) worked so well that it could not be removed when the patient asked for it to be removed for religious reasons at a later date. Failure of a bone graft, often attributed to the material used, probably happens more often due to host site healing deficiency or flawed surgical technique rather than the intrinsic property of the graft material per se.

One factor that has become extremely important is simplification of treatment, that is, economy of surgery, management, and expenditure. This means that the social contract between patient and physician has narrowed to favor minimally invasive procedures, shortened treatment times, simplified surgical management, and affordability. This is why an immediate function implant treatment has become so prevalent, even in the case of simultaneous bone grafting. The difficulty with simplification is proper diagnosis, comprehensive treatment planning, and adequate training. In addition, consensus on bone grafting and decision-making process are often limited to experience-based case report knowledge and lacking level I and II evidence-based controlled studies that are frequently difficult to find.

The purpose of this clinically oriented book in two volumes is to demonstrate the various techniques of implant-driven horizontal (Book I) and three-dimensional/vertical (Book II) alveolar bone augmentation treatment in use today in an easy to follow, step-by-step format. An international and multidisciplinary group of surgical specialists, well known in their own fields, will present various
surgical methods that will be illustrated graphically and supplemented by multiple intraoperative photographs. Benefits, risks, alternatives and complications of each technique will be demonstrated and scientific references will be provided, giving a reader a true insight into each surgical technique. This, hopefully, will help a reader to improve the knowledge of a selected technique as well as broaden the scope of surgical modalities that can be successfully employed in his or her practice. If you are a true learner, this book is for you.

Ole T. Jensen
Brånemark’s discovery of osseointegration arguably became one of the most significant events in dentistry in the twentieth century [1, 2]. It could be stated that this discovery divided dentistry into two periods: pre-implant era or era of symptomatic (symptom-driven) dentistry and an implant era or era of physiologic dentistry. In the first period, restorative dentistry had only two meaningful treatment options for failed teeth or edentulous jaws: removable dentures and fixed bridges. Both removable dentures and fixed bridges relied on support of adjacent teeth and underlying alveolar mucosa with little consideration for bone preservation.

For the last 50 years of the second and modern period of dentistry, restorative (reconstructive) dentistry has been utilizing physiologic treatment by replacing missing or failing teeth with bone-anchored (osseointegrated) endosseous implants that have an ability to maintain the alveolar bone in a similar manner to a natural dentition. A new principle of bone preservation was based on the concept of endosseous bone loading (EBL). Dental implants also removed an unnecessary load from adjacent teeth, thus decreasing and eliminating deteriorating effects of removable and fixed toothborne prostheses on natural dentition, strengthening masticatory function, and improving esthetics and patient’s comfort.

Initially surgically driven, implant dentistry was concerned mainly with an implant integration of dental implants. It was soon to become clear that in order to properly restore endosseously placed implants, they have to be inserted into the bone in a restoratively driven position, identical or close to where the natural teeth used to be, even if bone was no longer available in the area. Implant dentistry has emerged as a prosthetically driven surgical–restorative discipline.

In the last few decades, it became clear that success of implant dentistry and longevity of dental implants depend on three factors (“implant triangle”). These factors are: (1) a proper restoratively driven placement of implants, (2) the presence of a sufficient amount of bone stock, a foundation for the osseointegration, and (3) the presence of healthy peri-implant soft tissue for proper implant hygiene and maintenance. Missing any one component of the implant triangle tends to eventually result in compromise of implant health or longevity, and can often lead to implant failure.

The presence of bone atrophy or resorption due to tooth loss and trauma (among many other factors) has led to the development of a variety of implant-driven bone augmentation procedures in a single or staged fashion. This two-volume book is about bone augmentation techniques applicable to implant dentistry. A variety of bone augmentation procedures for the deficient (atrophied) alveolar bone has been proposed in the literature [3–5] and are described in these two books. Each method has its indications and contraindications, its proponents and opponents. The following four alveolar ridge reconstruction techniques are frequently used in oral implantology and are described in this book:

1. Guided bone regeneration (GBR) with particulate bone graft [6, 7].
3. Ridge-split/bone graft and sandwich osteotomy [12–14].
4. Alveolar distraction osteogenesis [15, 16].

To simplify learning of the surgical techniques, the editor (Tolstunov) of this book divided them roughly into two categories: horizontal augmentation and vertical (volumetric) augmentation. Book I inspects horizontal bone augmentation of alveolar ridges with bone width deficiency and Book II scrutinizes vertical bone augmentation of alveolar ridges with bone height loss. Both books do not claim to be a complete all-inclusive dissertation of all alveolar bone augmentation techniques. That would be impossible and impractical. Many surgical techniques are being proposed almost daily on the pages of peer-review oral surgical, periodontal, implant, and general dental journals and other publications. They are also often modified from the original versions with the discovery of new instrumentation and computer technology.

Classifications tend to simplify learning of a certain subject. They often give a reader a “bird’s-eye view” of the complex topic. There is a variety of different classifications of alveolar bone augmentation in implant dentistry. Table 1.1 demonstrates the editor’s classification. Based on years of teaching, practicing and in the process of writing this book, we offer the classification that can, hopefully, be well understood by students, surgical residents, and doctors, and be conceptually robust from the biologic point of view. Examine Table 1.1 after finishing this chapter.

The editor’s recommendation for readers of this two-volume book is to open the book on any chapter that seems clinically relevant at that particular moment and read/learn/study the technique thoroughly. Targeted (selective) reading is common and productive in medical literature. After finishing one chapter, you might want to come back later to the same chapter to re-think its content. Then, move on to another chapter on a different type of
Table 1.1 Classification of alveolar ridge augmentation procedures through bone grafting in implant dentistry (both vertical and horizontal).

<table>
<thead>
<tr>
<th>Types</th>
<th>Graft donor site</th>
<th>Type of augmentation</th>
<th>Graft type, flap type, and graft revascularization</th>
<th>Graft consolidation</th>
<th>Augmenting tissues</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Inlay (interpositional) bone graft:</td>
<td>None or autogenous</td>
<td>Static</td>
<td>Free graft</td>
<td>Woven-to-lamellar; starts with bone formation</td>
<td>Hard tissue</td>
</tr>
<tr>
<td>A. Particulate</td>
<td></td>
<td></td>
<td>Limited mucoperiosteal flap; endosteal (mainly) revascularization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. GBR (three–four-wall tooth socket or bone defect)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Ridge-split or pedicled sandwich osteotomy (two-wall horizontal or vertical bone defect)</td>
<td></td>
<td></td>
<td>Osteomucoperiosteal vascular flap [17–19]; two-to-three surfaces of vascularization: endosteal – from both split bone surfaces plus periosteal (lingual–for vertical, buccal–for horizontal) [20]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Sinus lift (subantral augmentation)</td>
<td></td>
<td></td>
<td>No flap (crestal approach) or mucoperiosteal flap (lateral approach); endosteal and periosteal neovascularization (sinus membrane plays a role of periostium)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Tent-pole technique with</td>
<td>Mucoperiosteal flap;</td>
<td></td>
<td></td>
<td>Woven-to-lamellar; starts with bone resorption</td>
<td>Hard tissue</td>
</tr>
<tr>
<td>autogenous cortical block bone</td>
<td>tenting block</td>
<td></td>
<td>graft does not get vascularity and tends to resorb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Block</td>
<td>Local (intraoral) or</td>
<td>No flap; endosteal</td>
<td></td>
<td>Woven-to-lamellar; starts with bone resorption</td>
<td>Hard tissue</td>
</tr>
<tr>
<td></td>
<td>distant (extraoral)</td>
<td>(mainly) revascularization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II. Onlay (juxtaposed) bone graft:</td>
<td>None or autogenous</td>
<td>Static</td>
<td>Free graft; mucoperiosteal flap; endosteal (mainly) revascularization initially, additional vitality from reattached periosteum comes in 3–4 weeks.</td>
<td>Woven-to-lamellar; starts with bone formation</td>
<td>Hard tissue</td>
</tr>
<tr>
<td>A. Particulate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. GBR (one–two-wall socket or bone defect)</td>
<td></td>
<td></td>
<td>Endosteal (mainly) revascularization of the particulate graft</td>
<td>Woven-to-lamellar; starts with bone resorption</td>
<td></td>
</tr>
<tr>
<td>2. Tent-pole technique with</td>
<td>Endosteal (mainly)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ti-mesh, screws or implants [21–23]</td>
<td>revascularization of the block graft</td>
<td></td>
<td>Endosteal (mainly) revascularization of the block graft</td>
<td>Woven-to-lamellar; starts with bone resorption</td>
<td></td>
</tr>
<tr>
<td>B. Block</td>
<td>Local (intraoral) or</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>distant (extraoral)</td>
<td></td>
<td>Endosteal (mainly) revascularization of the block graft</td>
<td>Woven-to-lamellar; starts with bone resorption</td>
<td></td>
</tr>
<tr>
<td>III. Alveolar distraction</td>
<td>None</td>
<td>Dynamic</td>
<td>No graft, mucoperiosteal flap</td>
<td>Callus formation, similar to fracture healing, intranembranous (mostly) ossification followed by bone remodeling</td>
<td>Hard and soft tissue (simultaneously distracted/ expanded)</td>
</tr>
<tr>
<td>osteogenesis</td>
<td></td>
<td></td>
<td>Endosteal (mainly) and periosteal revascularization (lingual or palatal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV. Free bone flap transfer (with</td>
<td>Distant</td>
<td>Static</td>
<td>Free bone–soft tissue flap</td>
<td>Callus formation, similar to fracture healing, endochondral ossification followed by bone remodeling</td>
<td>Hard and soft tissue (simultaneously transferred)</td>
</tr>
<tr>
<td>microvascular anastomosis)</td>
<td></td>
<td></td>
<td>Microanastomosis between local (recipient) and distant (donor) vascular networks plus endosteal (recipient) revascularization</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(horizontal or vertical) augmentation for comparison, as well as read current literature on this subject. This might help you to eventually select the technique that suits you (feels best in your hands). Always remember the biologic rationale of each procedure when selecting the one to help your particular patient.

For a novice dental surgeon or an experienced dental practitioner while studying surgical methods and techniques, I would suggest paying special attention to the following:

1. Soft tissue versus hard tissue augmentation: what is needed and what is the priority, especially in the esthetic zone.

2. Static versus dynamic bone augmentation techniques: block graft versus distraction osteogenesis, ridge-split versus orthodontic forced eruption, etc.

3. Two-dimensional (2D), three-dimensional (3D), and, finally, “four-dimensional” (4D) tissue augmentation: horizontal or vertical (2D) versus volumetric (3D) versus time-dependent bone and soft tissue grafting (considering the fourth dimension), with emphasis on aging changes that can be predicted and prevented by thoughtful augmentation techniques (especially, in the anterior maxilla).
Use this book as a surgical reference guide or manual at any locations – at the university, home, or in the operative room – and let us know what you liked or did not like, and what you would change, add, or delete in future editions of this book. We want each new edition to be better that the one before. Good luck on your learning journey for the benefit of your patients.

I. Particulate bone grafting

1. For INLAY grafts consider xenograft, possibly with autogenous bone (including bone morphogenetic protein (BMP)). Ideally, implant neck and apex are to be positioned in the native bone while the implant body is to be surrounded by the grafted bone. Primary implant stability in the native bone is important.

2. For ONLAY grafts consider mixed xeno-allograft, possibly with autogenous bone (including BMP). Implant neck is to be surrounded by the grafted bone, while the implant body is to be placed into the native bonewith good primary stability (30+ Ncm) at the time of insertion.

Tenting procedures for the particulate graft

1. Cortical autogenous tenting. Detached free cortical bone block in width or height-deficient ridges is used for a 2D augmentation with a particulate graft positioned in between the cortical block and basal (native) bone as an INLAY graft. Separated cortical “tenting” free bone has no blood supply initially and 4-5 weeks later–some re-established periosteal source of revascularization only, which limits its survival and increases its impending resorption. Both endosteal and periosteal revascularization are provided for the particulate graft that has a good survival potential.

2. Ti-mesh tenting. Titanium mesh is used for 3D (volumetric) reconstruction of the collapsed ridge and functions as a scaffold protective device for the particulate graft underneath. The particulate graft is placed in ONLAY fashion on top of native bone. Endosteal revascularization is provided for the particulate graft that has a good survival potential.

3. Periosteal tenting
   (a) Screw tenting: a soft tissue matrix is tented by metal screws for space creation for the particulate graft placed in ONLAY fashion on top of native bone. Both 2D and 3D ridge augmentations are possible (horizontally and vertically positioned screws). Endosteal and periosteal revascularizations are provided for the particulate graft that has a good survival potential.

   (b) Implant tenting: a soft tissue envelope is tented by dental implants for space creation for the particulate graft placed in ONLAY fashion on top of native bone. A 2D ridge augmentation in height-deficient ridges is possible. Endosteal and periosteal revascularization are provided for the particulate graft that has a good survival potential.

II. Block bone grafting

Onlay or inlay, horizontal, vertical or combination (J-graft), fixation screws and plates. Secondary bone resorption often occurs.

III. Alveolar distraction osteogenesis

Horizontal or vertical, specific distractor devices.

IV. Free distant bone flap transfer with microvascular anastomosis

Vertical and horizontal, plates and screws.

Graft Revascularization implies bone healing (from angiogenesis to mineralization and ossification) from the particular vascular source:

1. Endosteal (central or centrifugal). Bone-to-bone healing (ossification) through angiogenesis. This applies to any onlay or inlay grafts and also for a gap osteotomy created by osteoperiosteal flaps (as in the ridge-split procedure). This is a dominant source of blood supply needed for free bone graft survival.
   (a) Particulate graft: internal “coagulum” is converted into the woven bone; fast revascularization through bone formation.
   (b) Block graft: plasmatic imbition to block graft; slow revascularization through resorption.

2. Periosteal (peri- and centripetal). Periosteal proximal angiogenesis to the grafted bone that is exposed to the juxta-posed periosteme (as in an onlay block graft). This is a supplementary source of blood supply needed for free bone graft survival.

3. Microvascular anastomosis. The best source of blood supply. Vascular free graft with hard and soft tissue transfer. The endo- and periosteal sources are also established and are supplementary.

References

CHAPTER 2

Applied Surgical Anatomy of the Jaws

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In order to perform vertical augmentation of the maxillary and/or mandibular alveolus safely in preparation for placement of endosseous implants, one must consider adjacent anatomic structures, as well as the variability of the location of these structures and their relationship with adjacent structures secondary to skeletal development, inherent anatomic variations, and changes of the bony anatomy related to bone atrophy from aging and/or tooth loss. An appreciation of the anatomy of the jaws will allow the clinician to perform the procedures and techniques safely that are presented in this textbook.

Dental implant surgery and augmentation of the alveolar ridge when necessary is performed by a variety of dental practitioners and specialists with various levels of surgical training and clinical experiences; however, irrespective of clinical training all healthcare provision should have a mastery of anatomic structures within the relevant anatomic subsite. This knowledge is critical to avoid unnecessary morbidity to the patient and medical litigation. Figure 2.1a and b highlight cases in which there was gross error in the placement of endosseous implants within the maxilla and mandible as a result of inadequate appreciation of the local anatomy.

The maxilla and mandible are located within the oral cavity. The oral cavity by definition extends from the cutaneous–vermillion junction of the upper and lower lip with the hard–soft palate junction serving as the superior–posterior border, the anterior tonsillar pillars serving lateral–posterior borders, and the circumvallate papillae serving as the posterior–inferior border. All anatomic structures posterior to these anatomic borders (e.g., the base of the tongue, palatine tonsils, soft palate) are part of the oropharynx. The oral cavity provides a multitude of physiologic functions including: mastication, provision of salivary lubricants and buffers, mediation of the oral preparatory and oral transit phases of swallowing, special taste sensations, immunologic defenses mediated via innate immunity, speech, protection of adjacent deep anatomic structures, and contributing to human behavioral communication and interaction. Due to these varied and complex physiologic and social functions, the oral cavity is composed of a myriad of hard and soft tissue structures within a locally compact space in order to allow the execution of these highly organized functions. Furthermore, due to the complex interplay of these structures even a minor disturbance in an anatomic structure of the oral cavity will result in morbidity to the patient. Therefore, in this chapter we will review in detail the anatomic structures serving as the bony bases of the oral cavity, the maxilla and mandible, and also significant adjacent anatomic structures, which must be considered when performing surgical procedures on or within the maxillomandibular complex.

Anatomy of the mandible

Foramina and canals

The mandible is the only freely mobile bone as well as the densest bone within the craniofacial skeleton. The mandible articulates with the skull base via the temporomandibular joints. The mandible is an aesthetically prominent bone due to a mental protuberance, which is a bony prominence in the chin region located inferior to the mandibular incisors. The mandible is a “U-shaped” bone when viewed from above or below.

The mandible contains three named foramina: mandibular foramen, mental foramen, and lingual foramen. Clinically, the mental foramen becomes significant when performing procedures in the premolar region, such as placement of endosseous implants or alveolar ridge augmentation. However, the mandibular foramen is not of concern with procedures related to endosseous implants for restoration of dentition, due to the foramen being situated at a significant distance from the mandibular dentition. However, the mandibular foramen does become significant when performing operations on the ascending ramus of the mandible, such as sagittal split ramus osteotomy or vertical ramus osteotomy. The lingual foramen is a small foramen located along the medial surface of the mid-line of the mandible. Unlike the other two named foramina of the mandible, the lingual foramen is an arterial foramen, meaning that its contents are vascular rather than neurovascular, as is the case of the mandibular foramen and mental foramen. The lingual foramen in the dentate mandible is located towards the inferior border. Small perforating vessels enter the lingual foramen, which arises from anastomotic branches of the right and left sublingual arterial branches of the lingual artery.

The mandibular foramen allows entry of the inferior alveolar neurovascular bundle into the mandible, which is located along the medial surface of the mandibular ramus 15–20 mm inferior to the
sigmoid notch. The mandibular foramen is the beginning of the mandibular canal, which is a canal that runs obliquely downward and forward within the ramus of the mandible. The mandibular canal begins at the level of the mandibular foramen and for its first 8–10 mm, the canal typically runs close to the lingual cortex [1]. As the mandibular canal descends within the ramus it takes on a more central position. As the canal moves forward it will typically be positioned closer to the inferior border of the mandible until it passes the second molar and first molar teeth. The most inferior position of the canal is also most lingual position, which is in between the second molar and first molar region (Figure 2.2) [1].

Eventually, the mandibular canal will fork into the mental canal and incisive canal, which house the mental nerve and incisive nerve, respectively. Multiple, rare, variations of the mandibular canal have been reported, with the bifid mandibular canal being the most commonly observed anatomic variation of the mandibular canal with a reported incidence of 15.6% [2]. Four variations of the mandibular canal (Figure 2.3), with the retromolar canal variation being the most common occurring in 52.5% cone beam computed tomography (CBCT) scans [3, 4]. Trifid canals have also been reported. The true prevalence of these anatomic variations has only become recently known due to the advent and prevalence of CBCT [4].

The mental canal deviates superiorly towards the mental foramen. The mental foramen is spatially located within the same vertical plane as the infraorbital foramen. The vertical location of the mental foramen within the dentate mandible is consistent, with the foramen being located almost halfway between the tip of the alveolar process and the inferior (lower) border of the mandible; however, this could change with atrophy of the mandible. The transverse position of the mental foramen is varied with slightly conflicting distribution patterns depending on whether the studies utilize radiographic imaging or cadaveric dissection specimens [5, 6]. Von Arx and colleagues reported that the majority (56%) of mental foramina are located between the apices of the first and second premolar teeth and the remaining 35.7% of mental foramina are positioned below the second premolar tooth [5]. Furthermore, each mental foramen is on average 25 mm from the mid-line of the mandible. An accessory mental foramen has been reported to exist in 1.4–10% of patients [7].

The incisive canal will extend anterior to the mental canal and foramen, and houses the mandibular incisive nerve. The incisive canal is not always readily apparent radiographically. Pires and colleagues identified that the mandibular incisive canal was visualized in 83% of cone beam computed tomography scans, while on panoramic radiographs it was only identified in 11% of radiographs [8].

**Neurovascular structures**

In order to understand conceptually the innervation patterns of the maxilla and mandible, one must consider the embryologic origin of the jaws. Both the maxilla and mandible are first branchial arch derivatives; similarly, the trigeminal nerve is a first branchial arch structure. Therefore, the sensory innervation of the maxilla and mandible is provided by the trigeminal nerve as a result of a shared embryologic derivation. The trigeminal nerve is the largest of the twelve cranial nerves, and while the trigeminal nerve captures the entirety of the sensory information from the maxilla and mandible, there are additional neural structures that provide sensory and/or motor innervation to soft tissue structures within the oral cavity, such as *chorda tympani* (branch of seventh cranial nerve), *vagus nerve* (tenth cranial nerve), and *hypoglossal nerve* (twelfth cranial nerve). However, these are typically distant enough from the mandible to not be at risk from injury while performing vertical ridge augmentation within the alveolus of the mandible. Below we will discuss clinically significant nerves, which either receive sensory input from the mandible and associated structures (i.e., teeth) or lie in close proximity to the mandible (Figure 2.4).

Each of the two trigeminal nerves leaves the brain at the level of thepons. The trigeminal nerve then descends laterally to join the ipsilateral trigeminal (Gasserian or semilunar) ganglion located

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**Figure 2.1** (a) Orthopantomogram of implant in the mandibular left second molar position that violates the mandibular canal. (b) Orthopantomogram of implant displaced into left maxillary sinus, status – post-internal (crestal) sinus lift with an attempt to implant placement in the position of the maxillary left first molar.

**Figure 2.2** Coronal cross-section of cone beam computed tomography depicting most inferior and lingual position of mandibular canal as it traverses the mandible.
within the trigeminal (Meckel) cave, which is a cerebrospinal fluid containing an arachnoidal pouch near the apex of the petrous portion of the temporal bone. It is at the level of the trigeminal (Gasserian or semilunar) ganglion that the trigeminal nerve branches into three large nerve trunks: (1) ophthalmic division (V1), (2) maxillary division (V2), and (3) mandibular division (V3). The ophthalmic division (V1) is the smallest of the three and only receives sensory information from facial structures outside the oral cavity. However, the maxillary (V2) and mandibular (V3) divisions receive all of the sensory input from the jaws.

The inferior alveolar nerve (IAN) is a mixed (sensory and motor) nerve, which is the largest terminal branch of the mandibular division (V3). The IAN is primarily a sensory nerve; however, it gives off a motor branch, the nerve to the mylohyoid (mylohyoid nerve), which innervates the anterior belly of the digastric muscle and mylohyoid muscle. The IAN branches from the mandibular division (V3) at a level just below the lower head of the lateral pterygoid muscle, and then descends within the pterygomandibular space (lateral to the medial pterygoid muscle and sphenomandibular ligament) and also in a parallel route that is posterior and lateral to the lingual nerve. The IAN will enter the mandible via the mandibular foramen located on the medial surface of the ascending ramus of the mandible. Encasing the IAN just before it enters the mandibular foramen is the sphenomandibular ligament.

Through its course within the mandible, the IAN is accompanied by the inferior alveolar artery, vein, and lymphatic vessels. Anatomic studies have indicated there are often multiple inferior alveolar veins, which lie superior to the nerve. The inferior alveolar artery appears to be solitary and is generally located medial to the nerve [9]. Throughout its intrabony course, the IAN it will give off many small branches, which will receive sensory input from molar and premolar teeth, as well as their associated periodontal ligaments and alveolar bone. The IAN will eventually divide into the incisive and mental nerves in the vicinity of the premolar teeth.

The “anterior loop” of the IAN has been the subject of much debate [10]. When present, the anterior loop begins after the incisive branches from the IAN, with the remaining portion of the IAN running below and past the mental foramen, and then looping back towards the mental foramen to become the mental nerve. The anterior loop has been identified in 48% of study subjects, with a mean length and length range of 0.89 mm and 0–5.7 mm, respectively [11]. When performing surgery within the posterior mandible (i.e., placement of dental endosseous implants, ridge augmentation, etc.), one must always consider the relationship of the proposed operative procedures to the IAN. As the nerve cannot be visualized by standard radiographic techniques (i.e., plain

*Figure 2.3* Anatomic variation of mandibular canal. Adapted from Naitoh M, et al., *International Journal of Oral and Maxillofacial Implants*, 2009 [3].

*Figure 2.4* Major sensory nerves located within the oral cavity, which lie in close proximity to the mandible.
film radiography, cone beam computed tomography), a general recommendation of maintaining 2 mm from the superior lamina dura of the mandibular canal will avoid injury to the nerve unless there exists an anatomic variation, which was not readily detected on radiographic imaging. The following radiograph highlights a case where the mandibular canal was violated during such procedures when the patient presents with anesthesia of the inferior alveolar nerve distribution (Figure 2.1a). Of note, being that the mental and incisive nerves are terminal branches of the IAN, injury to the IAN within the body of the mandible will result in neurosensory deficits of all structures innervated by the IAN portion distal to the site of injury, as well as the mental and incisive branches.

The mental nerve is a strictly sensory nerve and, as previously discussed, is a terminal branch of the inferior alveolar nerve. The nerve begins within the mandible and then courses superiorly along an oblique angle to exit the mandible via the mental foramen. Subsequently, as the nerve exits the mental foramen it is surrounded by a tough sheath, and immediately divides into three branches deep to the depressor anguli oris muscle (Figure 2.5a and b). These branches receive sensory input from the skin of the chin, vestibular gingiva, mandibular facial gingiva, and skin and mucosa of the lower lip. The presence of these small distal nerve branches complicates augmentation of the alveolar ridge in the premolar region, and therefore consideration of the incision design and augmentation technique should take the mental nerve and its branches into account.

One must always consider the position of the mental foramen and branches of the mental nerve, for the incidence of permanent neurosensory disturbance within the mental nerve distribution subsequent to placement of dental implants has been reported in between 7 and 10% of cases [12]. Furthermore, in the atrophic mandible the position of the mental foramen will be variable dependent on the degree of bone atrophy. In cases of severe atrophy of the mandible the foramen could be located along the ridge of the mandible, which must be considered when making a crestal incision and/or performing dissection in the vicinity of the foramen. Even a minor disturbance within the mental nerve distribution could result in varying degrees of morbidity, including lower lip biting, drooling, and/or impaired speech.

As previously discussed, anterior to the mental foramen the mandibular canal is referred to as the incisive canal. The incisive canal houses the mandibular incisive nerve, which receives sensory input from the ipsilateral first premolar tooth, canine tooth, lateral incisor, and central incisor teeth. The nerve and its canal have been found to end below the ipsilateral lateral incisor tooth in the majority of patients. Difficulty in detecting the nerve and the canal past this region has been attributed to the nerve dispersing into microscopic tributaries [13]. Injury to the incisive nerve is generally not clinically relevant to patients and is sometimes sacrificed with trigeminal nerve reconstructive surgery. This allows ridge augmentation within the mental interferaminal region to be performed with little risk of post-operative neurosensory disturbances.

Figure 2.5 (a) Clinical photograph of the mental nerve with the overlying depressor anguli oris muscle. (b) Clinical photograph of the skeletonized mental nerve and its three branches.
Lastly, the lingual nerve must be considered when performing procedures within the posterior mandible. As a peripheral branch of the mandibular division (V3) of the trigeminal nerve, the lingual nerve receives sensory input from the anterior two-thirds of the tongue. While the glossopharyngeal nerve (ninth cranial nerve) receives the sensory input from the posterior one-third of the tongue, there is a zone of overlap between these two nerves within the posterior aspect of the anterior two-thirds of the tongue. Within the lingual nerve travels the chorda tympani, which is a nerve that arises from the facial nerve (seventh cranial nerve) and is responsible for the sensation of taste from the anterior two-thirds of the tongue and also provides secretory motor innervation to the ipsilateral submandibular and sublingual gland via presynaptic parasympathetic fibers terminating within the submandibular ganglion. The lingual nerve is given off the mandibular division just caudal to the foramen ovale; subsequently, it descends medial to the medial surface of the ramus of the mandible towards the anterior two-thirds of the tongue. During its course to the tongue it will cross with the submandibular duct in the area of the mandibular first and second molar teeth. However, in the region of the third molar the lingual nerve could be intimately associated with the lingual cortex of the mandible and the lingual alveolar crest. Miloro and colleagues reported that on magnetic resonance imaging (MRI) the in the third molar region the lingual nerve was in direct contact with the lingual cortical plate in 25% of patients, and above the lingual alveolar crest in 10% of patients [14]. Furthermore, Pogrel and colleagues identified that the mean distance between the lingual nerve and the lingual crest in the transverse plane is 3.45 mm ± 1.48 mm and the mean vertical distance between the lingual nerve and the lingual alveolar crest is 8.32 mm ± 4.05 mm (Figure 2.6) [15]. The variation of the relationship of the lingual nerve with the lingual cortex and lingual alveolar crest was not statistically consistent between the right nerve and the left nerve [15].

**Critical vascular structures**

When performing reconstructive procedures at the level of the mandibular alveolus in general local neural structures (i.e., inferior alveolar nerve, mental nerve, mandibular incisive nerve, and lingual nerve) are of greatest concern. While injury to these peripheral nerve branches could pose significant morbidity to the patient, injury to local vascular structures could result in a life-threatening hemorrhagic situation secondary to airway embarrassment [16]. When it comes to critical vascular structures when performing alveolar ridge augmentation and/or placement of endosseous implant no region of the mandible is as critical as the lingual cortex of the anterior mandible. There have been more than a dozen cases reported in the English literature of a life-threatening hemorrhage secondary to placement of endosseous implants into the mandible [16, 17]. The sublingual artery and the submental artery are the two arterial branches at risk of injury if the lingual cortex of the anterior mandible is perforated. In this section, we will discuss the anatomy of these two arterial branches and also the inferior alveolar artery, which must be considered when operating within the posterior region of the mandible.

The sublingual artery is one of the four branches of the lingual artery. The lingual artery is the third branch of the external carotid artery system. The lingual artery is given off at the level of C3 and ascends toward the greater cornu of the hyoid bone. The lingual artery has a total of four branches, which are the dominant arterial supplies to the tongue and floor of the mouth. The four branches are the suprathyroid branch of the lingual artery, deep lingual artery (ranine artery), sublingual artery, and the dorsal lingual branch of the lingual artery. The sublingual artery runs within the floor of mouth in between the ipsilateral mylohyoid muscle and the genioglossus muscle. At the level of the anterior lingual alveolar mucosa the sublingual artery will anastomose with its contralateral counterpart [16].

When operating within the anterior mandible, “perforating” the lingual cortex not only poses the risk of injury to the sublingual artery but also the submental artery. The submental artery is the largest branch of the facial artery. The facial artery is a branch of the external carotid artery. During its ascent the facial artery travels through the submandibular gland, and once it emerges through the gland the facial artery will give off the submental artery. This artery will travel anteriorly on the mylohyoid muscle, eventually anastomosing with the sublingual artery and with the mylohyoid artery [16]. In hopes of further elucidating the vascular anatomy along the lingual surface of the anterior mandible, Hofschneider and colleagues dissected 34 human cadavers [18]. In this study, the authors concluded that within this anatomic territory the sublingual artery was identified in 71% of cadaver specimens, and a large branch of the submental artery was identified in 41% of cadaver specimens. Of note, the branch of the submental artery had perforated the mylohyoid muscle in order to reach the anterior floor of the mouth. Therefore, when operating in the anterior mandible one must take precautions to not “perforate” through the lingual cortical plate, as within this region lies arterial branches of the lingual artery and submental artery, which have enough flow.

![Figure 2.6 Relationship of lingual nerve and lingual crest of mandible: (a) 8.32 mm ± 4.05 mm and (b) 3.45 mm ± 1.48 mm. Adapted from Pogrel MA, et al., Journal of Oral and Maxillofacial Surgery, 1995 [15], reproduced with permission from Elsevier.](image-url)
to result in the development of an expanding sublingual hematoma that could result in immediate airway embarrassment.

As previously discussed in the neurovascular structures section, the mandibular canal houses the inferior alveolar nerve, inferior alveolar artery, inferior alveolar vein, and lymphatics. While life-threatening hemorrhage from the inferior alveolar artery is extremely rare, it is still a known phenomenon [19]. The inferior alveolar artery is a branch of the internal maxillary artery and enters the mandible via the mandibular foramen. As the artery travels within the mandibular canal it gives off numerous branches to the teeth. Although this is an artery with a highly consistent anatomy, Jergenson and colleagues reported a case of an inferior alveolar artery arising from the external carotid artery [20]. In this cadaver specimen, the contralateral inferior alveolar artery originated from the internal maxillary artery. As previously discussed, the anatomic studies by Pogrel and colleagues described a condition within the mandibular canal where there are often multiple inferior alveolar veins that lie superior to the inferior alveolar nerve, while the inferior alveolar artery appears to be solitary and is located medial to the nerve [9].

Anatomy of the maxilla

Foramina and canals

Just as is the case with the mandible, the maxilla contains important foramina that transmit nerves and blood vessels in the vicinity of the dentoalveolar complex. These foramina include the incisive foramen, greater palatine foramen, lesser palatine foramen, and infraorbital foramen. The incisive foramen, also known as the nasopalatine foramen or anterior palatine foramen, is located in the mid-line of the anterior hard palate, immediately posterior to the maxillary central incisor teeth, and transmits the right and left greater palatine arteries from the oral cavity to branches of the sphenopalatine artery within the nasal cavity, as well as the right and left nasopalatine nerves from the nasal cavity to the oral cavity. The incisive foramen is the terminus of the incisive canal (also known as the nasopalatine canal). The right and left incisive canals end at the incisive foramen, and there is only one incisive foramen. The incisive canal in essence connects the floor of the anterior nasal cavity with the oral cavity. The greater palatine foramen is located along the posterior aspect of each of the palatine bones, always palatal to the maxillary molar dentition.

The greater palatine foramen transmits the ipsilateral greater palatine nerve and the greater palatine artery and vein. Most anatomic studies have determined that the most common location of the greater palatine foramina is medial opposite to the maxillary second or third molar. Westermoreland and colleagues observed that in 57% of dry human skulls the foramen was opposite to the third molar [21]. Furthermore, Sujatha and colleagues observed that in 85.9% of dry human skulls this foramen was opposite to the third molar [22]. The greater palatine canal transmits the descending palatine artery, which becomes the greater palatine artery as it emerges from the foramen. Likewise, the descending palatine nerve emerges from the greater palatine foramen as the greater palatine nerve.

The lesser palatine foramen is always situated posterior to the greater palatine foramen. The lesser palatine foramen transmits the lesser palatine nerve and blood vessels. Lastly, the infraorbital foramen is located along the anterior maxillary wall. It transmits the infraorbital nerve, artery, and vein. As previously mentioned, the infraorbital foramen lies along the same vertical plane as the mental foramen. The infraorbital nerve emerges approximately 10 mm below the infraorbital rim and may be encountered with surgical procedures of this region.

Maxillary sinus

The maxillary sinus is the largest of the four paired paranasal sinuses. Its anatomic dimensions are 33 mm high, 23 mm wide, and 34 mm in anteroposterior length. It is described as a pyramidal-shaped structure, being the lateral nasal wall. The sinus is lined by Schneiderian, which consists of pseudostratified ciliated columnar epithelium. The thickness of the Schneiderian membrane ranges from 0.13 to 0.5 mm. The drainage system of the maxillary sinus is via the medial meatus. Normal anatomic variants found within the maxillary sinus are bony septations. Velasquez-Plata and colleagues reported that these bony septations within the maxillary occur with an incidence of 24% [23]. The neurovascular architecture of the maxillary sinus consists of the anterior superior alveolar, posterior superior alveolar, and infraorbital arteries and nerves providing the blood supply and innervation to the maxillary sinus. A complex arcade exists between the arteries making up the arterial architecture of the maxillary sinus. Kiku and colleagues described the presence of an interosseous anastomosis in 100% and an extraosseous anastomosis in 90% of cases [24].

Growth of the alveolar process

Within the maxilla and mandible the alveolar processes function to support teeth and their associated structures. This interplay begins at the time of tooth and jaw development. The alveolar bone will typically mature with elongation and function of teeth. This unique interplay between the alveolar bone and teeth is highlighted in cases where there is congenital tooth agenesis and the alveolar bone does not develop at all [25]. Likewise, in situations of tooth loss, the alveolar bone will undergo resorption, which if not addressed could result in complete loss of the alveolar bone in the edentulous sites. Within the posterior maxilla this could result in pneumatization of the maxillary sinus.

Conclusion

The alveolar ridge of the maxilla and mandible is surrounded by many vascular structures, which, in the case of iatrogenic injury, could result in significant bleeding and in certain situations in life-threatening hemorrhage. Additionally, multiple nerves surround the alveolar ridge of the jaws and their injury could result in lasting and painful neurosensory deficits. Therefore, in-depth knowledge of the local anatomy allows clinicians to appropriately treat their case and be mindful of critical neurovascular structures in order to execute the reconstructive surgical treatment plan effectively and safely.

References

References:


CHAPTER 3

Prosthetic Comprehensive Oral Evaluation in Implant Dentistry: Team Approach

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History and the team approach
Partial and complete edentulism are clinical conditions that have created functional and esthetic challenges for men and women alike over many centuries. The simple loss of teeth can result in disabilities and handicaps for many patients due to their inability to speak and chew properly. Over the past hundred years, the dental profession has continually searched for products, procedures, and techniques to help liberate these patients from the suffering associated with the loss of their dentition.

Since its accidental discovery in 1952 by Dr. P.I. Brånemark, and subsequent introduction to dentistry in the late 1970s and early 1980s, osseointegration has revolutionized how dentists treat patients. Early work among different investigators consisted of treatment with blade, transosteal, and subperiosteal implants. It was the design of these implants that allowed their placement in atrophic jaws without vertical or horizontal augmentation procedures. Their use nonetheless demonstrated various levels of success, complications, and failures [1–9]. It was, however, the simple concept of intimate bone formation around root form endosteal titanium fixtures, without ingrowth of soft tissue, that has predictably helped thousands of patients get back to living near-normal lives. Without argument, it can be safely stated that the endosseous dental implant is the single greatest advance that dentistry has seen in the last century. Utilization of a few endosseous implants can significantly improve a patient’s quality of life by replacing missing teeth, restoring a smile and facilitating the ability to chew and function without experiencing pain and embarrassment [10, 11].

When patients were first treated with dental implants more than three decades ago, the focus of treatment was surgical. Suffice it to say, implants were surgically placed with little consideration as to the prosthetic end result. Implants were positioned in the jaws of patients where the best quantity and quality of bone was located. Treatments were considered successful if the implant(s) integrated and prosthetic teeth were secured to the fixtures. It was not long before the realization surfaced that the mere biologic integration of an endosseous implant was only the beginning of what was truly needed for optimal patient care and ideal treatment outcomes. In addition to a macromechanical and micromechanical interlocking of osseous tissue around titanium, implants need to be functionally and esthetically integrated. This means that the role implants play is merely to retain and/or support a removable (partial or complete) or fixed (single or multiple unit) dental prosthesis. It is the design and fabrication of removable prostheses that assist in achieving functional and esthetic integrated results for the removable patient. In addition, it is the design and fabrication of a fixed prosthesis as well as the surrounding hard and soft tissues that assist in achieving functional and esthetic integrated results for the fixed patient. For these reasons, since the time implants were introduced to dentistry, there has been a gradual paradigm shift in treatment approaches from a primarily surgical focus to a prosthetically driven discipline.

Bone grafting has a very lengthy history in regards to the selection of materials and techniques. As discussed by Horowitz et al., dental surgeons are faced with many choices at the time of extraction, ridge augmentation, or sinus grafting, including the type of material used (particulate, putty, or block), the site or mode of entry (flap or flapless), the source of bone replacement materials (autogenous, allogeneic, alloplast, or xenografts), the use of growth enhancers, the specific characteristic of the graft material, and the barrier type [12]. The material and techniques selected should allow for the best predictability in maintaining, repairing, or regenerating an appropriate volume and characteristic of bone for each clinical case. It should be noted, however, that prior to embarking upon the surgical grafting decision tree, the treatment plan should begin by determining the specific number and the desirable location of the implants needed. It is the final prosthesis (design and prosthetic goal) that should drive every surgeon’s decision making. The best implant outcomes are achieved with a team approach involving the patient, dental surgeon, restorative doctor, and laboratory technician. It is the patient that communicates what he or she wants, and it is the remaining three team members who are charged with the task of developing a joint plan that provides the patient with not necessarily just what is wanted but more importantly what is needed. It is imperative to understand that patients are great at knowing what they want; however, it is rare that they completely understand what they need. Every clinical team must develop a befitting treatment approach that will result in the most predictable outcome for each individual patient. In the event that patient expectations are unrealistic, it is the responsibility of the dental surgeon and
A restorative doctor to educate the patient as to the potential shortcomings and limitations of therapy. All team members, including the patient, must understand which goals are attainable and which goals are not.

Vertical and horizontal osseous tissue preservation or rebuilding should be directed by the specific prosthetic needs. The question that needs to be asked is who gets what? In other words, who will be treated with a crown and bridge type of fixed prosthesis? Who will be treated with a fixed–detachable hybrid prosthesis? Who will require a removable prosthesis? Does the patient need a flange for esthetics? Does the patient have a high or low smile line? What is the current bone volume? It is the answer to these simple questions that will dictate the additive or subtractive osseous surgical needs. When it is determined that the bone volume is insufficient, surgical plans and patient treatments should include predictable bone building procedures. If the surgical needs are not predictable, it may be necessary to choose an alternative prosthetic design. Conversely, some cases may have an excess of bone volume. These are the cases that may require bone trimming and removal. Finally, when considering prosthetic designs for patients, it should be understood that what can be predictably accomplished in the mandible cannot always be extrapolated to the maxillary arch.

**Vertical space requirements**

This prosthetic chapter belongs to the book volume that deals with vertical ridge augmentation. Surgical–restorative requirements of the presence of vertical bone stock for implant insertion and sufficient vertical prosthetic space for successful restorative element in implant dentistry are very important to understand.

The concept of restorative dimension requirements has been discussed in the literature [13, 14]. Different prostheses have different vertical space requirements. As a general rule, the needed restorative space is consistent for both the maxilla and the mandible since it is the prosthetic that dictates the space requirements. The three different prosthetic designs for consideration here are: (1) crown and bridge fixed prostheses, (2) fixed hybrid dentures, and (3) removable overdenture prostheses with a primary bar and a secondary superstructure. For the latter, the greatest amount of vertical space is needed due to the appropriate “stacking” of a variety of materials required in its construction. It is recommended that approximately 15 to 17 mm of vertical space be available for this primary bar overdenture. The space is measured from the residual soft tissue to the opposing occlusion and should allow for enough space between the primary bar and the soft tissue (approximately 2 mm), the bar itself (3 mm minimum), the nylon attachments and their associated metal housings (approximately 2 mm), the denture base resin superior and inferior to any secondary reinforcement casting (2–4 mm total), the secondary casting itself (1 mm), the prosthetic teeth (approximately 2–4 mm), and the cold cure resin used to connect the attachment housings to the denture base resin (1 mm) (Figure 3.1). Some primary bar overdenture cases may require less vertical restorative space (approximately 11 mm total) if secondary reinforcement castings are not utilized [15].

When determining the ideal vertical level of osseous tissue for overdenture prosthesis, one must remember that an average of 2–3 mm of soft tissue covers the bone. Thus, when a patient requires a primary bar overdenture prosthesis, vertical grafting may be needed only in those cases that exhibit severe atrophy. In these extremely atrophic cases, 10–12 mm of resulting vertical height may be needed to place implants of a minimal length. For cases with mild to moderate atrophy, subtractive surgical procedures may be needed to allow for the appropriate vertical “stack.” This involves removal of enough vertical hard tissue to provide for the 17–20 mm of space needed from the osseous crest to the opposing occlusion. Some rare edentulous maxillary cases may require both subtractive and additive surgical procedures. A great example of this scenario may be seen with patients that have excessive vertical down positioning of the posterior tuberosity with adequate bony height. These clinical cases may require vertical reduction of the posterior bone on the oral side along with sinus augmentation to build vertical height on the sinus side (Figure 3.2a to e).

Fixed crown and bridge prostheses need the least amount of vertical space since we are creating a restoration that closely mimics the height and width proportions of natural teeth. These restorations need approximately 7 to 13 mm of vertical height from the residual soft tissue to the opposing occlusion posteriorly and from the residual soft tissue to the incisal edge anteriorly (Figure 3.3a and b). The average interarch clearance for fixed prostheses has been reported as 10 mm [15]. Finally, hybrid denture prostheses need an intermediate volume of space. It has been recommended that 13 to 15 mm is the ideal vertical height for these prostheses [16]. This vertical volume allows for the appropriate veneering of prosthetic teeth and pink prosthetic material over and/or around traditional CAD/CAM titanium metal frames while maintaining accessibility for hygiene (Figure 3.4).
The edentulous patient

When an edentulous patient presents for treatment, the first decision to be made is what type of prosthesis is best for that specific patient. At times, clinicians can be too quick in rendering treatment recommendations without adequately examining and diagnosing each individual edentulous case. It is easy to hypothesize that fixed restorations are always better when compared to removable restorations since they seem to represent an end result that closely mimics a natural dentition. In addition, when comparing prostheses to natural dentitions, common sense may dictate that patients should have greater satisfaction with prostheses that have partial palatal coverage. However, is this really true? In other words, do fixed restorations and/or prostheses with an open palate always provide the most satisfactory prosthetic results for the edentulous patient?
Another patient-based outcome investigation by de Albuquerque et al. was reported in 2000 [18]. This was a crossover trial to measure differences in patient satisfaction of maxillary overdentures with and without palatal coverage. Totally edentulous French-speaking patients who had worn complete maxillary and mandibular dentures for at least five years were accepted into this study. Four implants were placed in the maxilla and four implants were placed in the mandible. The four data-gathering periods for this study were as follows: (1) new maxillary and mandibular complete dentures, (2) maxillary complete denture opposing a mandibular fixed restoration, (3) maxillary overdenture prosthesis with full palatal coverage opposing a mandibular fixed restoration, and (4) maxillary overdenture prosthesis with partial palatal coverage opposing a mandibular fixed restoration. Patient comparisons of treatments were evaluated with VAS and CAT scales. The authors of this study reported no significant differences between treatments in the four periods of the trial, suggesting that patients may be equally satisfied with maxillary overdenture prostheses regardless of whether they are fabricated with or without palatal coverage. It must be noted that the ratings given to the maxillary implant prostheses were not significantly higher than for new conventional maxillary prostheses. This suggests that maxillary implant prostheses may not be the ideal treatment of choice for patients with good bony support. In other words, patients that have excellent bony support may be treated satisfactorily with conventional maxillary complete dentures.

The two investigations mentioned above clearly illustrate the point that each edentulous patient must undergo detailed diagnostic procedures including clinical interviews with chief complaint and history gathering, digital imaging (two-dimensional and/or three-dimensional) examinations, and diagnostic wax-ups [15,16,19]. The treating restorative clinician is responsible for correlating the objective clinical findings and condition of the current prosthesis (es) with the patient’s chief complaint. If the patient is wearing a poorly designed and/or ill-fitting denture prosthesis, it may be indicated to fabricate a new provisional denture prosthesis to complete the diagnosis. The importance of fabricating new complete provisional denture prostheses, as part of the diagnostic phase of treatment, cannot be understated or overemphasized. In 1971, Dr. Earl Pound introduced the “branching” concept of denture fabrication [20, 21]. The provisional or trial denture described in this technique can be utilized to evaluate smile and profile esthetics,
Introduction

phonetics, vertical dimension of occlusion, vertical dimension of speech, tolerance of material thickness, support, stability, retention, comfort, and overall patient satisfaction. This initial phase of treatment begins by selecting the correct size and shape of anterior teeth followed by positioning them within the frame of the lips based on esthetics and speech. The location of these teeth are critical because it is the incisal edge position of teeth 8 and 9 that determines the proper restorative occlusal plane for both maxillary and mandibular arches. Initial treatment results with conventional provisional dentures will greatly assist in determining the type and design of the prosthesis(es) required, the number and position of implants, and finally the need for surgical additive tissue procedures (grafting) versus subtractive tissue procedures (bone removal).

**Treatment options for the edentulous mandible**
The general treatment options for the edentulous mandible include: (1) conventional denture, (2) implant-retained overdenture, (3) implant-supported overdenture, and (4) fixed hybrid denture with or without immediate occlusal loading. If the edentulous patient does not achieve total satisfaction with conventional provisional denture prosthesis, then treatment with dental implants may be indicated.

An implant-retained mandibular overdenture typically utilizes two implants positioned in the anterior mandible for the purpose of assisting with the retention of the denture prosthesis (Figure 3.5a and b). The functional loads of chewing are supported by the tissue posteriorly, which means the implants are utilized only to help retain the prosthesis.

An implant-supported mandibular overdenture usually requires at least four implants positioned between both mental foramen. A primary bar is fabricated with distal extensions for the purpose of supporting the functional loads of chewing posteriorly (Figure 3.6a and b). This prosthetic design is indicated for those patients who suffer from constant pain from denture pressure. Implants for these patients should be positioned with a large anterior/posterior (AP) spread between the mental foramen when posterior atrophy

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Figure 3.5 (a) The non-splinted stud attachments on two anterior implants assist in denture retention. (b) Intaglio of the definitive implant-retained overdenture prosthesis. Implant surgery by Dr. Robert Cain, Oak Ridge, TN. Reproduced with permission from Dr. Robert Cain.

Figure 3.6 (a) A primary bar is secured to four interforaminally positioned implants for an implant-supported mandibular overdenture prosthesis. (b) The intaglio of the definitive mandibular implant-supported overdenture prosthesis. Implant surgery by Dr. Jack Gotcher, Knoxville, TN.
Figure 3.7 Implants can be positioned at angles, up to approximately 30 degrees, to develop a greater AP spread. Implant Surgery by Dr. Joshua Campbell, Oak Ride, TN.

precludes placement of implants posterior to the foramen. Patients that require this form of treatment typically suffer from moderate to severe atrophy.

A hybrid mandibular denture prosthosis requires placement of four or more implants with a maximum AP spread. In atrophic cases, the dental implants are generally placed in the anterior mandible due to the lack of vertical height of bone over the inferior alveolar nerve posteriorly. A fixed, one-piece full-arch prosthesis can be secured to these implants with retaining screws and is indicated for those patients who cannot tolerate the base resin flange material associated with overdenture prostheses or for those patients who have a desire to have a restoration that is not removable. This can be accomplished with a delayed protocol or immediately following extraction of the remaining mandibular teeth. Cases that involve extraction and immediate placement will usually require removal of vertical bone height to satisfy the vertical restorative space requirements previously discussed. Patients with moderate mandibular atrophy will need minimal alveolar reduction only to reduce the “knife edge” occlusal osseous tissue to a level that allows an appropriate ridge width for placement of implants. For this prosthesis, the distal implants can be placed vertically or at angles with angle correction, up to approximately 30 degrees, to increase the AP spread of the implants (Figure 3.7). The anterior mandible must have enough vertical height to place implants with sufficient lengths to support the entire mandibular prosthesis. For patients who have suffered severe mandibular atrophy, vertical bone building may be necessary in order to place implants of minimal lengths. It has been suggested that four or more implants with a minimum length of 10 mm be utilized in the anterior mandible for implant-supported overdentures and implant-supported fixed prostheses [22–24]. Advanced mandibular atrophy can be a significant surgical challenge. When the vertical height of the mandible is insufficient, vertical grafting is needed. A variety of surgical techniques have been utilized including staged reconstruction with autogenous onlay grafts, inferior border grafts, and interpositional grafts [25–30]. In 2002, Marx described a vertical augmentation tenting technique [31]. This procedure involves an extra oral transcutaneous submental approach with placement of four to six dental implants positioned between the mental foramina with a large AP spread. The periosteum and soft tissue is reflected to provide for adequate soft tissue expansion. The dental implants are placed and secured to the inferior border of the mandible extending approximately 9 to 11 mm above the original level of bone. Corticocancellous bone harvested from the iliac crest is positioned around the implants that function as “tent poles” to support the overlying periosteum and soft tissue. Sagging and/or contraction of the soft tissue over unsupported grafts can lead to resorption of the grafted bone. This technique utilizes the dental implants to support the overlying soft tissue during the healing and consolidation of the graft. Following graft consolidation and implant integration, the implants can be traditionally uncovered and subsequently restored with an implant-supported overdenture or hybrid denture prosthesis. This tenting technique has been described as a safe and effective method to reconstruct the severely resorbed mandible [32] (Figure 3.8a to d).

When implants are positioned in the anterior mandible due to advanced posterior resorption, it is possible to design and fabricate implant-supported prostheses (hybrid dentures and primary bar overdentures) with cantilever extensions for the purpose of establishing posterior occlusion. This cantilever can extend posteriorly approximately 1½ times the AP spread of the implants [33]. This spread is measured from the mid-portion of the mid-line implant(s) and a line drawn through the distal aspect of both distal-most implants. If, for example, the AP spread measures 10 mm, the cantilever can be extended 15 mm (1.5 × 10 mm = 15 mm) (Figure 3.9). Shackelton et al. engaged in study that was prompted by several instances of component fracture and other prosthodontic problems with an implant-supported prosthesis [34]. The purpose of this investigation was to determine whether a relationship existed between the survival time of the prostheses and the lengths of their posterior cantilever segments, regardless of the AP spread of the implants. The authors reported that prostheses with cantilever lengths of 15 mm or less survived significantly better than prostheses with cantilever lengths greater than 15 mm. Finally, in 2000, Sadowsky and Caputo reported on load transfer characteristics of different mandibular overdenture designs, with and without edentulous ridge contact [35]. In this study the loaded cantilever bar generated the greatest stress to the distal ipsilateral implant, without intimate contact of the extension base. This study concluded that simulated tissue contact with the extension base of the mandibular overdenture prostheses demonstrated low stress transfer to the ipsilateral terminal abutment when loaded. These studies illustrate that hybrid dentures and implant-supported primary bar overdenture prostheses with appropriate cantilever lengths and distal base extension tissue support for the overdentures are predictable designs when implants are positioned in the anterior mandible. Therefore, when needed, vertical grafting for these two prosthetic designs should be focused in the anterior and not the posterior mandible.

Treatment options for the edentulous maxilla

Treatment of the edentulous maxilla poses unique challenges that include smile esthetics, profile esthetics, phonetics, and hygiene access [36, 37]. It can be easily stated that treatment of the edentulous maxilla may be the greatest challenge in dentistry. Top-down planning is crucial for any dental restoration, but no more critical than when treatment planning the edentulous maxilla. The surgical and restorative team should plan the case from the incisal edge or the occlusal plane instead of from the osseous tissue. Through a diagnostic work-up, the ideal position of the prosthetic teeth is established and the resulting interocclusal restorative...
Figure 3.8 (a) Four endosseous implants are positioned interferamnally extending above the existing bone level to support the overlying soft tissue. (b) Autogenous bone is positioned around all implants. (c) Definitive implant-supported primary bar. (d) Intaglio of the definitive implant-supported mandibular overdenture prosthesis. Grafting and implant surgery by Dr. Eric Carlson, Knoxville, TN.

The general treatment options for the edentulous maxilla are similar to those of the edentulous mandible with a few exceptions. The maxillary options include: (1) a conventional denture, (2) an implant-retained overdenture, (3) an implant-supported overdenture, (4) a fixed hybrid denture with or without immediate occlusal loading, and (5) a fixed crown and bridge splint with or without immediate occlusal loading. As is the case with treatment of the edentulous mandible, if a patient does not achieve reasonable satisfaction with a new provisional maxillary denture prosthesis, implants may be needed to achieve optimal results. It must be understood, however, that some form of denture prosthesis (conventional, implant-retained, or implant-supported [38]) is indicated when the patient requires a flange for lip support and its resulting facial/profile esthetics.

An implant-retained maxillary overdenture utilizes approximately four endosseous implants placed anteriorly, from the mid-line area to the piriform rims bilaterally. These implants assist in the retention of the denture prosthesis [39]. The literature does not contain much evidence regarding the success rates of non-splinted implants in the edentulous maxilla with implant-retained
overdenture prostheses. It can be hypothesized that if the edentulous maxilla has an extremely favorable bone type with excellent volume, and the implants can be positioned with relative parallelism, then an overdenture supported by non-splinted implants may be a viable option [40]. However, there may be very few maxillary arches requiring implants that fit in this classification, suggesting that most implant-retained maxillary prostheses are fabricated with splinted primary bars on four implants [39] (Figure 3.10a and b). With these cases, the majority of the retention is supplied by the proper design and construction of the prosthesis. Specifically, the proper height and thickness of the flanges, the accuracy of the intaglio, the design and finish of the polished surfaces, and the occlusion all play critical roles in retention of implant-retained maxillary overdentures. To that point, full palatal coverage is mandatory for ideal retention of maxillary implant-retained overdentures. When a primary bar is utilized with this type of prosthesis, the 15–17 mm of vertical restorative space is required where the bar is positioned as previously discussed.

If a patient cannot tolerate the palatal base material, a horseshoe design is desired, or the need for total implant support exists for functional loading (mastication and/or parafunction), then an implant-supported overdenture prosthesis may be indicated. If the patient has no objections to this type of removable appliance, then approximately six implants should be positioned in the edentulous maxilla. There are two design concepts to consider here: (1) one continuous primary bar or (2) two separate posterior bars. As with any primary bar overdenture, the vertical restorative space required is 15–17 mm whether the implants are located anteriorly and/or posteriorly.

In 2008, a retrospective study by Krennmair et al. was published in the literature [41]. The purpose of this investigation was to evaluate implant-supported maxillary overdentures using either an anterior or a posterior maxillary implant placement. No statistical differences in implant survival rates were seen between either the anterior (98.4%) and posterior (97.4%) group or the non-grafted (98.0%) and grafted (97.5%) implants. The authors concluded that high survival rates can be achieved for implants placed in the anterior or posterior (grafted or non-grafted) maxilla to support overdenture prostheses. Although the overall post-treatment maintenance of the integrated retentive prosthetic elements was relatively low for both groups, the need for clip activation or renewal was two times more common in the posterior group than in the anterior group. Since retention has been shown to be one of two ideal predictors of satisfaction for patients with overdenture prostheses [42], it may be optimal to place maxillary implants with a large AP spread with a continuous cross-arch primary bar to help maintain attachment retentive values over an extended period of time (Figure 3.11a and b). This means that adequate vertical bone volumes may be needed for implant placement in both the anterior and posterior areas of the maxilla to produce optimal long-term prosthetic results for maxillary overdentures supported by implants.

Fixed restorative options for the edentulous maxilla include hybrid denture prostheses and crown and bridge designs. These restorative designs must satisfy both smile and profile esthetics, support optimal phonetics, and allow for hygiene access. Accomplishing these three requirements may be most difficult with maxillary hybrid dentures [36, 37]. If a fixed restoration requires pink prosthetic material for smile or profile esthetics, it is imperative that the transition of the prosthetic pink material to the natural gingival soft tissue is either indistinguishable to the human eye or hidden beneath the lip with the highest smile. Improved and more suitable products are constantly being introduced to dentistry, but, due to the difficulties and challenges with color and shading of pink prosthetic material, hiding the “pink to pink” margin under the lip may provide for the most predictable esthetic results. If a patient has a high smile line and/or needs material extended facial and superior to the residual maxillary edentulous ridge for any reason, the intaglio surface of the prosthesis will have a concave design. This concavity will prevent the required access for appropriate hygiene. The result will be plaque buildup and debris accumulation (Figure 3.12a, b, and c). If a hybrid denture cannot be fabricated with a convex or flat intaglio surface, then the treating clinicians should consider an alternative prosthetic design such as a crown and bridge fixed prosthesis or an implant-supported overdenture (Figure 3.12d, e, and f). If a patient has minimal atrophy with excellent bone volume, the ideal fixed option may be a crown and bridge design since the optimal vertical space required for this restoration is minimal (approximately 7 to 13 mm). It should be noted that if immediate occlusal loading is planned for the edentulous maxilla, the decision for vertical bone reduction should be based on the planned definitive prosthesis and not the immediate load provisional prosthesis. In other words, a definitive crown and bridge prosthesis will require no