

Horizontal Alveolar Ridge Augmentation in Implant Dentistry

A Surgical Manual



Edited by
Len Tolstunov

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This book is dedicated to my father, Alexander Tsipis. He would be very proud.

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Edited by

Len Tolstunov, DDS, DMD

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Assistant Clinical Professor, Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA



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Contributors

Alexandre-Amir Aalam, DDS

Clinical Assistant Professor
Herman Ostrow School of Dentistry of USC
Los Angeles, CA, USA

Francesco Amato, MD, DDS, PHD

(University of Catania)
Private Practice, Catania, Italy

Shahid Aziz, DMD, MD, FACS

Professor
Department of Oral and Maxillofacial Surgery
Rutgers School of Dental Medicine
Newark, NJ, USA

Joseph Choukroun, MD

President of SYFAC (International Symposium of
Growth Factors)
Nice, France

Gregory J. Conte, DMD, MS

Private Practice, San Francisco, CA, USA

Bruno Ella-Nguema, DDS, PHD

Associate Professor
Head of Department of Anatomy and Physiology
Faculty of Dental Sciences,
Bordeaux University
Bordeaux, France

Mohammed E. Elsalanty, MBBS, MCTS, PHD

Associate Professor
Department of Oral Biology
and Department of Oral and Maxillofacial Surgery
College of Dental Medicine
Georgia Regents University
Augusta, GA, USA

Edgard El Chaar, DDS, MS

Director, Advanced Program in Periodontics
Clinical Associate Professor
New York University, College of Dentistry
New York, NY, USA

Mark C. Fagan, DDS, MS

Private Practice, San Jose, CA, USA

John F. "Eric" Hamrick, DMD

Associate Clinical Professor
Department of Periodontics
Medical University of South Carolina School of
Dentistry
Greenville, SC, USA

David Hatcher, DDS, MSC, MRCD(C)

Adjunct Professor, School of Dentistry, Department of
Orthodontics, University of Pacific, San Francisco, CA;
Clinical Professor, School of Dentistry, Roseman
University;
Clinical Professor, Orofacial Sciences, School of
Dentistry, University of California, San Francisco, CA;
Clinical Professor, School of Dentistry, University of
California, Los Angeles, CA;
Clinical Professor Volunteer, Department of Surgical
and Radiological Sciences, School of Veterinary
Medicine, University of California, Davis, CA;
Private Practice, Diagnostic Digital Imaging,
Sacramento, CA, USA

Alan S Herford, DDS, MD, OMFS

Chair and Professor
Oral and Maxillofacial Surgery Department
Loma Linda University
Loma Linda, CA, USA

A. Thomas Indresano, DMD

The Dr. T. Galt and Lee Dehaven Atwood Professor and
Chair
Department of Oral and Maxillofacial Surgery
University of the Pacific Arthur A. Dugoni School of
Dentistry, San Francisco, CA, USA
Department of Oral and Maxillofacial Surgery and
Chief, Highland Hospital
Oakland, CA, USA

Ole Jensen, DDS, MS

Oral and Maxillofacial Surgery
Denver, CO, USA

Richard T. Kao, DDS, PHD

Private Practice, Cupertino, CA;
Clinical Professor
Division of Periodontology, University of California;
Adjunct Clinical Professor
Department of Periodontology
University of Pacific, Arthur A. Dugoni School of
Dentistry
San Francisco, CA, USA

J. Daulton Keith Jr., DDS

Private Practice in Periodontics
Charleston, SC, USA

Joseph A. Leonetti, DMD

Oral Surgeon and Partner
Main Line Oral Surgery
Paoli and Lionville, PA, USA

Ugo Macca, DDS

(University of Catania), CAGS in Prosthodontics
(Boston University)
CAGS in Prosthodontics at Boston University;
Private Practice, Siracusa, Italy

Jay P. Malmquist, DMD

Oral and Maxillofacial Surgery
Portland, OR, USA

Robert E. Marx, DDS

Professor of Surgery and Chief
Division of Oral and Maxillofacial Surgery
University of Miami Miller School of Medicine
Miami, FL, USA

Agatino Davide Mirabella, DDS, DMD

Adjunct Professor
Department of Orthodontics
University of Ferrara, Italy;
Private Practice Catania, Italy

Gary A. Morris, BA, BS, DDS

Prosthodontist
Adjunct Clinical Assistant Professor
Department of Graduate Studies
Southern Illinois University, School of Dental Medicine
Buffalo Grove, IL, USA

Katina Nguyen, DDS, OMFS

Research Fellow
Oral and Maxillofacial Surgery Department
Loma Linda University
Loma Linda, CA, USA

Sami A. Nizam II, DMD, MD

Resident
Department of Oral and Maxillofacial Surgery
Rutgers School of Dental Medicine
Newark, NJ, USA

Masamitsu Oshima

Department of Oral Rehabilitation and Regenerative
Medicine
Graduate School of Medicine, Dentistry and
Pharmaceutical Sciences
Okayama University
Okayama, Japan;
Research Institute for Science and Technology
Tokyo University of Science
Noda, Chiba, Japan

Sarah Oshman, DMD

Clinical Associate Professor, Advanced Program in Periodontics, New York University, College of Dentistry, NY, NY, USA

Patrick Palacci, DDS

Brånemark Osseointegration Center, Marseille, France; Visiting Professor, Boston University, Boston, MA, USA; Visiting Professor, Andrés Bello University Santiago de Chile; Visiting Professor Maimónides University, Buenos Aires

Shikha Rathi, BDS, MS

Diplomate, American Board of Oral and Maxillofacial Radiology; Adjunct Professor, School of Dentistry, Department of Orthodontics University of Pacific, San Francisco; Private Practice, Diagnostic Digital Imaging Sacramento, CA, USA

Ayleen Rojhani, DDS, OMFS

Senior Resident Oral and Maxillofacial Surgery Department Loma Linda University Loma Linda, CA, USA

Sterling R. Schow, DMD

Professor Department of Oral and Maxillofacial Surgery Texas A&M University Baylor College of Dentistry Dallas, TX, USA

Devorah Schwartz-Arad, DMD, PHD

Head and Senior Surgeon Schwartz-Arad Day-Care Surgical Center Oral and Maxillofacial Surgery Advanced Implantology, Periodontology and Endodontology Ramat Hasharon, Israel

Mohamed Sharawy, BDS, PHD

Professor of Anatomy and Oral and Maxillofacial Surgery Georgia Regents University College of Dental Medicine Augusta, GA, USA

Erica L. Shook, DDS

Assistant Professor Department of Oral and Maxillofacial Surgery University of the Pacific Arthur A. Dugoni School of Dentistry and Highland Hospital San Francisco, CA, USA

Tetsu Takahashi, DDS, PHD

Department of Oral and Maxillofacial Surgery Tohoku University Graduate School of Dentistry Sendai, Japan

Len Tolstunov, DDS, DMD

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA; Assistant Clinical Professor, Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, CA, USA

R. Gilbert Triplett, DDS, PHD

Regents Professor Department of Oral and Maxillofacial Surgery Texas A&M University Baylor College of Dentistry Dallas, TX, USA

Takashi Tsuji, PHD

RIKEN Center for Developmental Biology Kobe, Hyogo, Japan; Organ Technologies Inc. Tokyo, Japan

Kensuke Yamauchi, DDS, PHD

Lecturer, Division of Oral and Maxillofacial Surgery Tohoku University Graduate School of Dentistry Vice Director, Dental Implant Center Tohoku University Hospital Sendai, Japan

Andrew Yampolsky, DDS, MD

Resident Department of Oral and Maxillofacial Surgery Rutgers School of Dental Medicine Newark, NJ, USA

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 “shelve-bound”, collecting dust but more importantly providing little practical use in spite of their original intent.

During my professional dental graduate and oral and maxillo-facial 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.

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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.

Introduction

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 face 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

SECTION I

Introduction

Introduction and Bone Augmentation Classification

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

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 tooth-borne 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].
- 2 Onlay (veneer) extraoral (hip, rib, calvarium) [8] and intraoral (chin, ramus, posterior mandible, zygomatic buttress, maxillary tuberosity) [9–11] block bone graft.
- 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).

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

(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 than 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 bone with 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 imbibition to block graft; slow revascularization through resorption.
- 2 **Periosteal** (peripheral or centripetal). Periosteal proximal angiogenesis to the grafted bone that is exposed to the juxtaposed periosteum (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 endosteal and periosteal sources are also established and are supplementary.

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Applied Surgical Anatomy of the Jaws

Mohamed Sharawy

Georgia Regents University, College of Dental Medicine, Augusta, Georgia, USA

Introduction

After extraction of teeth, the alveolar bone sockets heal and create an alveolar ridge. The new alveolar ridge is covered by thin cortex made up of compact bone overlying a core of cancellous bone and bone marrow. A full denture wearer's bite force decreases from 200 psi to 50 psi. In fifteen years denture wearers have a reduced bite force of about 6 psi [1,2]. As a result, loss of alveolar bone ridge width and height occur in most patients and the dentures become loose. Many edentulous persons with or without dentures have lost a significant amount or complete loss of their alveolar bone (Figures 2.1 and 2.2). In some patients the mental neurovascular bundle is abnormally located on the crest of the atrophied jaw, causing pain and numbness of the chin in denture wearers (Figures 2.2 and 2.3) [3–6].

In rare cases, the incisive nerve and vessels are found under the mucosa covering the ridge (Figure 2.4). The loss of alveolar bone in the maxilla is more complicated due to the expansion of the maxillary sinuses in the posterior ridges (Figures 2.1 and 2.5). The facial appearance of these patients is significantly altered due to the reduction of the vertical dimension of the lower one third of the face. The most recent US health survey has reported that over 40 million people are edentulous. The ones with a significant or complete alveolar bone loss have been named dental cripples.

The advances in our knowledge of bone biology and physiology in the past two decades and the results of translational research and clinical trials has led to the development of clinical procedures aimed at the bioengineering of the structure and function of the atrophied edentulous ridges using bone grafts and implants. Such clinical procedures involve surgical access to the basal bones of the maxilla, maxillary sinuses, and mandible. Most of the surgical approaches extend beyond the fornices (mucobuccal fold) of the oral cavity and may harm the vital structures in the subcutaneous areas of the head subjected to surgical manipulation from the intraoral approach. To employ such bioengineering procedure the dentist and specialists must acquire knowledge of surgical anatomy in order to assure safe access to the jaw bone without harming muscles, vessels, and nerves. Such knowledge will also enable the operator to handle unexpected complications such as hemorrhage, airway obstruction, and nerve injury.

In this chapter we will consider the surgical anatomy of the maxilla and mandible as organs. To consider individual bone as organ we will deal with anatomical landmarks of surgical importance, muscle attachments, arterial supply with emphasis on vessels

that may be injured during surgery, and on veins that may carry and spread infections. Lymphatic drainage from the maxilla and mandible will be discussed. The major sensory and motor innervation will be considered. The anatomy and physiology of the maxillary sinuses will be presented.

Maxilla, surgical anatomy [7]

In gross morphology (Figure 2.6) the maxilla is pyramidal in shape with the root of the zygoma as its apex. The latter can be palpated in the buccal vestibule of the oral cavity and represents an important surgical landmark; it divides the facial or lateral surface of the maxilla into anterior-lateral and posterior-lateral surfaces. The third surface of the maxilla is the orbital plate, which separates the orbit from the maxillary sinus. Facial trauma may lead to fracture of the orbital plate and the drooping of the eye in the direction of the maxillary sinus leading to a diplopia, a condition known as enophthalmia. The base of the maxilla is the lateral wall of the nose or the medial wall of the maxillary sinus. Puncture of this wall during a sinus lift procedure may lead to an antranasal fistula. The latter heals fast with little or no complications when compared to the oroantral fistula.

The mucobuccal fold, also called the fornix, limits the intraoral part of the maxilla, which is covered by a mucous membrane. Above the fornix is the basal bone of the maxilla and is covered by the skin and subcutaneous tissue. At the molar region the buccinators muscle origin acts as a barrier between the buccal vestibule and the subcutaneous tissue of the buccal surgical space. There is no muscle barrier above the mucobuccal fold from canine to canine. The spread of infection from anterior teeth can spread to the facial space and spread to the lower and upper eyelids. The buccinators limit the spread of infection to the buccal vestibule. If the infection spreads above the origin of the buccinators, the infection will spread subcutaneously into the buccal surgical space (Figures 2.7 to 2.9).

The alveolar process of the maxilla related to the anterior-lateral wall carries the incisors, the canines and the premolars, whereas that of the posterior-lateral wall carries the molars and ends as the maxillary tuberosity. The anterior-lateral surface of the maxilla can be palpated under the skin. At the mid-line the anterior nasal spine projects anteriorly and carries the medial nasal septal cartilage. Excision of this process can lead to drooping of the nasal septum. Intraorally, it is possible to palpate the canine eminence and the

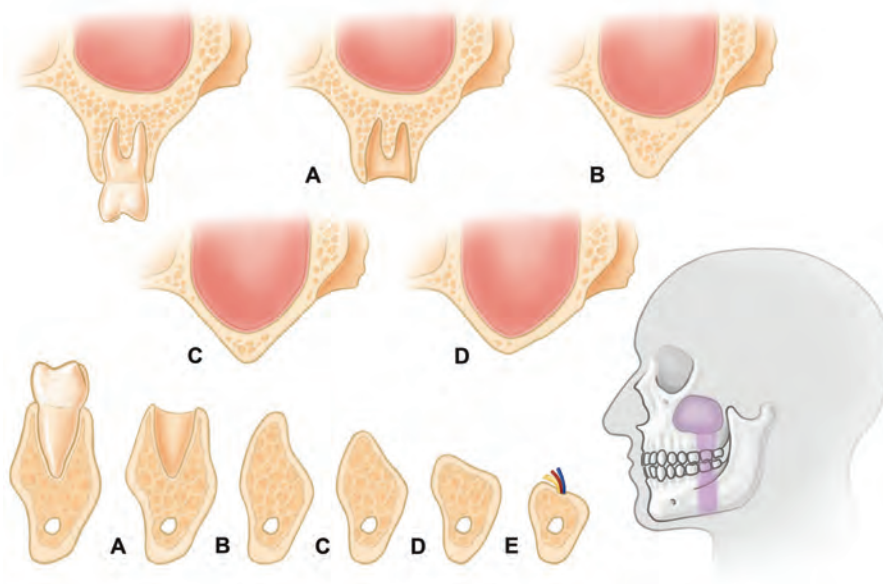


Figure 2.1 Bite force of full denture wearers decreases from 200 psi to 50 psi; by 15 years denture wearers have reduced the bite force to 6 psi. The decline in biomechanical force leads to progressive loss of alveolar bone. The maxillary sinus pneumatizes toward the alveolar bone and enhances the loss of alveolar bone in the posterior edentulous area. Progressive loss of alveolar bone of the mandible will bring the mental neurovascular bundle at the crest of the ridge.

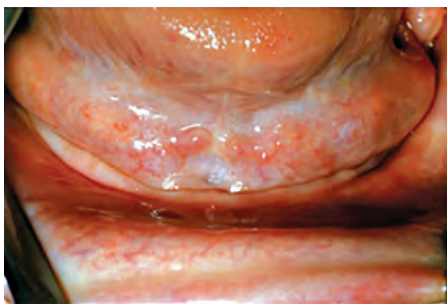


Figure 2.2 Loss of alveolar bone alters the anatomy of the floor of the mouth. Note the rise of the floor, by the mylohyoid muscles, above the posterior ridge. The genial tubercles are abnormally close to the crest of the ridge on the lingual side.

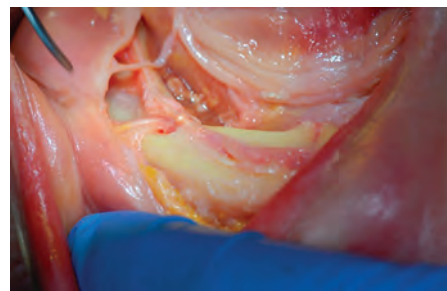


Figure 2.4 Morbid anatomy of an atrophied mandible in a cadaver specimen. Note the hypertrophied superior genial tubercles (*), the mental neurovascular bundle at the crest of the ridge (arrow), and the exposure of the incisive neurovascular bundle (arrow).

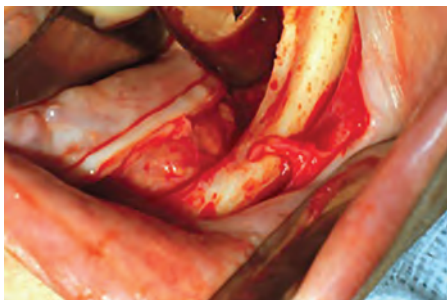


Figure 2.3 Total loss of the alveolar bone brought the mental neurovascular bundle lingual to the crest of the ridge. Note the loss of buccinator and mylohyoid attachments to the atrophied mandible.

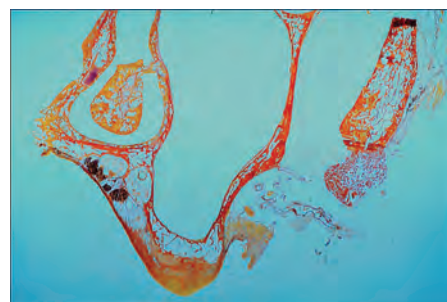


Figure 2.5 Expansion of the maxillary sinus into the alveolar recess and close to complete loss of the alveolar bone (arrow).

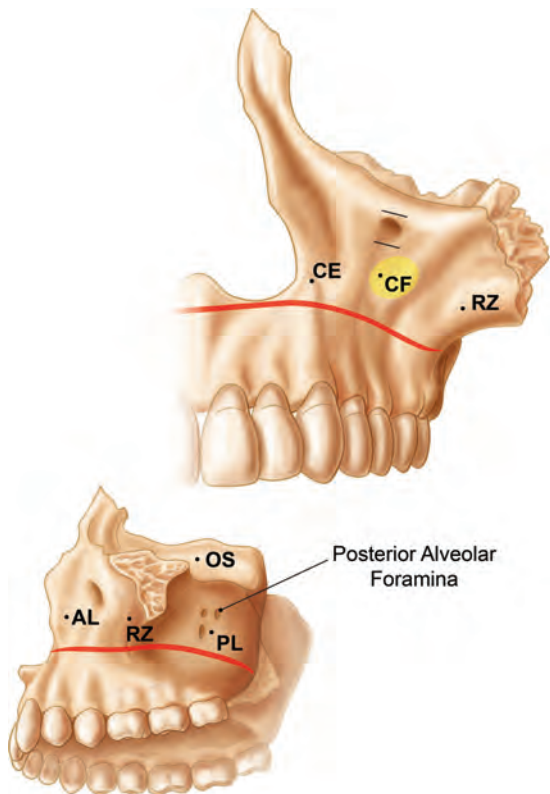


Figure 2.6 Anterior and lateral view of the left maxilla. The maxilla is pyramidal in shape where its apex is the root of zygoma (RZ) and its base forms the lateral wall of the nose. RZ divides the lateral surface into anterior-lateral (AL) and posterior-lateral (PL), the third surface is the orbital (OS). Note the canine eminence (CE) with its apex reaching beyond the fornix into the subcutaneous surface of the AL surface. Between RZ and CE is the canine fossa (CF) or the anterior surface of the maxillary sinus, which reaches superiorly to the infraorbital foramen (3). The inferior boundary of CF extends intraorally into the alveolar process. Distal to the root of the zygoma is the posterior-lateral surface of the maxilla divided by the fornix (thick red line) into the intraoral alveolar bone and above the fornix into the infratemporal surface. The arrow points to the posterior alveolar foramina for the transmission of the posterior superior alveolar artery and nerve. Note that the posterior-lateral surface leads superiorly to the infraorbital fissure, which connects the infratemporal fossa to the orbit. The barrier between the intraoral surface and the infratemporal surface is the buccinator muscle origin. Vestibular incision and violation of the buccinator may injure the posterior superior alveolar artery and nerve.

canine fossa. The latter is located distal to the canine eminence and proximal to the root of the zygoma. It extends superiorly to the infraorbital foramen and inferiorly to the base of the alveolar process.

Surgical access to the maxillary sinus

(Figures 2.5 and 2.6)

The canine fossa is the site for facial access to the maxillary sinus. A vestibular incision between the canine eminence and the root of the zygoma and reflection of tissue above the fornix should reach the canine fossa subcutaneously and expose the bone for the purpose of creating a window into the anterior-lateral wall of the sinus. One has to be careful not to extend the reflection far superiorly to avoid



Figure 2.7 Facial vestibule. The red line indicates a vestibular incision, where below the line is intraoral and above the line is subcutaneous.



Figure 2.8 The buccinator muscle attaches above the line of incision. Above the attachment of the buccinators is the posterior-lateral surface of the maxilla or anterior wall of the infratemporal fossa where the posterior superior alveolar artery and nerve are found.



Figure 2.9 CT showing all the learned anatomical features of the maxilla. Identify the root of zygoma, canine fossa (surgical access site to maxillary sinus), infraorbital foramen (arrow), origin of caninus muscle (black line), vestibular line or fornix (red line), and the posterior-lateral surface or anterior wall of the infratemporal fossa above the vestibular line (vertical arrow).

detaching the levator anguli oris or caninus muscle and injuring the infraorbital neurovascular bundle (Figure 2.10). A vestibular incision at the buccal vestibule will cut the buccinator. Insertion of a periosteal elevator above the vestibular incision should access the posterior-lateral wall of the maxilla, which is also the anterior wall of the infratemporal fossa (Figure 2.6). At this site one should be careful not to sever the posterior superior alveolar nerve and artery. The posterior-lateral wall of the maxilla extends superiorly to the infraorbital fissure and posteriorly to the pterygomaxillary fissure. Surgical manipulation of the posterior-lateral wall to create a window into the maxillary sinus should avoid extending the instruments into these fissures to avoid injury to the maxillary artery and nerve.



Figure 2.10 The infraorbital nerve (red arrow) is sandwiched between the levator labii superior and the caninus muscle. The nerve may be injured during access to the maxillary sinus from an intraoral approach after detaching the caninus muscle.

The medial wall of the maxilla provides attachment to the inferior nasal concha and to the vertical plate of the palatine bone. The latter is the medial wall of the pterygopalatine fossa. At the superior border of the vertical plate of the palatine bone the sphenopalatine foramen is found and through which the sphenopalatine neurovascular bundle exits from the pterygopalatine fossa to the nasal cavity. Injection of local anesthetic solution into the pterygopalatine fossa for the purpose of blocking the maxillary nerve may pass through the sphenopalatine foramen to the nasal cavity and drips on the upper lip from the nose or reaches the oropharynx. The sphenopalatine nerves and vessels supply the walls of the nasal cavity and exit to the palate by passing through the incisive canals, which begin at two foramina located at the floor of the nose above the central incisors. The sphenopalatine neurovascular bundle exits to the palate by passing through the incisive foramen under the incisive papilla.

The opening of the maxillary sinus is actually a canal found in the medial wall of the maxilla, close to the floor of the orbit. The opening is reduced in diameter by the uncinat process of the ethmoid bone. The latter provides the middle and superior nasal conchae. The middle meatus is located between the middle and inferior nasal conchae and is the site of the hiatus semilunaris. The maxillary sinus opens at the hiatus semilunaris. The roof of the maxillary sinus is the orbital plate of the maxilla. The infraorbital canal carries the infraorbital nerve and vessels and forms a bony ridge running along the roof of the sinus cavity.

The sinus space expands into the processes of the maxilla. It expands inferiorly toward the alveolar ridge (50% of all instances) as the alveolar recess, into the zygoma as the zygomatic recess (41.5%), frontal process (40.4%), and palatine process (1.75%). Palatal perforation leads into the floor of the nose and rarely into the sinus cavity. The sinus cavity is lined by a membrane approximately 1 mm in thickness, known as the Schneiderian membrane. The epithelial component of the membrane is made of pseudostratified ciliate epithelium with goblet mucous secreting cells. The subepithelial connective tissue layers contain blood vessels from anterior, middle, and posterior alveolar arteries and veins, as well as branches of anterior, middle, and posterior superior alveolar sensory nerves off

the maxillary (V2) nerve, autonomic nerves, and seromucous glands. The cilia of the sinus epithelium beat toward the sinus canal and along with the mucous carry the foreign particles brought to the sinus by the breathed air toward the sinus opening. Smoking paralyzes the cilia and makes the patient more susceptible to sinusitis.

The bone surfaces at the floor of the sinus show few cells, which appear flat and do not resemble periosteal cells. The floor of the sinus is not flat but is divided into three fossae separated by bony septae. The anterior fossa is related to the premolars, the middle fossa is related to the two molars, and the distal fossa is related to the third molar. The septae may vary in heights from 2 mm to 6 mm. They can be detected as radiopaque lines on panoramic radiographs. During the sinus lift procedure for the purpose of augmenting the floor of the sinus with bone grafts, the operator should be aware of the presence of the bone septae in order to avoid perforating the sinus membrane.

Possible functions of maxillary sinus:

- 1 Resonance of voice.
- 2 Lightening of skull weight.
- 3 Enhancement of craniofacial resistance to mechanical stress.
- 4 Secretion of bactericidal enzymes, which make the environment of healthy sinus sterile.
- 5 Warming of inspired air.

Normal sinus function requires patency of the sinus ostium, normal mucociliary function, and normal systemic and local immune function. Imaging of the sinuses using a panoramic view, Water's view, a periapical radiogram, or tomography using computed tomography (CT) or cone beam computed tomography (CBCT) can show a healthy sinus cavity as radiolucent. Any turbidity caused by fluid, polyps or mucous cysts, thickening of the sinus membrane, etc., should indicate disease. Consulting an ear, nose, and throat (ENT) specialist is highly recommended before proceeding with the sinus lift procedure.

Muscles attached to the maxilla of surgical importance (Figures 2.10 and 2.11)

As the maxillary edentulous ridge resorbs, the crest of the atrophied ridge migrates toward the muscles that take origin from the basal bone of the maxilla. Therefore a vestibular incision or reflection of mucoperiosteal flap may detach these muscles and any surgical manipulation will be subcutaneous rather than intraoral and therefore has the potential of severing or injuring vital structures such as nerves, vessels, and muscles, as will be described below.

Levator labii superioris muscle

It takes its origin from the infraorbital margin above the infraorbital foramen. The muscle covers the infraorbital neurovascular bundle. The muscle is penetrated during infraorbital nerve block anesthesia from a skin approach. The zygomatic branch of facial nerve innervates the muscle.

Levator anguli oris (Caninus)

It originates in the maxilla below the infraorbital foramen. The infraorbital neurovascular bundle is therefore located between the caninus and levator labii superioris. In the atrophied edentulous maxilla the infraorbital neurovascular bundle is closer to the crest of the ridge. Reflection of the tissue following a vestibular incision to access the canine fossa in order to create a lateral window for sinus membrane lift and insertion of bone graft may detach the caninus muscle and injure the infraorbital neurovascular bundle leading to hematoma and subsequent paresthesia or anesthesia of the receptive

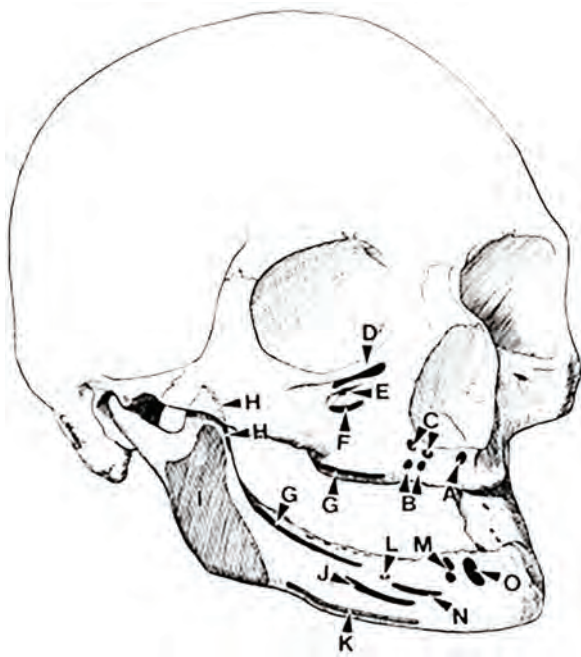


Figure 2.11 (A) Origin of the depressor septi muscle; (B) origin of the superior incisivus muscle; (C) origin of the nasalis muscle; (D) origin of the levator labii superioris muscle; (E) infraorbital foramen; (F) origin of the caninus muscle; (G) origin of the buccinator muscle; (H) insertion of the lateral tendon of the temporalis muscle; (I) insertion of the masseter muscle; (J) origin of the triangularis muscle; (K) insertion of the platysma muscle; (L) mental foramen; (M) origin of the inferior incisivus muscle; (N) origin of the depressor labii inferioris muscle; (O) origin of the mentalis muscle.

field of the infraorbital nerve (lower eyelid, ala of the nose, skin of the lip, and the gingiva opposite to anterior teeth on the side of the injury). Detached muscles commonly reattach to the periosteum but heals shorter than its original length and may cause slight elevation of the corner of the mouth. The zygomatic branch of facial nerve innervates the muscle.

Incisivus labii superior muscle

The incisus labii superioris muscle originates from the floor of the incisive fossa of the maxilla above the eminence of the lateral incisor and deep to the orbicularis oris. To expose the bone of the

premaxilla between the canines, a mucoperiosteal flap reflection may detach the incisus labii superioris. It may also detach the septalis and oblique fibers of the nasalis muscle. The first is attached to the skin of the nasal septum and the latter to the ala of the nose. These small muscles will reattach after placement of the flap. However, if the muscles were damaged, then drooping of the septum and flaring of the ala of the nose may result.

Buccinator muscle

The buccinator muscle originates from the base of the alveolar process opposite to the first, second, and third molars of both jaws. This muscle also takes origin from the pterygoid hamulus of the medial pterygoid plate of the sphenoid bone and therefore bridges the gap between the maxillary tuberosity anteriorly and the hamulus posteriorly. Extension of a subperiosteal frame design into the pterygoid plates may interfere with the fibers of these muscles without adding too much to the retention of the implants. The buccinator muscle crosses the retromolar triangle in order to reach the pterygoid hamulus (a process of the medial pterygoid plate of sphenoid) and pterygomandibular raphe. The latter links the superior constrictor muscle of the pharynx to the buccinator, which runs medial to the medial pterygoid muscle. The long buccal nerve and vessels reach the lateral surface of the buccinators by crossing the retromolar triangle deep to the buccinator muscle fibers. Incision at the retromolar pad that extend along the ramus in order to access more of the external oblique ridge during harvesting a ramus block for autologous ridge augmentation may sever the buccinator fibers and also sever the long buccal nerve and vessels. The buccal branches of the facial nerves innervate the buccinators.

Sensory innervation of the maxilla (Figure 2.12)

The maxillary nerve (V2) innervates the maxilla. The nerve leaves the middle cranial fossa by exiting through the foramen rotundum and crosses the pterygopalatine fossa (pterygopalatine portion). It then exits the fossa through the pterygopalatine fissure and appears at the infratemporal fossa (infratemporal portion). The nerve enters the orbit by passing through the infraorbital fissure and then runs into the infraorbital canal located at the floor of the orbit or the roof of the maxillary sinus (infraorbital portion). It then exits to the face by passing through the infraorbital foramen (facial portion).

Pterygopalatine portion of the maxillary nerve

This portion of the maxillary nerve gives rise to the descending palatine and sphenopalatine nerves. The descending palatine nerves

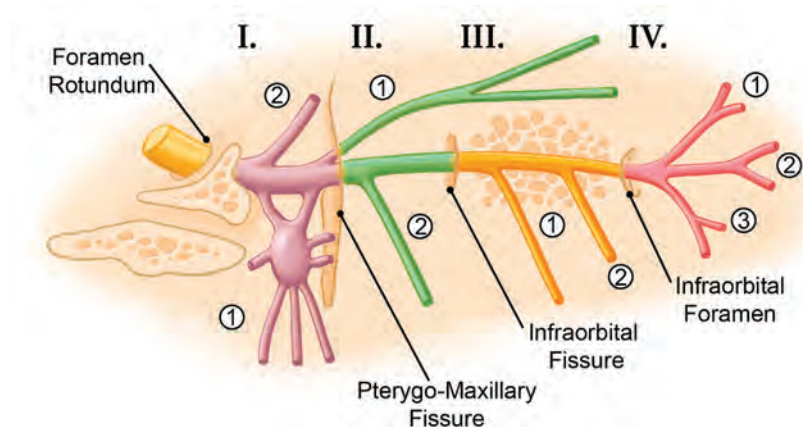


Figure 2.12 Maxillary division of the trigeminal nerve as it exits the cranial cavity through the foramen rotundum and appears in the pterygopalatine fossa (I). This part of V2 supplies the descending palatine and sphenopalatine nerves and V2 then exits through the pterygomaxillary fissure to the infratemporal fossa (II). This portion supplies the zygomatic and posterior superior alveolar nerves. Then V2 enters the infraorbital fissure to become the infraorbital portion (III); it supplies the anterior and middle superior alveolar nerves and then V2 exits to the face through the infraorbital foramen (IV) and branches into the labial, nasal, and palpebral nerves.

descend through the descending palatine canal and branch into the greater palatine nerve, which supplies the mucosa of the hard palate and the lesser palatine nerves that supply the mucosa of the soft palate. These sensory nerves carry autonomic fibers from the sphenopalatine ganglion. Both sympathetic and parasympathetic nerves supply the mucous glands of the palate. The sphenopalatine nerve exits to the nasal cavity by passing through the sphenopalatine foramen. It supplies the nasal mucosa and terminates as the incisive nerve that supplies the mucosa covering the hard palate opposite the upper six anterior teeth. The sphenopalatine nerve carries autonomic nerves that supply the mucous glands and vessels of the nasal cavity. The infratemporal portion of the maxillary nerve gives rise to the zygomatic branch and posterior superior alveolar nerves. The zygomatic nerve divides into the zygomatico-facial and zygomatico-temporal cutaneous branches. The zygomatic nerve also carries autonomic fibers that supply the lacrimal gland in the orbit. The posterior superior alveolar nerve gives rise to a mucous branch that supplies the gingiva opposite the upper three molars and then enters the posterior wall of the maxillary sinus and contributes to the dental plexus that supplies the third molar, second molar and the mesio-buccal root of the first molar teeth and the surrounding bone. After teeth extraction most of the dental nerves degenerate. In some cases few dental branches remain within the alveolar ridge. Insertion of implants at this site may impinge on the residual nerves and cause phantom pain that the patient may feel as if the pain is originating from the extracted teeth. In some cases the severity of the pain may necessitate unscrewing the implant to relieve the pressure or removal of the implant.

Infraorbital portion of the maxillary nerve

It gives rise to the anterior and middle superior alveolar nerves. These nerves run in bony grooves in the facial wall of the maxillary sinus under the Schneiderian membrane. The nerves supply the sinus wall and roots of the premolars, the canine, lateral and central incisors on the same side, and also the central incisor at the contralateral side. The infraorbital facial portion of the maxillary nerve exits the infraorbital foramen and supplies cutaneous branches to the lower eyelid, side of the nose, and the upper lip.

It also supplies the mucosa lining of the upper lip and the gingivae opposite the incisor and premolar teeth. V2 block anesthesia can be achieved by intraoral routes either via the descending palatine canal, via the greater palatine foramen, or via the pterygomaxillary fissure into the pterygopalatine fossa by following the slope of the posterior-lateral surface of the maxilla distal to the root of the zygoma.

Arterial supply to the maxilla (Figure 2.13)

The maxillary artery supplies the majority of arterial blood to the maxilla. It is one of the terminal branches of the external carotid artery. The maxillary artery starts deep to the neck of the mandibular condyle (mandibular portion) and then continues either superficially or deep to the lateral pterygoid muscle in the infratemporal fossa (pterygoid portion). It then reaches the pterygomaxillary fissure where it branches into one artery that enters the pterygopalatine fossa (pterygopalatine portion) and the infraorbital artery that enters the infraorbital fissure and then proceeds in the infraorbital canal (infraorbital portion) and exits on the face by passing through the infraorbital foramen.

Branches of the maxillary artery are as follows:

- 1 Mandibular portion: deep auricular, tympanic, meningial, and inferior alveolar arteries.
- 2 Pterygoid portion: deep temporal, lateral pterygoid, medial pterygoid, and masseteric arteries.
- 3 Pterygopalatine portion: posterior superior alveolar artery, descending palatine and sphenopalatine arteries.
- 4 Infraorbital portion: anterior and middle superior alveolar, palpebral, nasal, and labial arteries.

The collateral or supplemental arterial blood supply reaches the maxilla via five arteries: two branches from the cervical portion of the facial artery (ascending palatine and tonsillar), two dorsal lingual arteries from the lingual artery, and the ascending pharyngeal branch from the external carotid artery. These arteries ascend in the head lateral to the lateral wall of the pharynx medial to the mandibular ramus. The operator of surgical osteotomy of the ramus needs to be aware of these parapharyngeal arteries. The latter arteries penetrate the lateral pharyngeal wall of the oropharynx and supply the palatine mucosa and the bone of the maxilla. During

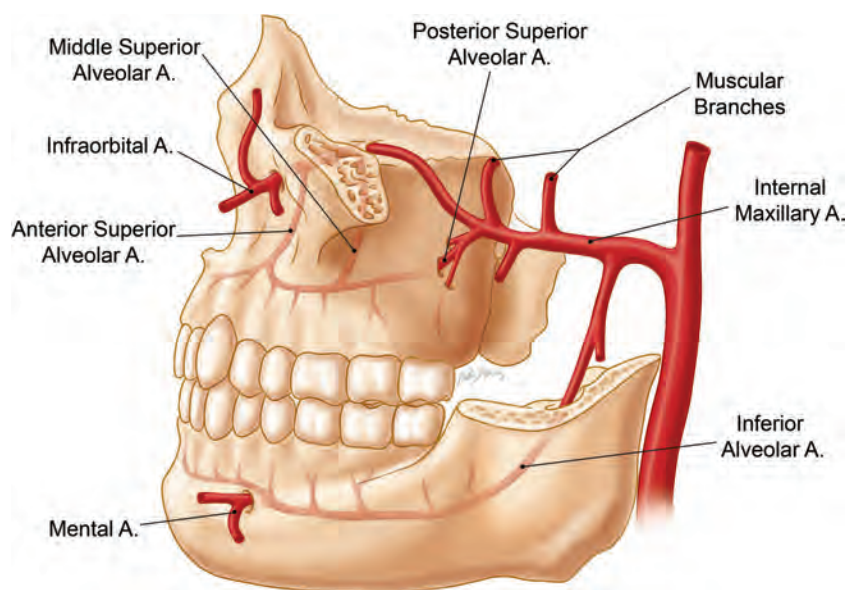


Figure 2.13 Arterial supply of the maxilla and mandible.

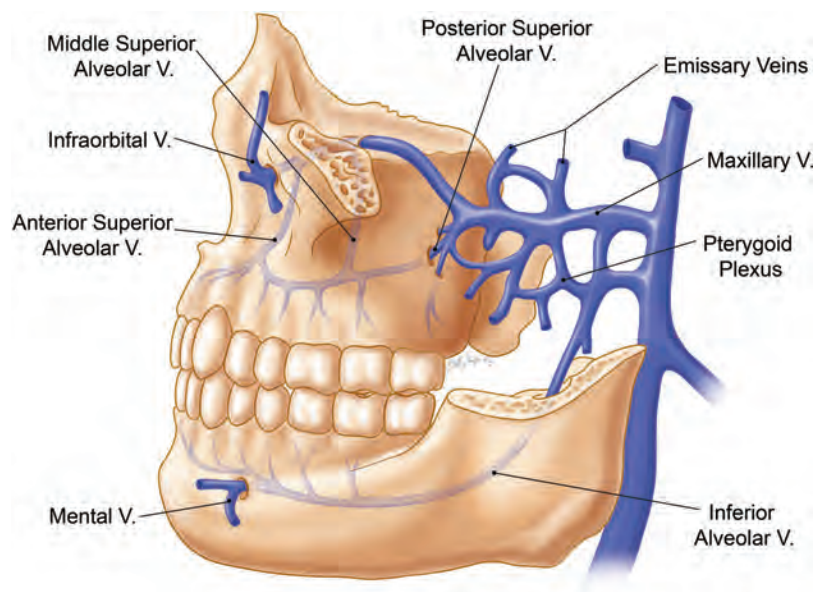


Figure 2.14 Venous drainage of the maxilla and mandible.

orthognathic surgery the surgeon cuts the posterior, middle, and anterior superior alveolar arteries and occasionally the descending palatine arteries without compromising the blood supply to the maxilla because of the presence of the supplemental blood supply from the branches mentioned previously. Reflection of the palatine mucosa and the facial mucosa covering the maxilla during orthognathic surgery is contraindicated since it can lead to necrosis of the maxilla.

Venous drainage from the maxilla (Figure 2.14)

The maxillary vein provides venous drains from the maxilla. It is located in the infratemporal fossa and communicates freely with the pterygoid plexus of veins and then joins the superficial temporal vein to form the posterior facial vein within the parotid gland. Infection anywhere in the maxilla may follow the maxillary vein to the pterygoid plexus of veins. The latter communicate to the cavernous sinuses in the middle cranial fossa via emissary veins, causing infected cavernous thrombosis. An adequate arterial blood supply and healthy venous drainage are essential for bone regeneration and remodeling of bone grafts. Bilateral significant blockage of the carotid arteries may compromise the blood supply to the bone of the maxilla and cause a delay of healing after insertion of implants or bone grafting to the area.

Lymphatic drainage from the maxilla

The submandibular lymph nodes are the primary nodes that drain the maxilla including the maxillary sinuses. The most posterior portion of the maxilla drains into the deep facial nodes or retropharyngeal nodes, part of the deep cervical nodes. Normal nodes are not clinically palpable except the jugulo-digastric or tonsillar nodes and the jugulo-omohyoid or tongue nodes. Preoperative palpation of lymph nodes is an essential part of physical examination of the head and neck.

Mandible, surgical anatomy (Figure 2.15) [7]

The clinician should be familiar with the anatomical landmarks of the dentulous and edentulous mandibles, not only by

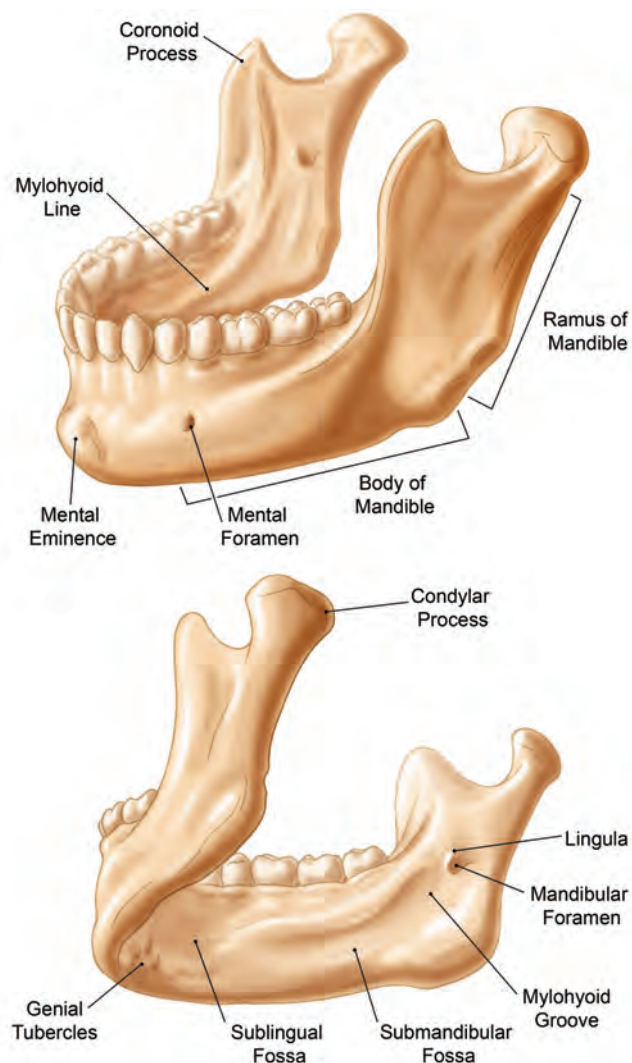


Figure 2.15 Anatomical landmarks of the facial and lingual view of the mandible.

radiographs but also by clinical examination. The mental eminence, inferior border premaseteric notch, gonial angle, lateral pole of the condyle, and coronoid process are all palpable under the skin. Intraoral palpable features of the mandible from the facial aspect are the external oblique ridge, coronoid process, and the boundaries of the retromolar triangle. The external oblique ridge forms its lateral boundary, the temporal crest forms the medial boundary, the retromolar alveolar bone forms its base, and the coronoid process forms the apex of the triangle. The mental foramen can be palpated at the interpupillary line at the apices of the premolars. In severely atrophied edentulous ridge the mental foramen along with the mental neurovascular bundle can be palpated at the crest of the ridge. Incision at the crest of the ridge should avoid injury to the mental neurovascular bundle. The cone beam CT imaging is helpful in confirming the location of the mental nerve prior to surgery. Vestibular facial incision at the symphyseal area will expose the mentalis muscles. Mucoperiosteal flap reflection at the molar region beyond the mucobuccal fold may sever the buccinator muscle attachment and periosteal reflection beyond this line will be subcutaneous. The operator needs to be aware of the presence of the facial artery, facial vein, and marginal branch of the facial nerve close to the premaseteric notch of the mandible. Physical examination of the lingual side of the mandible should palpate the internal oblique ridge and the torus mandibularis in the premolar region, the temporal crest (site for insertion of the medial tendon of the temporalis muscle), and coronoid process of the ramus. In some cases of edentulous severely atrophied mandible the mylohyoid muscles push the sublingual salivary glands up to cover the crest of the ridge and the buccinators attachment in the molar regions may also reach the crest of the ridge and in some cases the muscle loses its attachment to the mandible. An abnormally enlarged superior genial tubercle can be palpated lingually at the mid-line in a severely atrophied edentulous mandible. The lingual nerve, which has a close relationship to the alveolar bone of the third molar in the dentulous mandible, may run close to the crest of the atrophied edentulous ridge and in some cases it may be found under the retromolar pad. The operator needs to be aware of the possibility of having the lingual nerve in the line of incision. Retromolar pad incision should be done buccally and in layers rather than down to the bone in order to avoid injury to the lingual nerve.

Muscle attachment to the mandible of surgical importance to oral implantologists

Mylohyoid (Figure 2.16)

The muscle takes its origin from the internal oblique ridge bilaterally. The most posterior fibers insert into the body of the hyoid bone while the rest of the fibers meet the mid-line from the mandible to the hyoid bone. The muscle forms the floor of the mouth. The structures above the mylohyoid are intraoral while the structures below the muscle are subcutaneous under the skin of the submandibular region. Atrophy of the edentulous mandibular ridge will bring the origin of the muscle close to the crest of the ridge. A crestal incision may injure the muscle and manipulation at this site may cause swelling and ecchymosis above the mylohyoid in the sublingual space or below the mylohyoid in the submandibular space. The mylohyoid depresses the mandible if the hyoid bone is fixed in position by the infrahyoid muscles and it can also raise the hyoid when the mandible is fixed in centric occlusion during swallowing. The nerves to the mylohyoid branch of V3 innervate the mylohyoid muscle.

Genioglossus muscle

The muscle takes its origin from the superior genial tubercle and inserts into the tongue from the tip to its base. Its posterior fibers insert into the body of the hyoid bone. The genioglossus muscles are the main protruders of the tongue. In the edentulous atrophied mandible the superior genial tubercles may become close to the crest of the ridge and in some cases are found at the same level as the crest of the anterior ridge (Figure 2.15). Surgical manipulation at this site should avoid severing the tendons of the genioglossi, which may lead to life threatening fall-back of the tongue, and obstruction of the airway. Branches of the hypoglossal nerves innervate the muscles. Paralysis of the genioglossus muscle on one side will lead to deviation of the tongue toward the affected side.

Medial pterygoid muscle

The majority of the muscle fibers take their origin from the medial surface of the lateral pterygoid plate of the sphenoid bone. A small slip of the muscle originates from the tuberosity of the maxilla (maxillary head). The muscle inserts on the medial surface of the angle of the mandible. The pterygomandibular surgical space is located between the medial pterygoid and the ramus of the mandible. This space contains the sphenomandibular ligament, the inferior alveolar nerve,

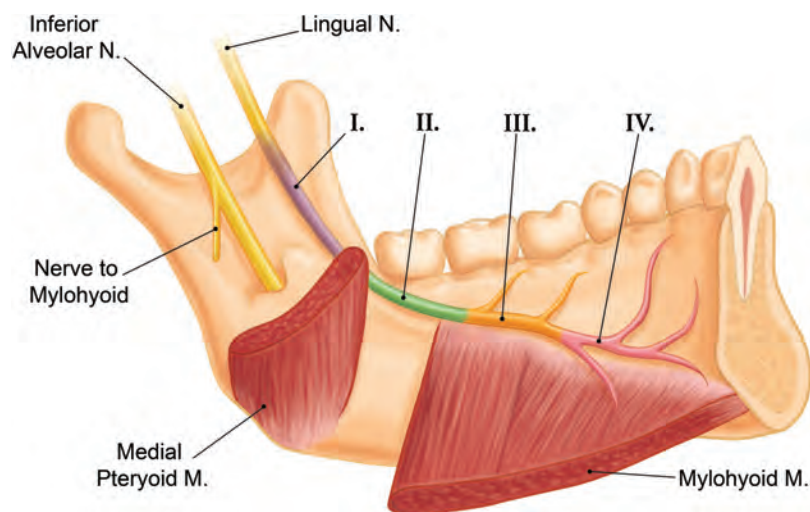


Figure 2.16 Lingual view of the mandible showing the lingual nerve at the pterygomandibular space (I) passing to the floor of the mouth at the edge of mylohyoid muscle (alveolar portion II), then runs in the floor of the mouth on the hyoglossus muscle (III) and send branches to the tongue, lingual gingiva and mucosa of the floor of the mouth (IV). The pterygomandibular portion is the most commonly injured by the needle during inferior alveolar nerve block anesthesia while the alveolar portion is most susceptible to injury during complicated surgical removal of an impacted third molar tooth.

inferior alveolar artery and vein, and the lingual nerve. The pterygomandibular space is entered during inferior alveolar nerve block anesthesia. The spread of dental infection into the space is dangerous because of its location lateral to the parapharyngeal space in the infratemporal fossa. The latter has no inferior boundary and therefore the infection may descend to the neck surgical spaces and reach the mediastinum. The muscle is a powerful elevator of the mandible and receives innervation from the mandibular nerve (V3).

Lateral pterygoid muscle

This muscle is located in the infratemporal fossa. It consists of inferior and superior heads. The superior head originates from the roof of the infratemporal fossa (greater wing of the sphenoid bone), whereas the inferior head originates from the lateral surface of the lateral pterygoid plate of the sphenoid. The superior head inserts on the anterior band of the temporomandibular joint (TMJ) disc (~15% of its fibers) and the remaining fibers insert on the pterygoid fovea on the neck of the condyle. The inferior head inserts on the fovea of the condyle, the median pole of the condyle, and the median collateral ligament of the TMJ disc. Because of the angulation of the lateral pterygoid muscle it is thought to cause adduction of the mandibular rami during maximum opening or yawning. The phenomenon of mandibular flexure may cause the pain experienced by patients with a full arch subperiosteal implant. The muscle normally is a protractor and able to shift the mandible from side to side. Branches of the mandibular nerves innervate the muscles.

Temporalis muscle

The muscle takes its origin from the temporal fossa and descends deep to the zygomatic arch and inserts on the coronoid process and ends in two tendons. The lateral tendon inserts on the lateral boundary of the retromolar triangle while the medial tendon inserts on the medial boundary of the retromolar triangle, known as the temporal crest. The long buccal nerve and vessels are closely related to the medial tendon before it crosses the retromolar triangle deep to the buccinator muscle fibers. During ramus bone block harvesting the incision line may extend along the retromolar triangle and the operator should be aware of the presence of the long buccal neurovascular bundle in order to avoid severing these important vital structures. The temporalis muscles are powerful elevators and retractors of the mandible. Branches of the mandibular nerves supply the muscles.

Mentalis muscles (Figure 2.17)

The mentalis muscle takes its origin from the mental tubercle and the side of the mental eminence and inserts into the skin of the chin

and superiorly some of its fibers interdigitate with the orbicularis oris muscle. The bone of the mental eminence lying between the right and left mentalis muscles is covered by fibroadipose tissue. Vestibular incision from canine to canine will expose the two mentalis muscles. To access the symphyseal bone the two mentalis muscles should be detached from the periosteum to expose the mental eminence for the purpose of harvesting a bone block graft. The mentalis receives its innervation from the marginal mandibular branch of the facial nerve.

Buccinator muscle (mandibular portion)

The muscle takes part of its origin from the external oblique ridge opposite the lower three molars. It serves as a barrier between the oral vestibule and the subcutaneous tissue. In an edentulous atrophied ridge the reduction in the ridge height brings the origin of the buccinators close to or at the crest of the ridge. The buccal mucoperiosteal flap may sever the buccinator and may injure the facial artery, facial vein, and marginal branch of the facial nerve, which are located at the premaseteric notch at the second molar region.

Masseter muscle

The muscle takes its origin from the zygomatic arch and inserts on the lateral surface of the ramus and the angle of the mandible. Surgical access of the ramus should avoid reflection of the masseter from the zygomatic arch since it will interfere with the masseteric nerve and masseteric artery, which enter the deep surface of the muscle by passing through the sigmoid notch. A deep masseteric fascia covers the muscle. The space between the muscle and the fascia is a potential surgical space, known as the masseter space, into which an infection may spread causing trismus and myositis.

Innervation of the lower jaw and associated structures (Figure 2.18)

The third division of the trigeminal nerve (V3) exits through the foramen ovale and appears in the infratemporal fossa deep to the lateral pterygoid muscle. The main trunk gives off meningeal and medial pterygoid branches. It divides into anterior and posterior divisions. The anterior division gives all motor branches to muscles of mastication and one sensory nerve, called the *long buccal nerve*. The posterior division gives all sensory branches (*auriculotemporal*, *lingual* and *inferior alveolar*) and one motor branch (nerve to mylohyoid).

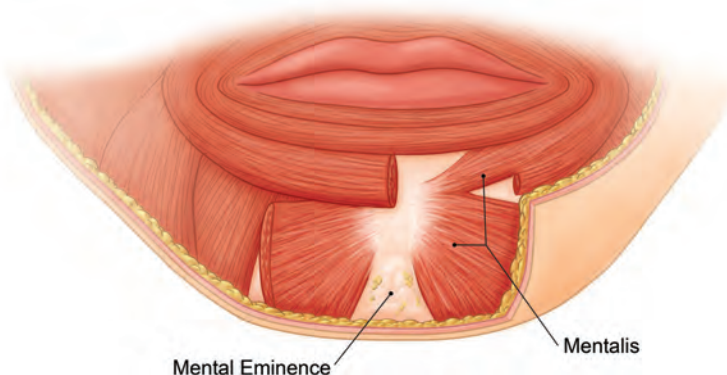


Figure 2.17 The mentalis muscle takes its origin from the side of the mental eminence and inserts on the chin skin, where few fibers interdigitate with the orbicularis oris muscle. Fibroadipose tissue separates the two muscles. Vestibular incision from canine to canine exposes the mentalis muscles.

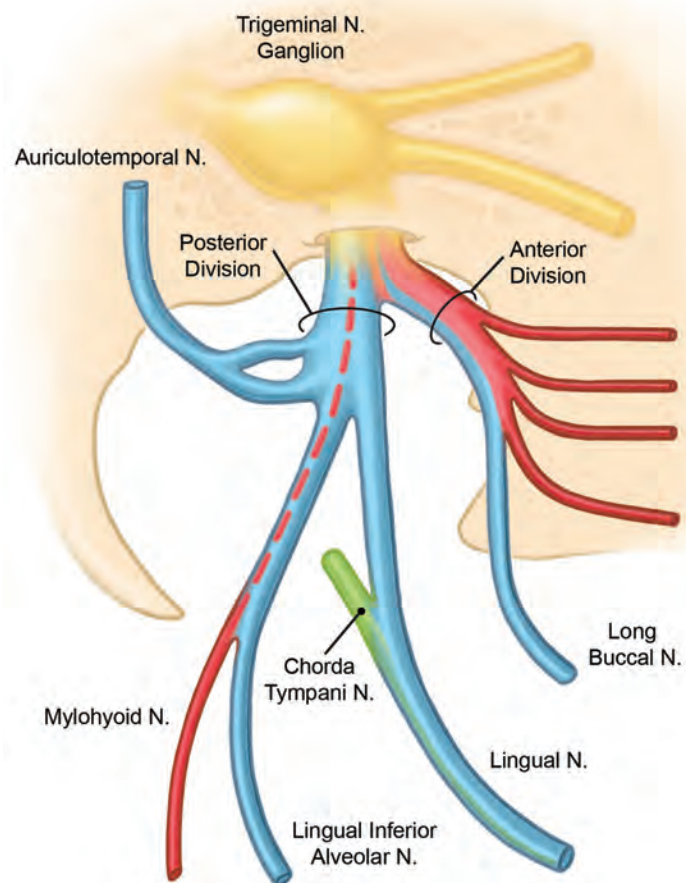


Figure 2.18 V3 red (motor) and blue (sensory). The mandibular nerve exits the foramen ovale and appears at the infratemporal fossa, before dividing into an anterior division (all motor to muscles of mastication and one sensory, long buccal nerve). The posterior division is all sensory (auriculotemporal, lingual, inferior alveolar, and one motor nerve to mylohyoid). The chorda tympani nerve, branch of the facial nerve (green), carries taste fibers and secretomotor parasympathetic fibers and joins the lingual nerve.

Inferior alveolar nerve

This nerve appears at the inferior border of the lateral pterygoid muscle and courses inferiorly toward the mandibular foramen. It gives numerous sensory branches that innervate the mandibular bone. These small nerves are in association with small vessels in neurovascular channels. The inferior dental nerve can run as one unit through the mandibular canal until it reaches the premolar region, where it divides into the mental and the incisive nerves. The mental nerve exits the canal through the mental foramen. In an excessively resorbed ridge, the mental foramen, with its contents of mental nerve and vessels, can be found on the crest of the ridge. When making an incision or reflection of the mucosa in this area, avoid injury to these vital structures. Knowledge of the position of the inferior dental canal in vertical and buccolingual dimensions is of paramount importance during site preparation for implants. The potential use of reconstruction techniques on computed tomographic scans and magnetic resonance imaging may increase clinicians' ability to locate the inferior dental canal precisely within the jawbone. Much less expensive techniques using panoramic cross-sectional tomographic imaging are also available. In some cases the inferior dental nerve may divide into two or three rami, which occupy separate canals as the nerve travels in the mandible to supply the bone. These variations can be determined by conventional radiographic techniques and the operator should modify the surgical approach and type of implant to avoid injury to the portion of the nerve that exits the foramen. Injury to the portion of the inferior alveolar nerve that remains in the atrophied bone and does not innervate soft tissues is of far less consequence. The nerves in the

bone, when in contact with an implant, may account for the rare but occasional observation of tenderness, even though the implant is rigid and appears healthy. In addition, the fibrous tissue around these nerves may cause an increase in the amount of fibrous tissue around an implant that is inserted in contact with these structures.

Lingual nerve (Figure 2.16)

The lingual nerve is one of the most commonly injured nerves in dental surgery. The dentist needs to learn the details of the course of the nerve and its anatomical location, particularly its relationship to an impacted third molar socket and to the retromolar pad in edentulous atrophied mandibles. The nerve is a branch of the mandibular nerve that is given off in the infratemporal fossa. The nerve is given off the posterior division of V3 deep to the inferior belly of the lateral pterygoid muscle. This part of the lingual nerve (pterygoid portion) is rarely injured in dental practice. The next portion of the lingual nerve is found in between the medial pterygoid muscle and the ramus of the mandible (pterygomandibular portion). This part is commonly injured during an inferior alveolar nerve block injection with little or no consequences. The nerve then proceeds from the infratemporal fossa to the oral cavity. It seeks the most posterior portion of the mylohyoid muscle and proceeds on its surface close to the lingual cortex of the third molar tooth (alveolar portion). The alveolar portion of the lingual nerve is the most commonly injured, particularly during removal of an impacted third molar tooth. The nerve then continues on the surface of the hyoglossus muscle (floor of the mouth portion). The lingual nerve sends its branches to the anterior two-thirds of the tongue, the mucosa of the

floor of the mouth, and the lingual gingiva. Severing of the alveolar portion of the lingual nerve will deprive the patient not only of general sensory functions (pain, temperature, pressure, touch) but also taste to the anterior thirds of the tongue (fibers of the chorda tympani nerve branch of the facial nerve) and autonomic parasympathetic secretomotor function to the submandibular and sublingual salivary glands (fibers of the chorda tympani nerve carried by the lingual nerve). Some patients also suffer from post-traumatic neuralgia and severe intolerable pain. Incision at the retromolar pad should be done buccally and in layers before reaching bone in order to avoid injury to the lingual nerve.

Nerve to mylohyoid nerve

The mylohyoid nerve is a motor branch of the inferior alveolar nerve given off before the nerve enters the inferior alveolar canal. The nerve follows the path of the submental artery branch of the facial artery in the submandibular triangle and supplies the anterior belly of digastric and mylohyoid muscles.

Long buccal nerve

The long buccal nerve is a branch of the mandibular nerve (V3) given off in the infratemporal fossa. It appears between the superior and inferior heads of the lateral pterygoid muscle and then proceeds by crossing the retromolar triangle close to the medial tendon of the temporalis. The latter guides the nerve to the lateral surface of the buccinators. The nerve supplies the skin of the cheek and runs down to the level of the external oblique ridge, penetrates the buccinators, and branches to supply the mucosa of the cheek and buccal gingivae opposite the lower molar teeth. The implant dentists who extend the incision along the ramus in order to obtain a large ramus block for grafting should be aware of the crossing of the long buccal nerve and vessels at the retromolar triangle area. Unfortunately, the location of the nerve crossing is inconsistent. It may cross high and close to the coronoid process, at the middle, or close to the base of the retromolar triangle.

Blood supply to the mandible [8,9]

The mandible receives its arterial blood supply from the inferior alveolar artery branch of the internal maxillary artery. It also receives a supplemental blood supply from the arteries supplying the muscles attached to its surface. Cadaveric studies after perfusion of the arteries with radiopaque polymer showed clearly that the lingual cortex at the symphyseal area of the mandible receive branches from the sublingual and the submental arteries. Lingual perforation during implant surgery may injure these arteries. Hemorrhage in the floor of the mouth from these arteries under the tongue may lead to hematoma in the sublingual surgical space and a swollen tongue, which may lead to airway obstruction. Hemorrhage from the inferior alveolar artery within the bone should be controlled by crushing bone around the vessels or using bone wax. The facial artery passes through the submandibular gland and exits lingual to the mandible under the mylohyoid muscle at the second molar region. Insertion of a dental implant at this region may perforate the mandible and lead to facial artery hemorrhage in the submandibular region (Figure 2.19)

Summary and conclusions

The root of the zygoma is a palpable intraoral bony landmark of surgical importance. It represents the location of the apex of the maxillary sinus. The root of the zygoma divides the lateral wall of

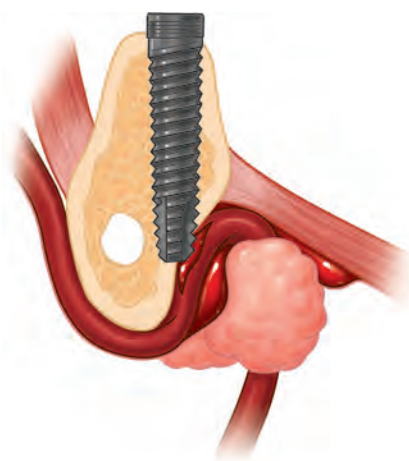


Figure 2.19 Coronal cut of the mandible at the second molar region showing the relationship of the facial artery below the mylohyoid muscle to the lingual cortex of the mandible. This area of the mandible is thinner because of the presence of the submandibular fossa. Perforation of the lingual cortex during *implant insertion* may lead to severe hemorrhage at the submandibular region.

the maxilla into anterior-lateral and posterior-lateral walls. Between the root of the zygoma and the canine eminence is the canine fossa or the site of lateral window access to the maxillary sinus. Accessing the canine fossa through the mucoperiosteal flap may detach the caninus muscle and may cause injury to the infraorbital neurovascular bundle. Therefore clinical location of the infraorbital foramen and marking it on the skin prior to accessing the canine fossa is an important safeguard to avoid injury to the infraorbital nerve and vessels.

The vestibular fornix (mucobuccal fold) locates a plane that divides the maxilla into an intraoral part covered by oral mucosa and a subcutaneous part. The facial fornix between the right and left premolars has no muscle barrier while the posterior fornix at the molars has the buccinators as a barrier. Surgical manipulation at the premaxilla may cause facial swelling that may spread to the lower and upper eyelids. Violation of the attachment of the buccinators opposite the posterior edentulous ridge may injure the superior alveolar artery and nerve at the posterior wall of the maxillary sinus.

Buccal mucoperiosteal flap reflection may violate the buccinators origin from the external oblique ridge, particularly in cases of partial or complete loss of the alveolar process of the edentulous mandible. Surgical manipulation at this site may injure or sever the marginal mandibular motor nerve, facial artery, and facial vein at the second molar region. On the lingual side of the mandible the operator must be aware of the location of the superior genial tubercles and the attachment of the genioglossi muscles. Severing of the genioglossi tendons will cause fall-back of the tongue and airway obstruction. Incision at the retromolar pad and/or surgical manipulation lingual to the third molar region may cause injury to the lingual nerve. Extension of a retromolar incision along the anterior border of the mandible may sever the buccinator fibers and the long buccal neurovascular bundle as it crosses the retromolar triangle. Insertion of the dental implant in the mandibular second molar region of an atrophied mandible may perforate the lingual cortex and injure the facial artery, causing a serious hemorrhage in the submandibular region.

Surgical procedure aimed at accessing the symphyseal bone of the mandible for harvesting an autologous bone block graft will expose the mentalis muscles. If the mentalis muscles are detached during surgery, effort should be made to re-suture them to the periosteum or apply an elastic bandage to the chin for at least four days. Failure to do this may result in double chin appearance.

Partial or complete loss of the alveolar bone at the mandibular premolar region may bring the mental neurovascular bundle close to or at the crest of the ridge. Therefore, an incision at the crest of the ridge without preoperative CBCT imaging may injure or sever the mental nerve and vessels.

Knowledge of applied surgical anatomy of the maxilla and mandible is the foundation of safe oral surgery. Such knowledge will make the operator aware of the anatomical locations of muscles, nerves and vessels during surgery and therefore avoid unnecessary injury to these vital structures, with serious consequences such as hemorrhage, paresthesia, anesthesia, and post-traumatic neuralgia.

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CHAPTER 3

Bone Development and Histiogenesis of the Jaws

Mohammed E. Elsalanty

Department of Oral Biology and Department of Oral and Maxillofacial Surgery, College of Dental Medicine, Georgia Regents University, Augusta, Georgia, USA

Development of bone

Patterning of the human skeleton occurs during the first eight weeks after fertilization [1], with the ossification of the mandible occurring around the sixth or seventh week [2]. Evidence of bone remodeling is detected as early as the fetal period, but it becomes more pronounced around the fifth intrauterine month [2]. Bone formation in the fetus proceeds very fast and exerts a high toll on the mother's supply of calcium and phosphorus. Typically, more than 150 g of calcium and 70 g of phosphorus per kilogram of fetal body weight is required for the development of the fetal skeleton [3]. The dynamics of such heavy trafficking across the placenta are not yet completely understood. After birth, the neonatal parathyroid gland should compensate for the loss of the transplacental supply of calcium, by extracting it through the gastrointestinal wall. Vitamin D also controls calcium homeostasis in the neonate.

Development of the mandible and maxilla

During the fourth week after fertilization, the first pharyngeal arch develops. The arch is composed of a core of migrating neural crest cells enclosed in a sleeve of ectoderm. As the right and left arches advance forward toward the mid-line, each splits into a maxillary and a mandibular process (prominences). The advancing processes from both sides appear as surface elevations lateral to the developing pharyngeal space. By the end of the fourth week, four pharyngeal arches are evident on the outer surface, separated from each other by pharyngeal grooves (clefts). Two more arches (fifth and sixth) are present but not visible on the outside surface [4].

The first arch gives rise to both the mandible and maxilla. It is the only pharyngeal arch where both the external and internal surfaces are covered by ectoderm. Therefore, the oral epithelium is derived entirely from ectoderm. The advancing prominences from both sides surround a space that represents the stomatodeum (primordial oral cavity).

The right and left mandibular prominences unite in the mid-line, forming the arch of the lower jaw. The maxillary prominences, however, unite with the prominences, extending down from the mid-line frontonasal process, namely the medial and lateral nasal processes (Figure 3.1). The maxilla is, therefore, derived from the bilateral maxillary prominences plus the medial nasal processes in between. More specifically, the medial nasal processes give rise to the premaxilla (bone carrying the four maxillary incisors), the primary palate (the triangle of bone anterior to the incisive fossa), and the

covering gingiva. The rest of the maxilla, as well as the zygoma and part of the vomer, are derived from the maxillary prominence of the first pharyngeal arch. Recent studies have shown that the entire upper lip is derived from the maxillary prominences [4].

Initially, the stomodeum is separated from the pharyngeal cavity by a temporary diaphragm, the oropharyngeal membrane, which ruptures around day 26. Like other pharyngeal arches, the first arch contains an artery, a nerve, a cartilaginous rod, and a muscular component. The blood vessels are formed by endothelial cells that originate mostly from the lateral mesoderm, the nerve cells are derived from the neural plate, while the myogenic cells originate from the paraxial mesoderm. All of these cells migrate into the developing arch.

The first skeletal component of the first pharyngeal arch is the rod-shaped, hyaline, Meckel's cartilage, which appears during the sixth week. Between the seventh and twentieth week, it forms the first articulation between the developing lower jaw and the skull base, a joint that will eventually become the malleus-incus joint of the middle ear.

Although the Meckel's cartilage predates, and seems to guide, the development of the mandible, it does not become a component of the mandibular bone itself. In other words, the developing mandible does *not* form by endochondral ossification of the scaffold formed by the Meckel's cartilage. Instead, the mandibular bone, including the mandibular condyle, forms by intramembranous ossification laterally to the cartilage and separately from it. The proximal part of the cartilage eventually forms the malleus and incus and becomes part of the middle ear. The middle part regresses, but its perichondrium forms the *anterior ligament of malleus* and the *sphenomandibular ligament*. The ventral parts of the right and left cartilages fuse in the midline to guide the three-dimensional outline of the symphyseal region of the mandible.

The muscular components of the first pharyngeal arch are derived from the paraxial mesoderm and the prechordal plate. They give rise to many muscles in the head and neck, including the muscles of mastication.

The nerve of the first pharyngeal arch is the trigeminal nerve (CN V). The two caudal divisions of the nerve, namely the maxillary and mandibular divisions, supply all the tissues derived from this arch, including the muscles of mastication (motor) and the facial skin, facial bones, oral mucous membranes, and teeth (sensory). However, the rostral division (ophthalmic nerve) does not supply any of the derivatives of the first arch. The facial nerve (CN VII),

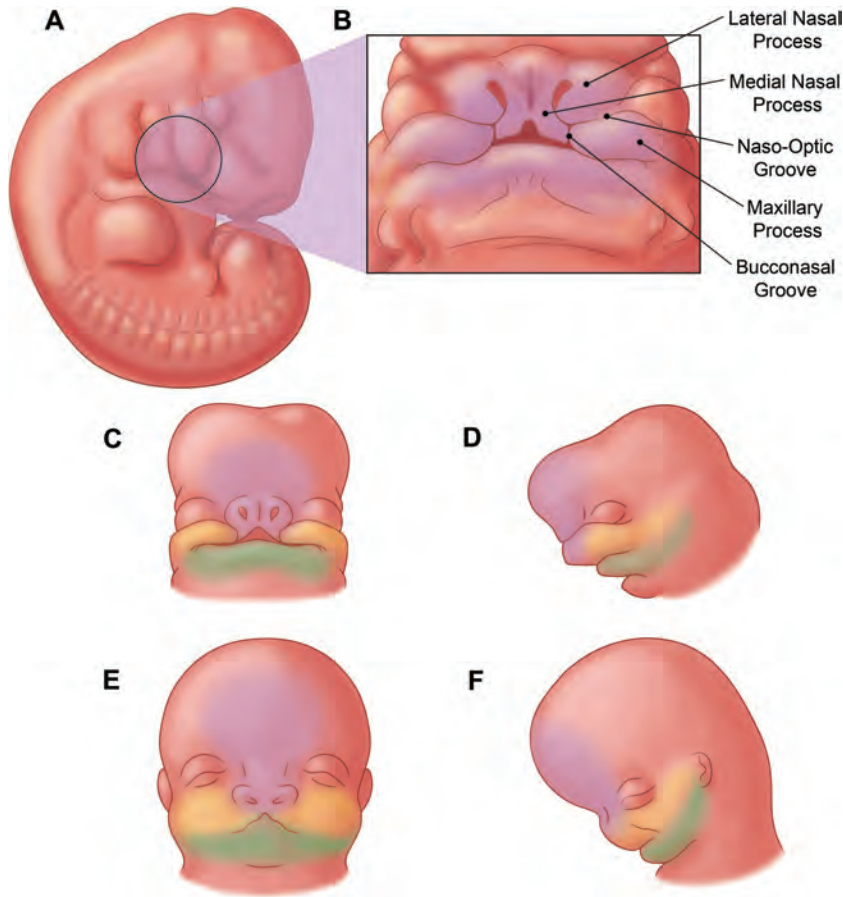


Figure 3.1 Development of the face. The upper jaw is derived from the fusion of the bilateral maxillary processes (first pharyngeal arch) to the two medial nasal processes (from the frontonasal process). The upper lip is derived entirely from the two maxillary processes (yellow). The mandible is formed by the fusion of the two mandibular processes (first pharyngeal arch) at the mid-line.

along with myoblasts that form the facial muscles, invade the first arch, migrating from the second pharyngeal arch.

Dental tissues are all derived from the first pharyngeal arch. The first indication of a dental arch appears during the sixth week as a shelf of ectoderm (the dental lamina), growing into the underlying ectomesenchyme. Later, tooth buds appear at certain areas of the dental lamina. Both the ectoderm and the ectomesenchyme contribute to the tooth bud. There are three components of a tooth germ: the enamel organ, the dental papilla, and the dental follicle. The enamel organ is ectodermal in origin and gives rise to the enamel and the reduced enamel epithelium (a layer that will enclose the formed crown, is important for tooth eruption, and contributes to the formation of junctional epithelium). The dental papilla will give rise to the dentin-pulp complex, while the dental follicle (sac) will give rise to the cementum, periodontal ligament, and alveolar bone. Remnants of epithelial structures within the developing jawbone, namely the enamel organ and dental lamina, can give rise to different types of odontogenic cysts later in life.

Bone as a tissue

Regardless of the type of bone, it is composed of a matrix, cellular component, and marrow. The bone cells include the bone-forming cells (osteoblasts), bone-resorbing cells (osteoclasts), and resident bone cells (osteocytes).

Osteoblasts are mononucleated cells that synthesize and then mineralize the organic matrix of bone. Osteoblasts originate from the pluripotent stem cells, which are of mesenchymal lineage in the

case of the axial and appendicular bones and ectomesenchymal (derived from the neural crest) in the case of the mandible and maxilla, as explained above.

Osteoblasts appear as flat (squamous) cells overlying the bone surfaces, when they are inactive. They are termed bone-lining cells. Once osteoblasts are activated, they attain a cuboidal shape owing to the expansion of the cytoplasm by cellular organelles required for protein synthesis (Figure 3.2). Osteoblasts synthesize type I collagen, the dominant structural protein in the bone matrix. They also produce alkaline phosphatase, an enzyme believed to play a key role in the mineralization of collagen. Osteoblasts and their precursors also secrete various cytokines and growth factors that affect other cells in

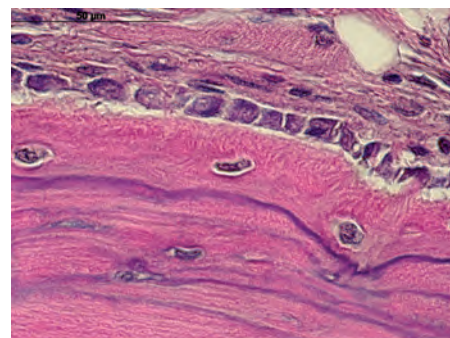


Figure 3.2 A line of osteoblasts lining the surface of bone, with recent bone formation evident by the presence of a reversal line. (×40; Hematoxylin and Eosin).

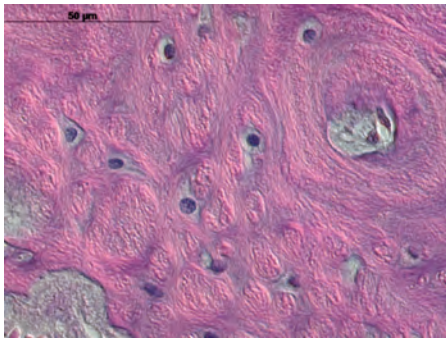


Figure 3.3 A histologic section of healthy bone matrix showing multiple osteocytes within lacunae. (×40; Hematoxylin and Eosin).

the bone microenvironment; they include bone morphogenetic proteins (BMPs), transforming growth factor beta, insulin-like growth factors, and fibroblastic growth factors. Importantly, osteoblasts possess receptors for parathyroid hormones, which trigger downstream expression of receptor activator of nuclear factor kappa-B ligand (RANKL), a major stimulating factor for osteoclasts [5].

As osteoblasts form bone, they maintain cellular connections with other osteoblasts and with the resident osteocytes through gap junctions. Then, some of these active osteoblasts become embedded into the matrix they secrete, becoming osteocytes (Figure 3.3). The spaces within which the osteocytes reside are called lacunae, while their cellular processes extend into small canaliculi (channels) that connect neighboring lacunae. The result of this organization is an extensive cellular network that connects the osteocytes within the bone to the surface osteoblasts, especially the dormant bone-lining cells. This network is believed to be essential for the bone's ability to sense and respond to mechanical stimuli and for the control of the bone homeostatic mechanisms.

Osteoclasts are large, multinucleated cells that descend from the hematopoietic stem cell lineage, specifically from circulating monocytes. Osteoclasts attach to the surface of bone as a response to specific chemotactic signals. The attachment ring creates a confined subcellular compartment against the bone surface, called the Howship's lacuna (Figure 3.4). The cell membrane opposite the lacuna has extensive folding – hence its name: the ruffled border. The osteoclasts synthesize tartrate-resistant acid phosphatase (TRAP) and many other lysosomal enzymes, which are synthesized in the rough endoplasmic reticulum, modified in the Golgi vesicles, and transported via small vesicles toward the ruffled border. The ruffled border also possesses an efficient proton pump. After attachment to the bone surface, the activated osteoclast pumps hydrogen ions into the confined space of the Howship's lacuna. The resulting rapid

decline in pH within that space causes demineralization of the opposing bone surface. This is followed by digestion of the matrix proteins. The osteoclast uptakes the degradation products through the ruffled border and releases them into the surrounding tissue through other parts of the cell's membrane. The osteoclast then detaches from the surface and moves to a different spot [5].

Organic material constitutes 50% of the volume and about 33% of the dry weight of bone. Inorganic material (hydroxyapatite crystals) constitutes 50% to 67% of the weight of dry bone. This makes bone less hard but more resilient than enamel and dentin. Matrix proteins are mostly type I collagen, in addition to type III and traces of type V, XII, and XIV collagen. Many non-collagenous proteins also exist in bone, including osteopontin, osteocalcin, osteonectin, dentin matrix protein, dentin sialophosphoprotein, and others. Non-collagenous proteins mostly have regulatory rather than structural functions [5].

Bone as an organ

From a functional perspective, there are multiple classifications of bone. Based on the mode of formation, bone can be categorized into primary (woven) versus secondary (lamellar). Woven bone is the initial bone that is formed and is typically remodeled into cortical or trabecular bone in response to mechanical signals. The second classification of bone would be, therefore, cortical (compact; osteonal) versus trabecular (cancellous; spongy). Cortical bone has a dense matrix with Haversian systems. Each Haversian or osteon has a central canal through which runs the blood vessels and nerve fibers. Concentric layers of compact bone surround the central canal. The collagen fibers in each layer are arranged in a spiral that is at a right angle to that of the adjacent layer. This intricate arrangement of collagen fibers in the osteon gives the cortical bone the ability to withstand compressive loading along its long axis and still maintain considerable stiffness along other axes. Along the borders separating the concentric layers lie the osteocyte lacunae, which are interconnected by an elaborate network of canaliculi. The osteocyte network is responsible for sensing and responding to mechanical load. It is also believed to regulate the bone remodeling over time.

Trabecular bone, on the other hand, does not have Haversian systems. Instead, the bone is composed of a network of interconnecting rods or sheets of bone. The three-dimensional orientation of those minute structures, named trabeculae, seems to be determined by the type, pattern, and direction of mechanical loading. The shape of the trabeculae (rod versus sheet), as well as their number, density, spacing, connectivity, and quality (mineral density), are important parameters that determine the mechanical integrity of bone.

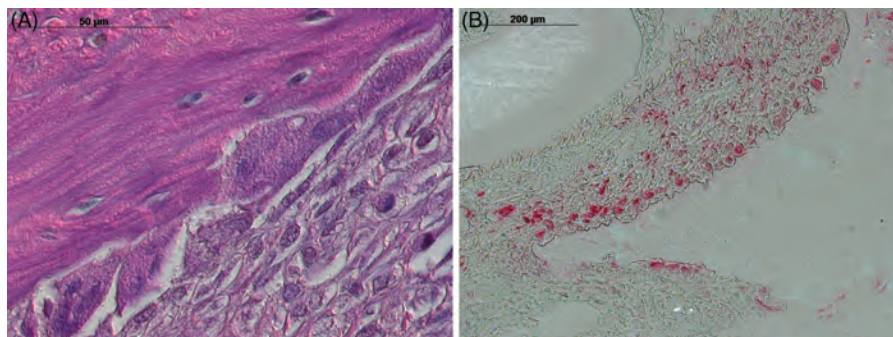


Figure 3.4 Osteoclasts. (A) Histologic section showing the border between bone (upper left) and bone marrow (lower right). Along the bone surface, three multinucleated osteoclasts are actively resorbing bone (×40; Hematoxylin and Eosin). (B) Histologic section showing a wedge of bone being destroyed from the surface by an active osteoclast front (×10; Hematoxylin and Eosin).

Another classification of bone addresses its embryonic mechanism of formation: whether the bone formed within a cartilage scaffold (endochondral) or a connective tissue membrane (intramembranous). Skull bones (except those of the skull base) are all formed through intramembranous ossification. The mandible initially forms through intramembranous ossification lateral to the Meckel's cartilage (as outlined above). However, during the condylar growth spurt (ages 12 to 18 years), the mandibular ramus grows through endochondral ossification of the activated condylar cartilage.

Alveolar bone is the portion of the mandible and maxilla that carries teeth. Alveolar bone is typically composed of three structures: the alveolar bone proper (cribriform plate or lamina dura in X-ray) that forms the walls of the dental socket, the cortical plates that form the outer shells of the mandible and maxilla, and the spongiosa (trabecular bone; interalveolar septum) in between. The spongiosa is typically scanty or completely absent around the anterior teeth.

Nerve fibers and capillaries pass through this sheet of bone from the interalveolar septum into the periodontal space – hence the term “cribriform” plate. This means that the blood and nerve supply for the periodontal ligament originates mainly from the interalveolar septum, as opposed to teeth, which receive their supply through the apical foramina at the root tips.

Alveolar bone is covered from the outside by periosteum. The periosteum has an outer layer of tough fibrous tissue and an inner layer (osteogenic) of bone-lining cells. The fibrous layer extends vertical bundles of type I collagen into the underlying bone (Sharpey's fibers). At certain areas, the periosteum is fused with the lamina propria of the oral mucosa, giving the mucous membrane a very firm attachment to the underlying bone without an intervening layer of submucosa. This arrangement is called mucoperiosteum and is found in the attached gingiva and most of the palatine mucosa. The inner spaces of bone are lined with endosteum, which is composed of only one layer of bone-lining cells. The periosteum and endosteum provide a major supply of osteogenic cells for bone regeneration.

The oral cavity is lined by oral mucosa, which is composed of oral epithelium, lamina propria, and submucosa. The oral epithelium is stratified squamous, which is keratinized on the surfaces that are involved in mastication, namely the gingiva, palatine mucosa, and the dorsal surface of the anterior two-thirds of the tongue. Keratin provides a tough scratchproof coating that resists shear forces produced by friction with food particles. The lamina propria is the connective tissue layer underneath the epithelium that provides its blood and nerve supply. It is a mechanically stiff layer that includes an intricate network of collagen types III, IV, and VII. The submucosa, on the other hand, is more flexible, being rich in fat and elastic fibers. The submucosa is the layer that houses the minor salivary glands. The submucosa also provides a potential space, which can be expanded easily either by a hematoma, infection, or an injection.

At certain areas of the oral mucosa, the lamina propria fuses with the periosteum of the underlying bone surface, with no intervening submucosa. These areas include the attached gingiva and the anterior and mid-line zones of the palatine mucosa. This arrangement is called mucoperiosteum. Due to the firm attachment between the mucosa and bone, surgical incision in these areas does not result in mucosal retraction, and therefore does not warrant approximation of the wound edges and/or suturing afterwards. On the other hand, submucosal dissection is quite tedious and frequently results in tearing of the mucosa. Submucosal injections in these areas are also limited and painful.

Overall, the rate of epithelial proliferation in the oral mucosa far exceeds that of fibroblasts in the underlying lamina propria. Therefore, wounds heal mostly by re-epithelialization rather than scar formation, even in the presence of mucosal gaps.

Bone remodeling

Bone remodeling is the process of coupled bone formation and resorption (breakdown) (Figure 3.5). Remodeling activity continues throughout life, with the balance between bone formation and resorption shifting with age. The rate of bone turnover, as well as its net result of bone loss or gain, varies according to age, gender, anatomical site, and numerous biomechanical and calcium homeostatic mechanisms. While some bones hardly remodel throughout life, such as the middle ear ossicles and the wall of the dental socket, others have a high turnover rate, such as the spongiosa of alveolar bone [6–8].

The bone turnover rate seems to be highest at the bone surfaces lining the bone marrow cavities, where osteoclasts are readily accessible. Bone disuse is known to activate remodeling. A similar response is observed after estrogen or androgen depletion, and chronic corticosteroid treatment. Furthermore, trabecular bone that houses red marrow shows a higher remodeling rate than bone that contains yellow marrow. Remodeling of cortical bone also seems to vary according to the anatomical site. However, the mechanisms that determine the “geographical” pattern of bone remodeling are not fully understood [6–8].

Physiological loading and bone remodeling

In 1892, Wolff described the law of bone remodeling based on the prevailing views about bone biology at that time. It stated that: “every change in the form and function of bone or of its function alone is followed by definite changes in their internal architecture and equally definite changes in their external configuration in accordance with mathematical laws” [7,9]. Two concepts emerged from this dogma. The first is that skeletal elements are strategically positioned to optimize bone strength in relation to the type, distribution, and magnitude of applied loading. The second is that bone mass is also directly related to the applied loading [10].

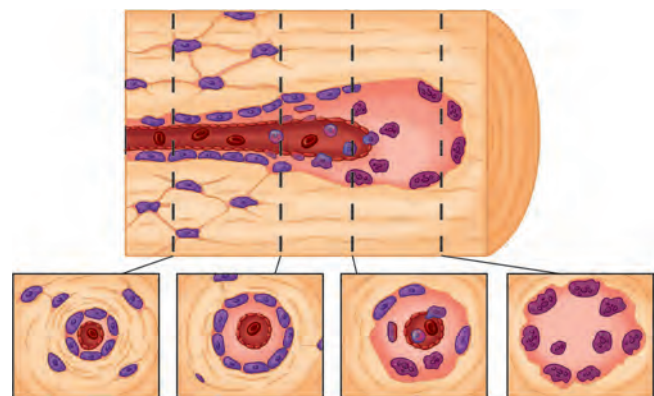


Figure 3.5 A diagram showing the bone-remodeling unit (cutting cone). The osteoclast front is creating a tunnel within the old bone, guided by a chemotactic signal. A new capillary follows the osteoclasts, bringing in more osteoclast-forming monocytes as well as mesenchymal stem cells that differentiate into osteoblasts. The osteoblasts line up against the wall of the tunnel and lay down new layers of lamellar bone.

It is believed that the form of adult bone is determined by two main factors: genetic and physiological loading, defined by its magnitude and pattern. Frost (1987) proposed the *mechanostat hypothesis*, which suggested that bone seeks to stabilize its strength through a negative feedback mechanism that regulates the addition or removal of bone at different sites. According to this hypothesis, genetic factors determine some kind of a “baseline condition”, while the applied loads determine the mechanical needs of the skeleton. The current understanding of the relationship between mechanical loading and bone remodeling has culminated in the *Utah paradigm*. Its applications involve the organization of bone, as well as ligaments, tendons, and fascia, with possible implications on muscle organization as well [7].

Mechanical loading of bone causes deformation (strain) in the matrix proportional to the magnitude of load. Several factors affect the strain distribution, including the bone type, quality, and internal and external architecture, as well as the pattern of loading. Strain is a key controlling factor of bone remodeling: where strains exceed a “modeling threshold” range, the *conservative-mode remodeling* is turned on, while *modeling* mechanisms start altering the bone architecture to reduce future strains. Below this threshold range, typically below the microdamage threshold, the mechanically controlled modeling is turned off. However, at this “disuse mode” remodeling keeps removing bone. It is characterized by thinning of the cortex, enlarged marrow cavity, and widening of spacing between trabeculae with *no* reduction of the outside bone diameter [7].

According to this understanding, bone is designed to have just enough strength to prevent voluntary loading from causing bone damage. Our understanding of how and why bone loss occurs is still evolving. We can hypothesize that strain *programs* the process and turns it on and then it continues as programmed even if the strain stops. In complete unloading, as in paraplegia, bones of the lower extremity can lose up to 40% of their mass, however they do *not* disappear [7]. This suggests that there are other controls for bone remodeling even in the absence of mechanical strain. This discussion is highly relevant for the understanding of alveolar resorption after tooth loss.

Hormones and bone remodeling

One major objective of bone remodeling is mineral homeostasis, especially calcium and phosphorus. Bone is therefore under the influence of hormones that regulate metabolic activities. Bone marrow is central to hematopoiesis and the regulation of the immune system. Hormones known to have a high impact on bone metabolism include the parathyroid hormone (PTH), osteocalcin, gonadal hormones, corticosteroids, growth hormone and its soluble receptor IGF-1, and thyroid hormone.

Bone regeneration

Bone formation is a very slow process. Apart from microfractures, bone breaks cannot be bridged by direct (primary) bone healing. On the other hand, bone fractures cause significant mechanical strains across the fracture line. Therefore, the fractured bone has to be stabilized in order for the “interfragmentary strain” to be reduced to a level at which bone can form. In other words, an intermediary tissue, one that can form in a high-strain environment, has to stabilize the fracture first, and then bone can replace it later (ossification). This concept is the basis for secondary (callus) bone healing. The intermediary tissue can be fibrous tissue or cartilage.

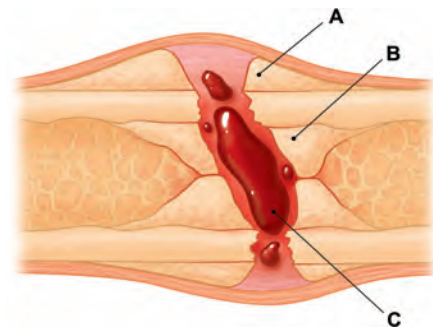


Figure 3.6 Bone fractures heal by a combination of ossification mechanisms. The subperiosteal and endosteal surfaces (A, B) show intramembranous and/or appositional ossification. The fracture gap (C) itself shows endochondral ossification at the center and intramembranous ossification near the edges.

The critical first stage of fracture healing is the formation of a fracture hematoma. It is during this stage that bone regeneration cascades are triggered. The hematoma brings the cells that will clean the necrotic bone edges, the monocyte-derived osteoclasts, as well as circulating mesenchymal stem cells that will differentiate into osteoblasts. Platelets release multiple important factors for both angiogenesis and osteogenesis, including platelet-derived growth factor (PDGF). The result is an initial inflammatory response that culminates in the formation of the soft callus, which will later ossify into hard callus (bone). Based on the mode of ossification, bone regeneration can be categorized into endochondral, intramembranous, and appositional. A typical fracture heals by a combination of all three mechanisms (Figure 3.6).

The final stage of bone healing is the modeling/remodeling stage, during which the local microstrain environment will dictate not only how much of the newly formed bone will remain but also the quality and architecture of that bone. Remodeling activity can take one or two years to stabilize. Post-operative “relapse” typically takes place during this phase. Therefore, it is not accurate to evaluate the outcome of bone reconstructive procedures before the end of the remodeling phase.

Alveolar ridge atrophy

As discussed above, mechanical loading largely determines the outline and integrity of the alveolar bone. Partial or complete loss of the dental arch invariably leads to bone loss at the alveolar ridge. Edentulism-induced ridge atrophy follows certain patterns, typically reducing the ridge thickness before its height [11,12]. In the maxilla, the labial cortical wall of the tooth socket disappears before the palatal (centripetal resorption) [13]. In the mandible, on the other hand, the lingual wall disappears before the buccal (centrifugal resorption). This discrepancy in the resorption pattern can result in a disruption of the sagittal and axial intermaxillary relationship [14,15].

Classifications of the alveolar ridge

Ridge atrophy has been classified in different ways:

Atwood (1963) described six stages of alveolar ridge atrophy [16]:

- I. Pre-extraction, normal bone.
- II. Post-extraction, normal bone: after extraction and before resorption started.

- III. High, well rounded, adequate in height and width.
- IV. Knife-edge, adequate height and inadequate width.
- V. Low, well rounded, inadequate height and width.
- VI. Depressed ridge.

More recently, Juodzbalys and Raustia classified ridge atrophy into three types [17]:

Type I: Alveolar height is ≥ 10 mm and width is ≥ 6 mm and the vertical defect in the anterior region of ≤ 3 mm, which is optimal for implant placement.

Type IIA: the height is ≥ 10 mm and the width is 4 to 5 mm, narrow edentulous jaw dental segment (narrow eJDS).

Type IIB: the height is 4–9 mm and the width is ≥ 6 mm (shallow eJDS).

Type IIC: the height is 4–9 mm and the width is 4–5 mm (shallow and narrow eJDS).

Type II D: the height is ≥ 10 mm and the width is ≥ 6 mm, the vertical cosmetic defect in an anterior region is more than 3 mm from the crest of the alveolar bone to the necks of adjacent teeth.

Type III: the height is < 4 mm and the width is < 4 mm (too shallow and too narrow for implantation).

Another popular classification was based on bone architecture. Based on this classification, there are four types of alveolar bone [18]:

D-1 bone: the ridge is almost entirely composed of cortical bone, with little or no spongiosa. This type is typically found in the anterior part of the mandible.

D-2 bone: the ridge has cortical plates, with intervening coarse trabecular bone. This type is typical for the posterior mandible and sometimes the anterior maxilla.

D-3 bone: the ridge has cortical plates, with intervening fine trabecular bone. It is typically found in the anterior maxilla. This type is considered more fragile than D1 and D2.

D-4 bone: fine trabecular bone, with very little cortical cover. This type is most commonly found in chronically edentulous posterior maxilla. This type is the least favorable for implant placement.

Conclusion

Planning of surgical interventions must be based on a solid understanding of the basic biological and biomechanical systems that govern the involved tissues. On the other hand, disregarding or violating these systems can have a negative impact on the long-term surgical results, regardless of how well the surgical technique itself

was conducted. Healing of tissues after surgical trauma typically mimics, to a large degree, their embryonic development. Finally, the alveolar bone follows certain patterns of resorption after tooth loss that should be considered during reconstruction.

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CHAPTER 4

Prosthetic Comprehensive Oral Evaluation in Implant Dentistry: A Team Approach

Gary A. Morris

Department of Graduate Studies, Southern Illinois University, School of Dental Medicine, Alton, Illinois, USA
Private Practice, Buffalo Grove, Illinois, USA

Introduction

Dental implant therapy is a restorative and surgical treatment modality designed to restore the dentition both cosmetically and functionally by replacing missing teeth and contiguous oral structures. The collaborative application of this therapy requires an interdisciplinary team approach to ensure the patient has a predictable and satisfying outcome. The purpose of this chapter is to identify and explain the necessary components to a restorative evaluation of a patient prior to the initiation of the surgical phase of treatment – in particular to the patient in need of *horizontal ridge width augmentation*, to provide a proper foundation for the restoration and long-term success for the surgical, restorative, and patient team.

Components of the evaluation

Initial evaluation

The evaluation of a patient prior to the initiation of dental implant therapy by a prosthodontist or general restorative dentist is critical for the ultimate success of a treatment plan. Determination of the diagnostic needs as well as the type of site preservation, site development, provisional restorations, and prosthetic design necessary to accomplish the restorative goal prior to the initiation of therapy can be the difference between success and failure. Communication between the patient's restorative dentist, surgical specialist, and laboratory technician requires an understanding of the ultimate goal of therapy [1]. Treatment planning is both site specific and dependent on the design of the desired final prosthesis. Ridge width defects cause different issues depending on their anatomy, cause, position in the mouth, and teeth to be replaced. Ridge width augmentation can be critical in the success of an implant case, but does not come without challenges [2].

Diagnostic work-up

The prosthodontic work-up begins with a comprehensive examination and interview of the patient. A thorough review of the patient's medical history, current medications, allergies, habits, and dental history are taken [3,4]. A review of their chief complaint and the history associated with the concern is recorded. During the

patient interview, it is important to determine the patient's desires and to assess whether their expectations are realistic. If not, it is important to educate them as to what they can expect from treatment, result, maintenance requirements, and potential for revision or replacement of their restoration in the future. It is also imperative that alternative treatment options are discussed, including the option of no treatment and the consequences of such. The clinical evaluation is made up of the following examinations.

Radiographic examination

A thorough radiographic examination is required to determine the patient's candidacy for dental implant therapy. Three-dimensional radiographs such as spiral and cone beam computed tomography (CBCT) scans provide useful information regarding the ability to place a dental implant in an appropriate position. These radiographs will allow for the determination of hard tissue deficiencies and need for grafting prior to or in conjunction with implant placement [5]. The use of radiographic guides is most helpful, as they will provide the restorative coordinates and emergence-positioning information for the final restoration based on a diagnostic wax-up. With the use of implant planning software, the size and position of a dental implant can be illustrated in the planning phase. The need for ridge augmentation will be evident and can be planned in advance [6] (Figure 4.1).

Dental examination

The dental examination consists of an evaluation and charting of the dentition. The presence and condition of the teeth and supporting structures are evaluated and recorded. Clinical evidence of decay, attrition, erosion, and fracture of the teeth are observed. The presence of existing restorations and the condition of the restorations is also evaluated and recorded in the chart. The edentulous spaces are evaluated for the thickness of tissue overlying the site, the presence or absence of keratinized tissue, ridge width dimensions, the presence of undercuts, height irregularities, and position of muscle attachments are examined and recorded.

Periodontal examination

Complete periodontal probing and charting, including bleeding points and areas with a suppurative discharge, is essential to a

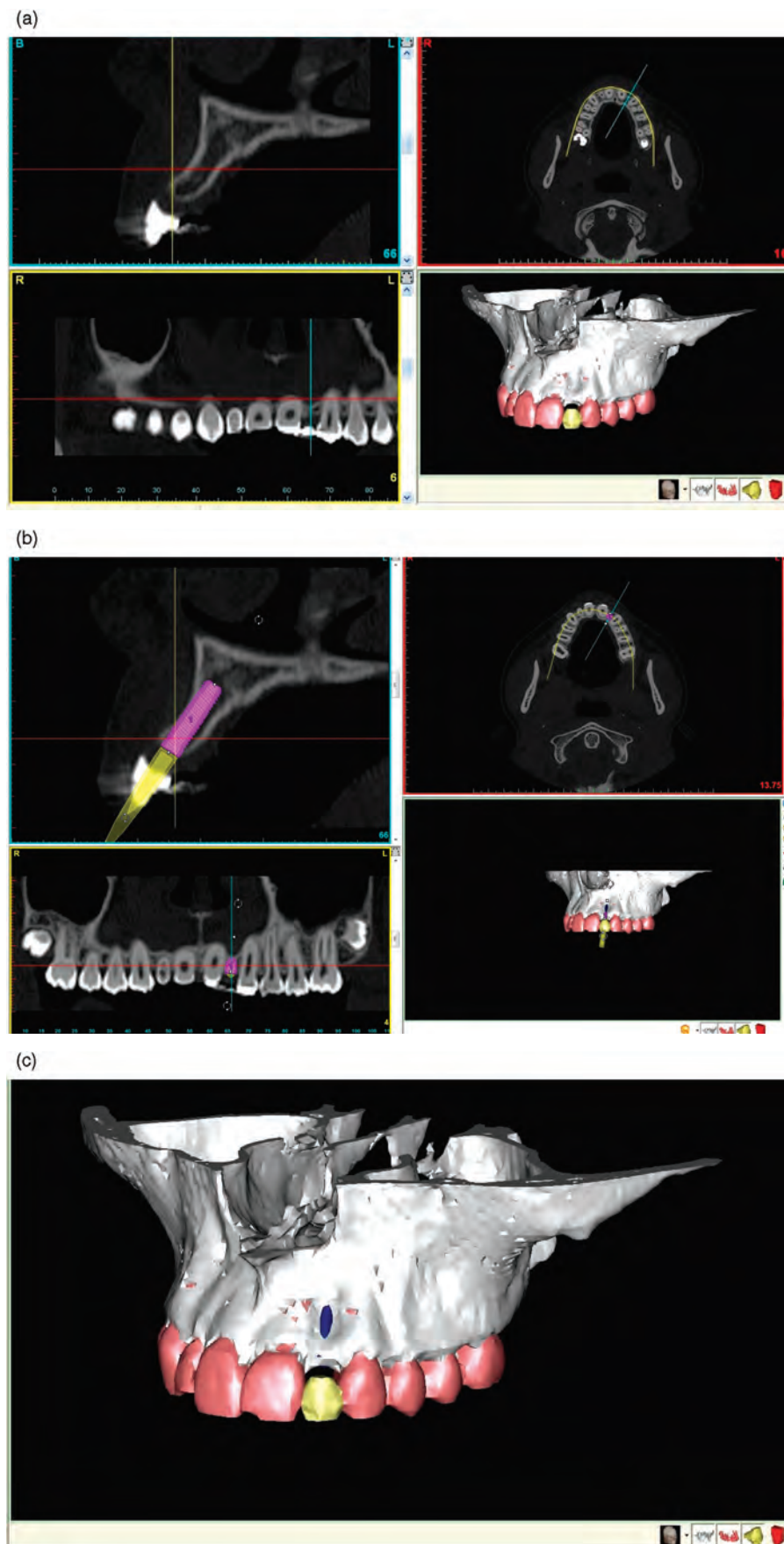


Figure 4.1 (a) Cone beam computed tomography (CBCT) scan demonstrating a horizontal defect mid-facial and apically. (b) The planned dental implant will fenestrate the bone exposing threads. (c) 3D view of the defect. (d) CBCT scan demonstrating the defect caused apically surrounding the failure of endodontic therapy and subsequent apicoectomy.

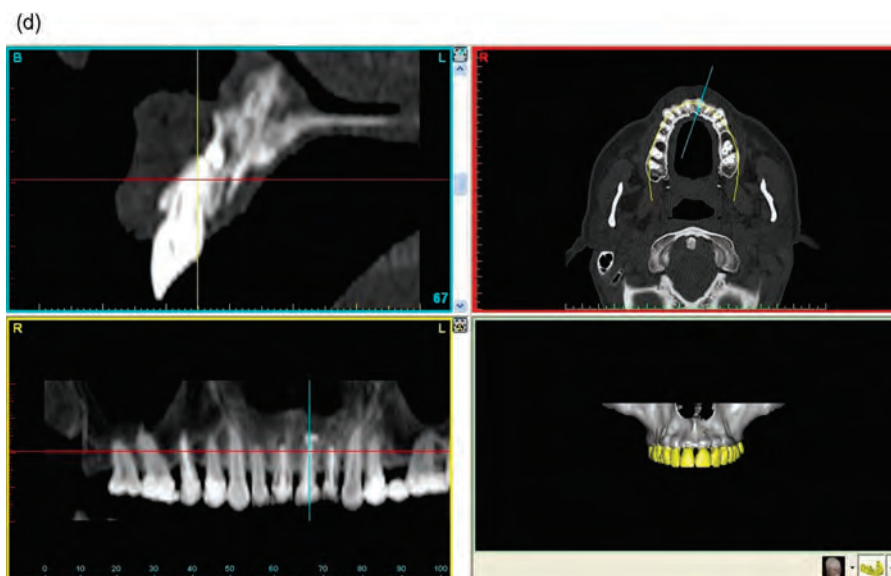


Figure 4.1 (Continued)

complete diagnosis. Charting of recession and mobility as well as gingival attachment levels are diagnostic and provide essential information needed to form a proper diagnosis. Determination of the gingival biotype will help guide the plan with respect to conversion of biotype through hard tissue grafting, soft tissue grafting, or a combination of both to provide the proper supporting structures for a predictable emergence profile or healthy gingival sulcus surrounding dental implants in the partially edentulous patient.

Occlusal examination

A thorough occlusal examination is important for several reasons. One in particular is that it relates to the three-dimensional placement of the dental implant to ensure that the platform is appropriately positioned beneath the abutment and occlusal surface of the restoration. This will allow forces to be directed vertically down the long axis of the implant in function. The relative placement of the implant may be centered in the ridge, but this is not sufficient to allow for proper force mitigation. Skeletal and dental relationships as well as resorption patterns will influence the position of the implant. Adjunctive services such as orthodontic correction of occlusion may be necessary in addition to site preparation through ridge augmentation to allow for proper dental implant positioning [7]. Root proximity is often an issue, especially in patients with congenitally missing teeth. In some cases site development benefits from intrusion or extrusion of teeth prior to extraction and implant placement [8,9]. Malocclusion needs to be addressed prior to commencement of restorative and surgical care. It is important to look to the opposing arch to rule out eruption of teeth that will interfere with implant placement and occlusion. In some cases this can be corrected with a crown and bridge or orthodontic intrusion [10]. In other cases this may be corrected with extraction and placement of additional implants. Included in this is a thorough evaluation and examination of the temporomandibular joint (TMJ).

Intra and extra oral soft tissue exam

Examination of the intra and extra oral soft tissues for pathology is a critical part of the prosthodontic examination. Any lesions of

concern should be noted and referred for evaluation by the oral and maxillofacial surgeon. The surgeon should biopsy the lesion if appropriate. Intra oral pre-malignant, malignant, and inflammatory lesions should be treated and the patient cleared medically prior to initiation of dental implant therapy [4].

Diagnosis and treatment plan

Presenting the patient with a diagnosis is an important part of informed consent and also an educational opportunity. A thorough diagnosis will allow for an open discussion not only of the restorative plan and recommendations but will also allow for a discussion outlining the procedures needed to accomplish this goal. A classification system for dental implant patients has been suggested in the literature and is based on several factors, including the size and position of the edentulous site, complicating factors such as the need for grafting, and an assessment of patient factors that may require the need for modification of expectations [11]. It is the responsibility of the restorative dentist to provide information to the patient regarding their care along with the risks and benefits of the proposed plan. Alternative plans including the option of no treatment must be discussed. It is appropriate for the restorative dentist to speak to the patient about the need to create the foundation for the restoration with site development and communicate this need with the oral and maxillofacial surgeon. The surgical specialist can then discuss the type of grafting or site development needed more thoroughly.

Smile evaluation

The smile evaluation largely looks to assess the probability of creating an aesthetic restoration. Multiple data points from the restorative evaluation are taken into account when determining the possibility of achieving this goal. Beyond the dental characteristics below, a thorough review of the patient's habits including whether or not they smoke, their hygiene habits, bruxism, as well as patient expectations can have a dramatic effect on outcome. The shape and shade of the teeth are evaluated as well as the patient's smile line aesthetics. The facial symmetry and lip to incisal edge distance in repose and at high smile are evaluated [12]. The amount of marginal gingiva exposed at



Figure 4.2 High lip profiles are more aesthetically challenging as the gingival emergence profile is evident when the patient smiles. Volume grafting in these instances are often for cosmetics. In some cases the grafts serve both functions, cosmetics and for the adequate housing of bone to support the implant.



Figure 4.3 Moderate lip profiles are less aesthetically challenging as the gingival emergence profile rarely exposes the gingival emergence profile. Volume grafting in these instances is more for support of the dental implant and less often for gingival cosmetics.

high smile if any is recorded. A discussion of the patient's perception of their smile and dental health is essential. Examination and recording of the tooth shape and proportion to other teeth is critical for understanding the possibility of creating an aesthetic, natural looking restoration. Papilla generation is more predictable on square teeth and thicker biotype as the interdental contact is in the gingival third, bringing it closer to the interdental bone. Evidence in the literature suggests the critical distance for papilla formation to be 5mm from the interdental contact point to the supporting point on the adjacent tooth [13,14]. This is less predictable in the circumstance of implants placed side by side. Most tissue changes are found to occur in the first year after placement of the restoration, but this can be variable (Figures 4.2, 4.3 and 4.4).

Diagnostic casts and wax-up

Diagnostic casts and a diagnostic wax-up are important tools allowing for the prediction of the final result. Mounted diagnostic casts on the articulator will provide information regarding the shape and position of the proposed restoration, angle of emergence from the ridge, interaction with the opposing dentition, and amount or significance of the soft tissue defect accompanying the loss of the teeth. Duplication of the wax-up and fabrication of a radiographic guide with varying amounts of barium sulfate creates a replica of the proposed tooth position on the CT scan. The wax-up must be to the proper tooth dimensions so that the thickness of tissue can be evaluated. The implant can be sounded to the proper angulation and depth based on the desired result and allow for a quantification of the bone and/or soft tissue grafting needed to achieve success. An implant placement guide using this information is then fabricated and, where indicated, computer guided surgery allows the surgical

restorative team to provide a predictable treatment and achieve the best possible results (Figure 4.5).

Radiographic implant guide

A properly fabricated radiographic implant guide is anatomically correct to the design of the final proposed prosthesis. The guides differ based on the area being restored. Radiographic markers are embedded in the guide to ensure that the footprint of the proposed prostheses can be appreciated clearly on the radiograph. These fiduciary markers must be of a material that will impart a clean, clear image on the radiograph. Many different materials have been used to create the radiopaque image. In some cases metal spheres of a defined geometric size and shape have been used to determine the magnification of a panoramic radiograph (Figure 4.6). Other materials such as gutta-percha points embedded in the acrylic resin matrix and painted on radio-reflective materials have been used to coat the proposed restorative center or shell of the diagnostic wax-up. These appear as points or a silhouette on the radiograph. More commonly barium sulfate of varying percentages is mixed into the acrylic resin used to fabricate the guide in order to identify the different parts of the restoration. This allows the clinician to accurately determine the volume and dimension of graft needed in both hard and soft tissues in order to appropriately support the restoration [15,16].

In the partially edentulous patient, the radiographic implant guide is a duplicate of a diagnostic wax-up (Figure 4.7). The guide can be stabilized on the adjacent teeth with solid occlusal land similar to the design of an occlusal orthotic appliance. In other instances the guide can be fabricated and stabilized on the palate or ridges similarly to a removable partial denture. Clearly the more the

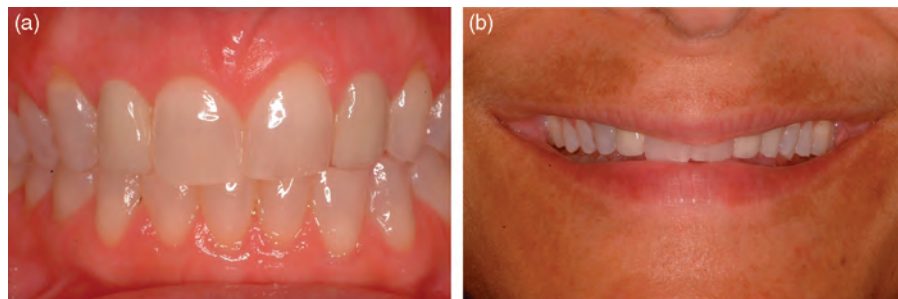


Figure 4.4 Low lip profiles are aesthetically neutral. Grafting in these instances is more for the creation of an adequate bony housing for the dental implant.

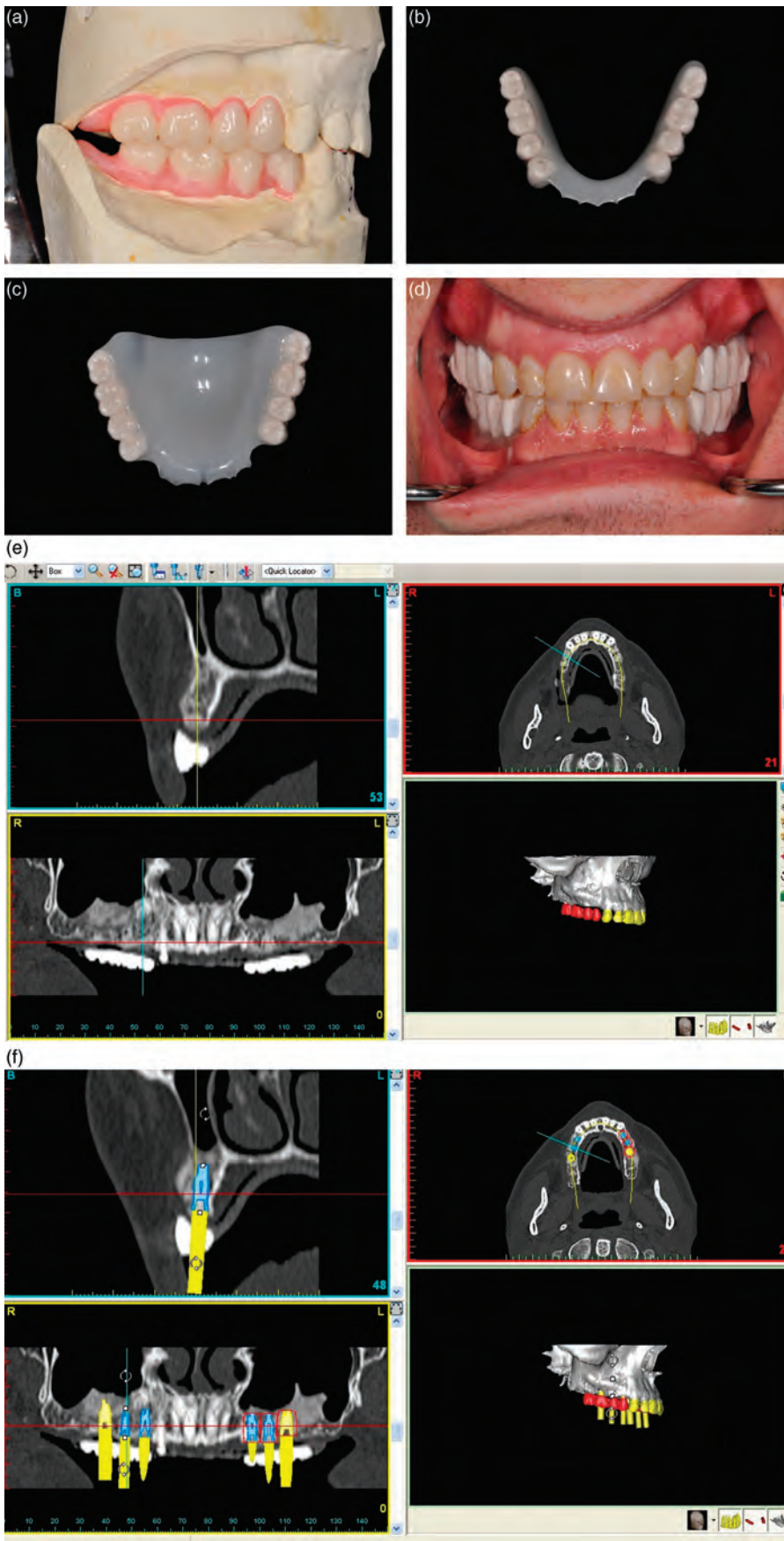


Figure 4.5 The diagnostic wax-up can be duplicated in acrylic resin impregnated with a radiographic marker such as barium sulfate after intraoral verification. The radiographic guide is worn during the CT scan and appears as a halo on the radiograph. This is used for the purpose of implant planning. Both the position of the implant as well as the need for grafting to produce a sound housing for the implant can be determined with this technique. A computer generated implant guide is ordered and used to ensure the plan is followed out accurately.

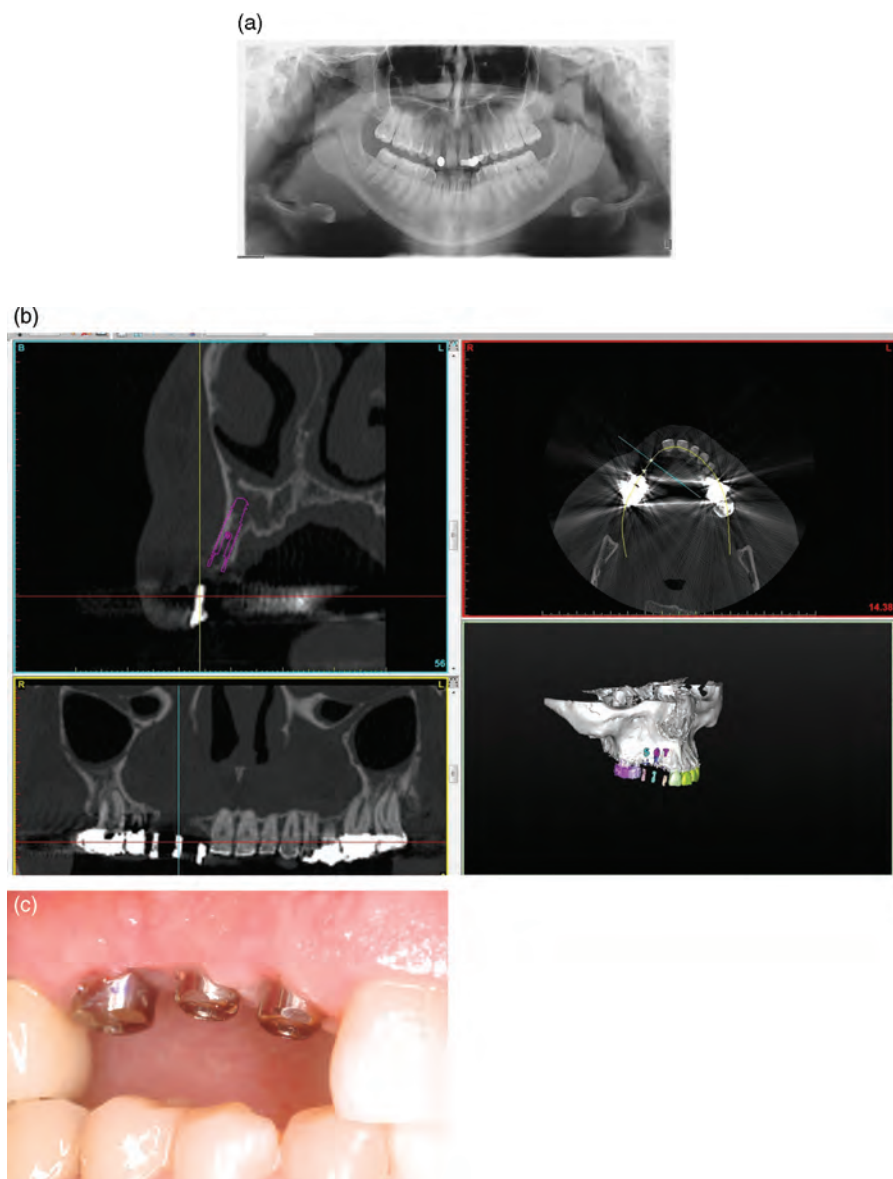


Figure 4.6 Examples of fiduciary markers on radiographs. (a) The sphere is of a defined dimension allowing for determination of the degree of magnification in the radiograph. (b) Gutta percha points can be used to define center lines of planned prosthetics. (c) The resulting implant placement.

guide relies on non-resilient or non-moving structures, the more accurate it is [17,18].

A dual-scan technique allows for the diagnostic wax-up to be scanned in a three-dimensional optical scanner (Figure 4.8). The resultant scan can be overlaid in a CT scan to allow for planning of the final restoration digitally without the use of an additional guide.

The edentulous patient brings a new set of considerations for prosthesis design. Depending on the restorative goal, spacing must be considered in developing an implant placement treatment plan. As an example, if a patient desires a bar-supported overdenture, more prosthetic clearance will be needed to accommodate the bar, abutments, and attachments. In these cases implants are likely to be placed deeper and ridge width augmentation may be necessary to accommodate the dental implants. In some cases, ridge width can be gained with alveolectomy. In either case the implant depth and angulation is dependent on the final prosthetic design. Other

considerations such as incisal edge to lip distance will require knowledge of the prosthetic design and correlation with the facial anatomy. Often alveolectomy will be necessary in order to place the dental implants at the appropriate level for the prosthetics. The ridge will have adequate width for dental implants once the procedure is complete. At times the ridge will require horizontal augmentation. In any case, the information gained from the radiographic guide will be the determinant.

In the edentulous patient, a full diagnostic setup is required to determine the proper placement of the teeth. This wax-up can be duplicated in acrylic resin mixed barium sulfate of varying density and worn by the patient during the CT scan. A recommended formula is an acrylic resin mix with 30% barium sulfate in the teeth and 10% in the tissues. The planning software will allow for each different layer of the guide to be masked and used to plan the position of the dental implants relative to the tooth position and

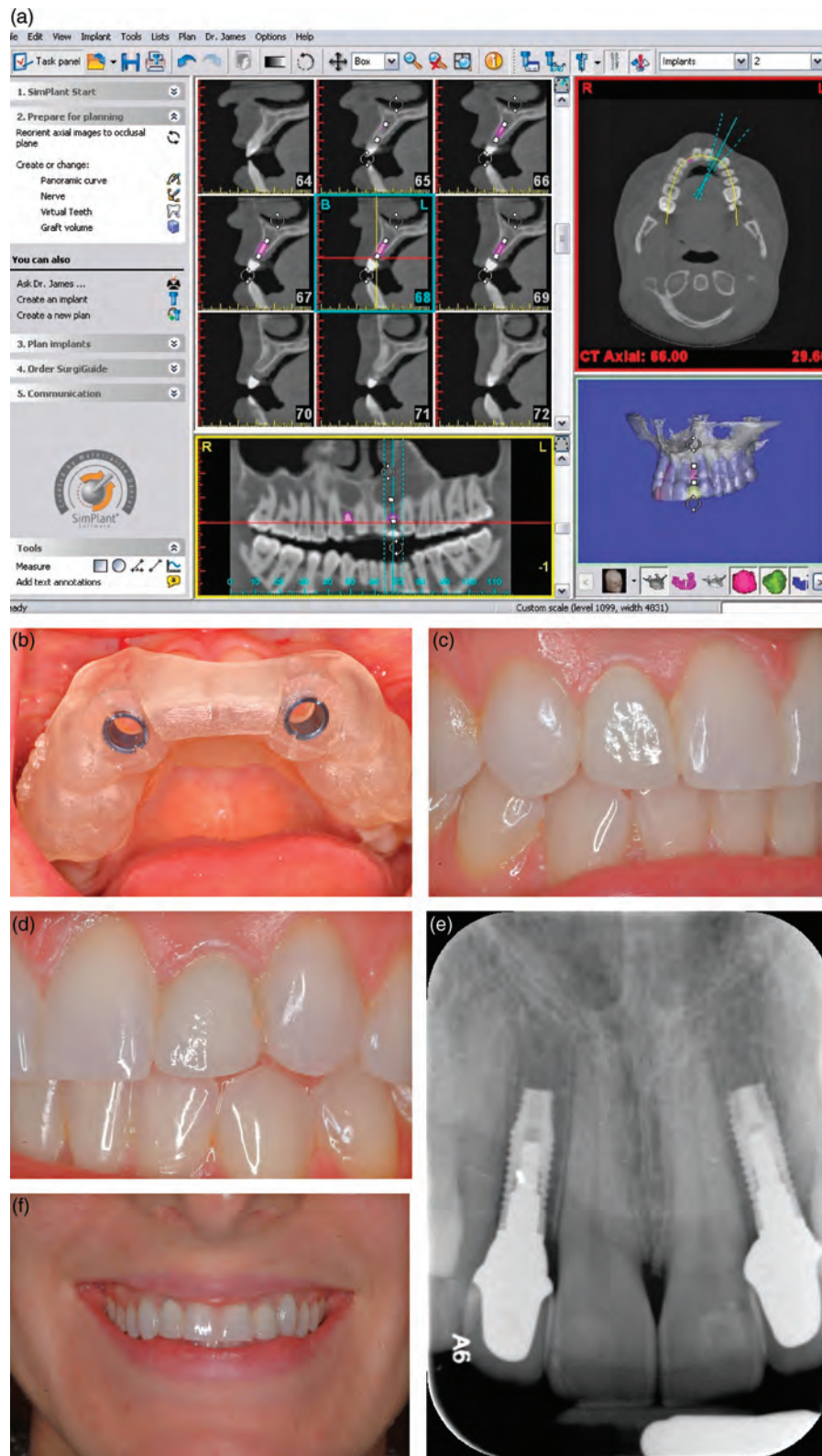


Figure 4.7 (a) CT scan with a SimPlant plan for the placement of lateral incisor implants with computer guided surgery. (b) Navigator guide stabilized by the teeth. (c–f) Dental implants replacing maxillary right and left lateral incisors.

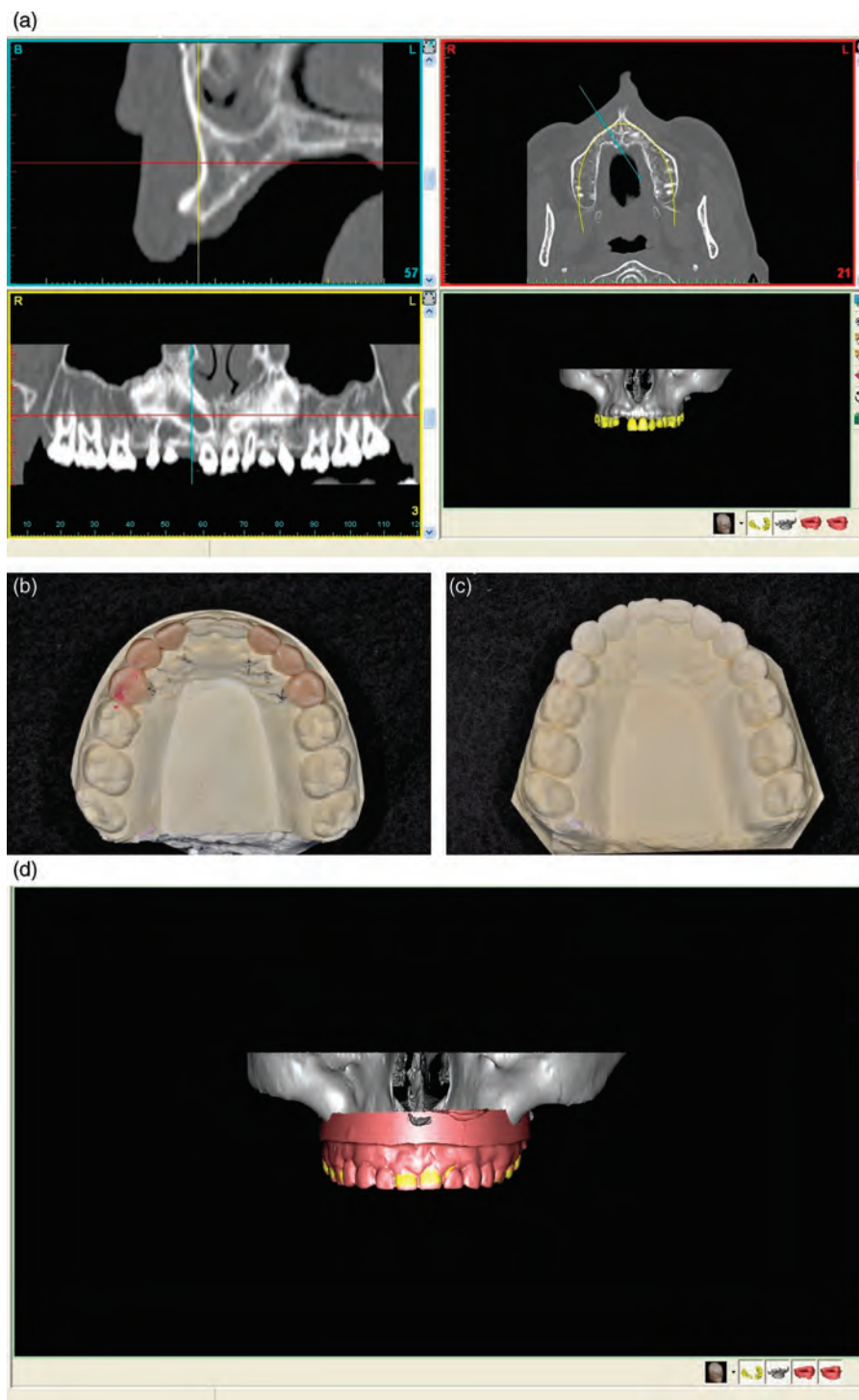


Figure 4.8 The dual-scan technique is demonstrated in this figure. The diagnostic wax-up is scanned and overlaid in the patient's CT scan. Dental implants and grafts are virtually planned, making it possible to predict the final outcome. (a) The CT scan without the overlaid wax-up. (b, c) The diagnostic wax-up is duplicated in stone and scanned. (d, e) The scan is shown with the wax-up overlay. (f) The dental implant planned in the software. Implant guides are fabricated based on this plan.

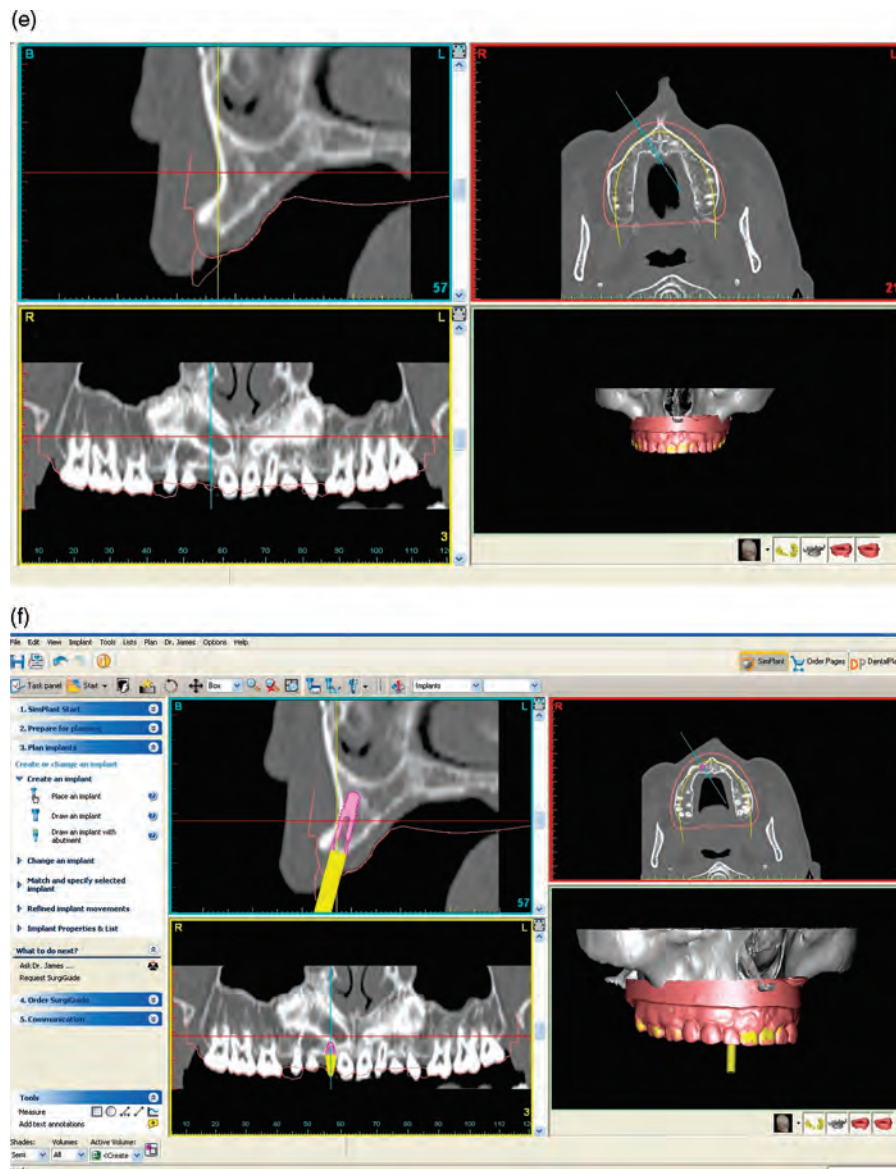


Figure 4.8 (Continued)

amount of soft tissue volume replaced by the flanges. This is more challenging when there are remaining teeth in place. A dual-scan technique is also useful in these instances [19] (Figure 4.9).

Clinical applications

A: Prosthetic evaluation and treatment planning of partially edentulous patients in the aesthetic zone

Ridge width defects are very difficult to overcome from a prosthodontist's point of view. When these defects occur in the anterior maxilla, they pose several threats to the ultimate success of a treatment. An insufficient anatomical site can occur due to the traumatic extraction of a failing tooth, causing the buccal plate of bone to be lost (Figure 4.10). Teeth exhibiting endodontic failure with

a periapical lesion or previous apicoectomy can cause a deficient housing for a dental implant in the mid to apical third (Figure 4.11). This will result in the need for angulation of the implant to avoid a fenestration of the bone. Thin scalloped biotypes and congenitally missing teeth can also be problematic in allowing an implant to be placed properly for the creation of a natural looking and aesthetic restoration [20]. Implant site development with orthodontics in addition to grafting may be necessary to create an ideal site for the replacement of congenitally missing lateral incisors [21] (Figure 4.12). In all cases, the width of the ridge needs to be preserved or regenerated prior to or as part of dental implant placement. Often a staged approach is more predictable than an immediate approach, depending on the anatomy of the defect and position in the mouth. This is especially true in the anterior maxilla [22].

The position of the dental implant in three dimensions influences biologic width and height of bone and soft tissue. Ultimately the soft

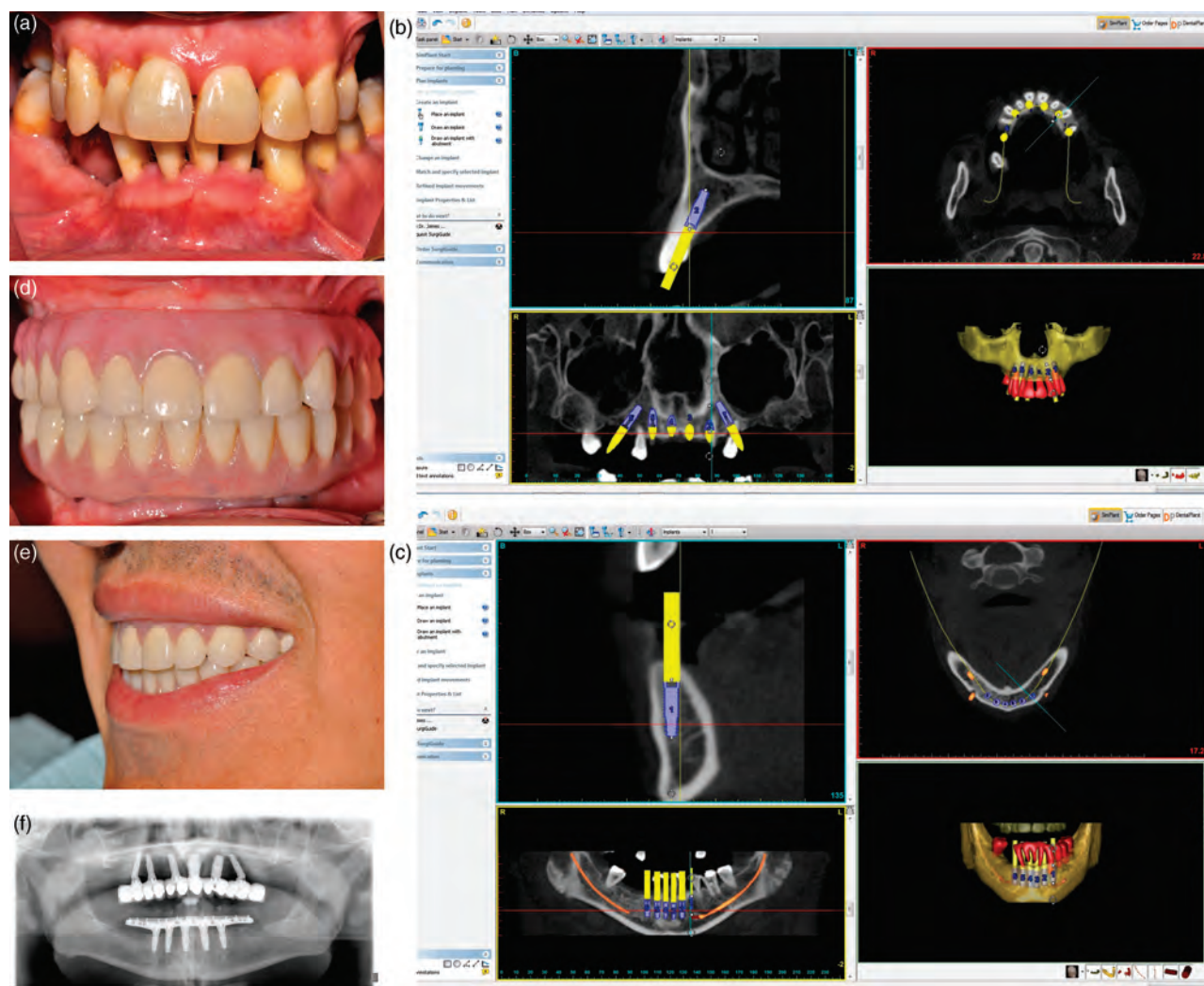


Figure 4.9 Examples of a plan and final result for a patient requiring full maxillary and mandibular implant supported restorations.

tissue contours are determined by the supporting bone and implant position. This has a direct effect on the final aesthetic outcome of the case [22–25]. When dental implants are placed with an angle that is too far to the buccal in order to avoid a ridge width defect apical to the alveolar crest, labial bone remodeling will result in recession of the facial gingival margin, causing an asymmetry between the dental implant and adjacent natural teeth [26,27]. Thread exposure can

occur causing a change in tissue color relative to the adjacent teeth (Figure 4.13).

Complicating factors such as side-by-side dental implant placement can create other issues that will lead to a compromised result (Figure 4.14). If the dental implants cannot be placed parallel to each other, unpredictable aesthetics due to a lack of papilla, dental asymmetry, or improper alignment of the labial surfaces relative to the facial plane are a likely result [28,29].

An additional complicating factor is a palatal width defect (Figure 4.15). These can be missed and cause a great deal of concern. The implant threads can be exposed in this circumstance, causing an implant to fail. These defects are often overlooked and are best treated in a staged manner.

Mechanical and functional concerns such as angled load generation on the implant abutment interface, inadequate occlusal force distribution, and food trapping will also alter predictability and patient satisfaction. Other complicating factors such as screw loosening can occur due to the off-angle loading of the implant. In circumstances where dental implants are positioned relative to the existing bone and soft tissue anatomy, rather than creating a proper site with hard and soft tissue grafting, long-term results are

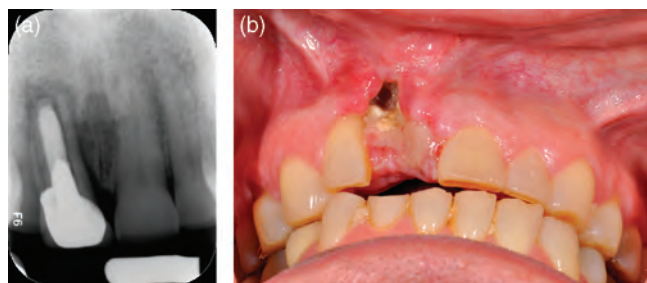


Figure 4.10 (a–b) Examples of a failing endodontically treated tooth and subsequent defect left by the extraction.

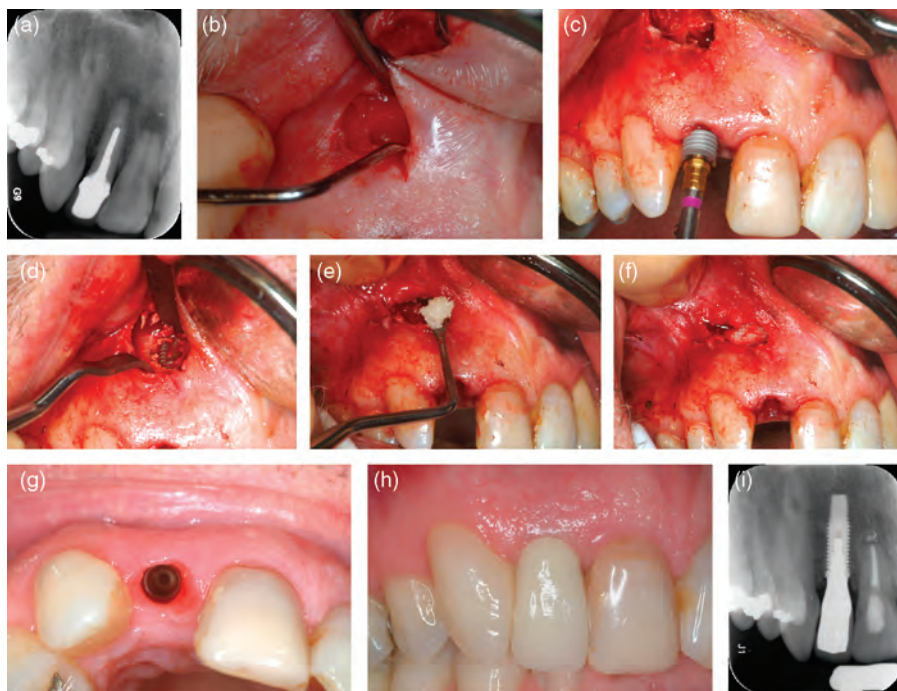


Figure 4.11 (a, b) Radiograph and clinical photo of a failing endodontically treated lateral incisor. (c) The tooth is extracted and the apical lesion is debrided with a vestibular approach after verification of the presence of the labial plate after extraction. (d) The dental implant is placed to the proper depth and angulation. (e) The apex of the dental implant is visualized. (f) A graft is placed. (g) A membrane is placed and the site is sutured. (h, i) The dental implant is restored.

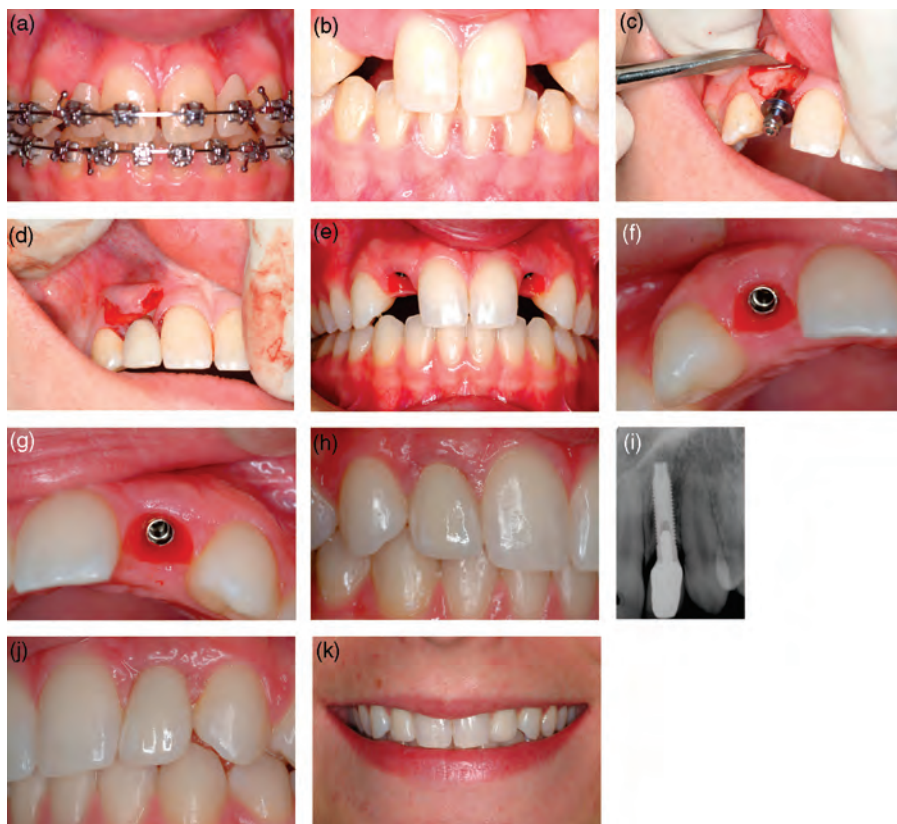


Figure 4.12 The replacement of congenitally missing lateral incisors after spacing is corrected orthodontically. There is a pan facial horizontal defect that will effect the emergence of the dental implant. Adequate bone is present to house the implant, but the emergence is not supported. Dental implants are placed in concert with a hard and soft tissue graft. At the restorative phase, the biotype has been altered to support the gingival emergence of the restoration. The final clinical photograph and radiograph represent an 8-year follow-up.



Figure 4.13 Maxillary right lateral incisor presents with a grey gingival hue. The thin biotype does not block the color of the abutment supporting the crown. Exposure of the collar of the implant due to the angle of placement is a contributing factor. Changing the abutment to a pressed ceramic UCLA abutment along with a connective tissue graft to convert the biotype corrected the complication.

unpredictable and can cause a variety of complicating issues for the restorative dentist.

Ideal implant placement in the aesthetic zone is easy to accomplish. Reverse engineering and design is the key element. Placement parameters include the following:

- 3 mm of space is needed between dental implants with a matched platform and abutment to prevent the horizontal aspect of crestal bone remodeling from eliminating the bone between dental implants.
- 2.1 mm of space is needed between dental implants with a dental implant platform that is wider than the restorative abutment (platform switching implants).
- 1.5 mm of space is needed between dental implants and natural teeth so as not to compromise the bone supporting the adjacent tooth.
- Screw access between the incisal edge and cingulum.
- Platform depth 3 mm deep to the zenith of the facial gingival margin.



Figure 4.14 (a–d) Central incisors replaced with dental implants and screw-retained crowns. Adequate spacing is present between the implants, but the implants were placed without vertical or horizontal augmentation. (e–i) The central incisors were lost to trauma. This patient underwent horizontal ridge augmentation prior to implant placement. Ceramic abutments and crowns were used to restore the dental implants. Grafting allowed for normal dental proportions to be restored.

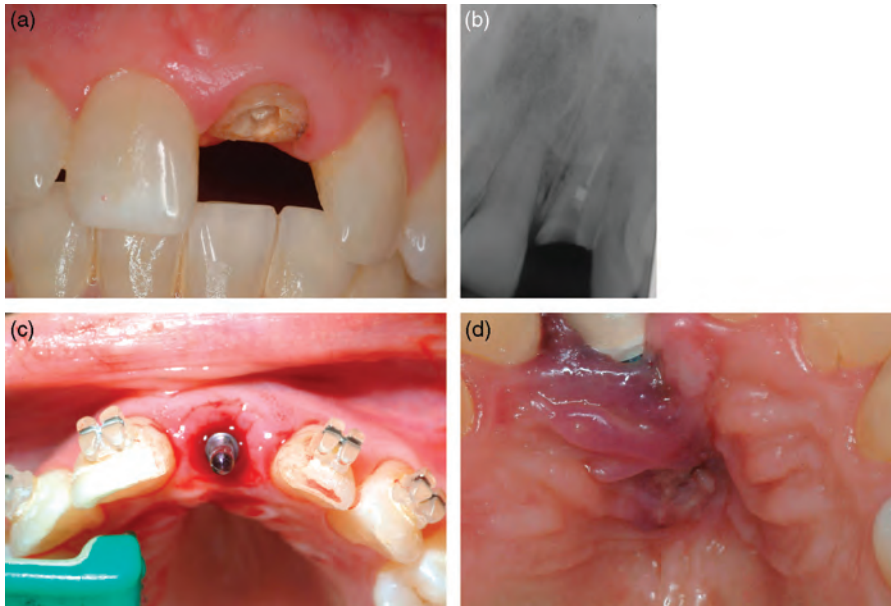


Figure 4.15 Palatal defects are often overlooked. In this case the dental implant perforated the palatal plate.

Ridge augmentation in a horizontal dimension is often necessary to satisfy the placement parameters. When possible, defect avoidance can create the ideal implant recipient site (Figure 4.16).

B: Prosthetic evaluation and treatment planning of partially edentulous patients in the posterior dentition

When ridge width defects occur in the posterior dentition, they influence implant size in terms of diameter and position. Implant placement can have a significant impact on occlusion. As the maxilla recedes, it tends to narrow. If an implant is placed centered in the ridge, the implant will be placed in the cross bite. The same holds true in the mandible. With the resorption pattern being buccal in direction, the same will occur. This can be magnified if the teeth being replaced are concurrently on the same side in opposing jaws. Long-standing tooth loss complicated by the use of removable prosthetics to replace the posterior teeth can create anatomical issues that will be difficult to overcome. Ridge width defects can be created by a traumatic extraction of a failing tooth, causing the

buccal plate of bone to be lost. Periodontal disease, dental caries, endodontic failure and tooth fracture are common causes of posterior tooth loss. One possible prevention of this can be to have a dental implant placed at the time of extraction [30,31]. Ridge width defects are prevented in this scenario by the preservation of the extraction socket with the dental implant. Sound socket preservation techniques are also useful to prevent the need for grafting [32].

In circumstances requiring grafting to provide adequate width to place an implant with a suitable diameter to support the occlusion, ridge width augmentation is a powerful tool used by the surgical specialist at the time of or prior to implant placement to provide adequate foundation. In most cases the graft is in the coronal third. Anatomic structures such as the mental foramen can complicate this. Many different materials and techniques have been described to increase ridge width. The advantages advantages are many and include providing a stable base for the abutment and restoration [34]. Adequate ridge width can prevent complications such as screw loosening and breakage. Further, food trapping can be an

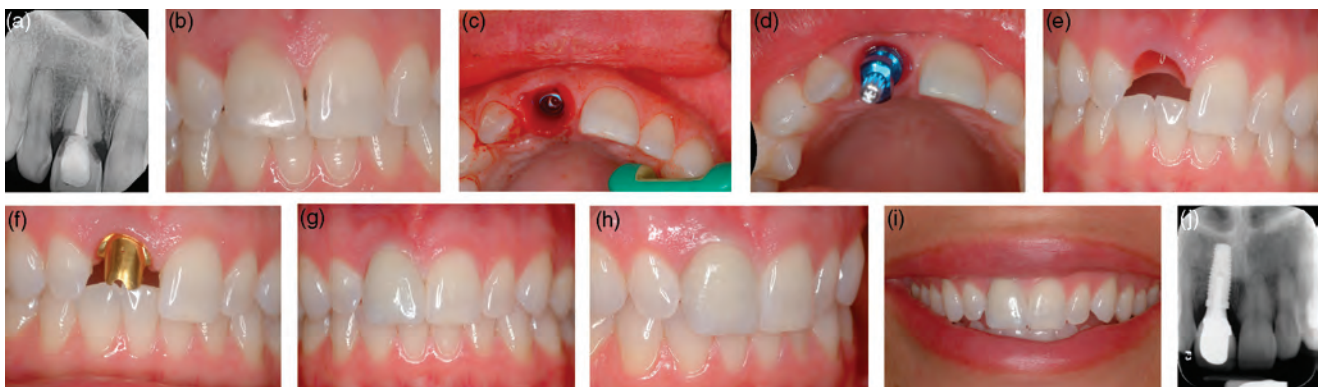


Figure 4.16 Extraction and immediate placement of dental implants can prevent the need for grafting for emergence support in some cases. Maxillary right central incisor was extracted and a dental implant immediately placed. A provisional restoration was immediately loaded out of occlusion. After healing, a custom computer aided design/computer aided manufacture (CAD/CAM) abutment was placed and restored with porcelain fused to a high noble metal crown. An 18 month follow-up reveals nice gingival symmetry between the dental implant and adjacent natural teeth.

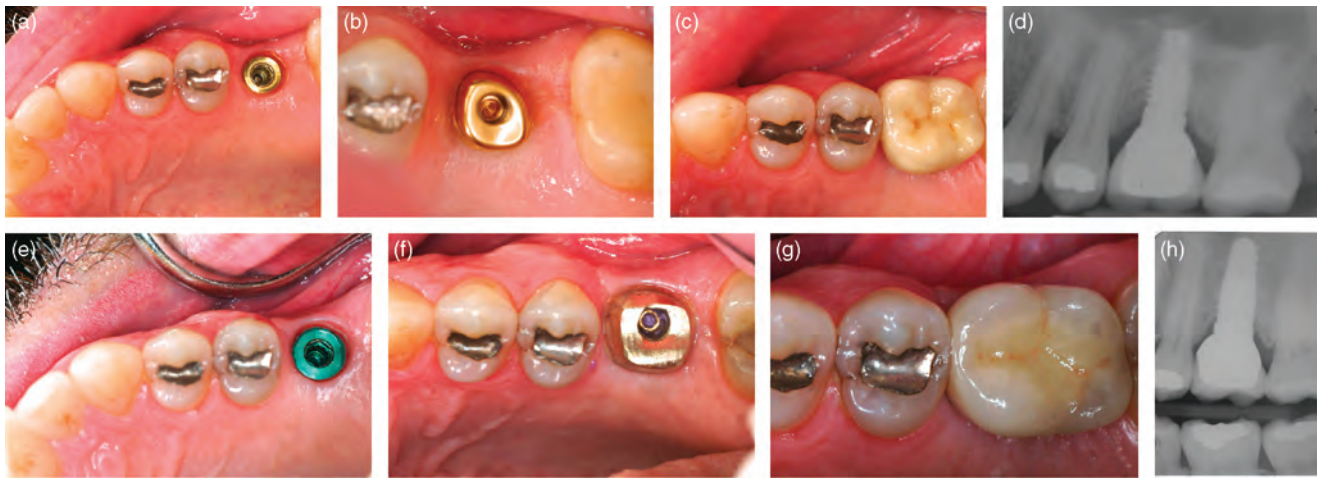


Figure 4.17 (a–d) A 5.0 mm dental implant is used to restore a missing maxillary first molar. There is a horizontal deficiency noted on the buccal aspect of the restoration. This is an area that can be problematic for a patient as it may cause a buccal corridor shadow. In addition, it can be a food trap. (e–h) A 6.0 mm dental implant is used to restore a maxillary first molar. The ridge was augmented horizontally and vertically prior to dental implant placement. The augmentation of the ridge provides resistance to food trapping.

issue around dental implant restorations as the implant diameter can be narrower than the intercuspal width of the restoration. By widening the ridge, a larger diameter implant can be placed, decreasing the over contouring of the restoration and preventing food from being directed into the sulcus or to the emergence base of the restoration (Figure 4.17). Implants requiring placement at an angle to the occlusal plane can alter the screw exit, making it difficult to screw-retain a restoration if desired. Congenitally missing premolars can also be problematic in allowing an implant to be placed properly for a natural looking and aesthetic restoration (Figure 4.18). In all cases, the width of the ridge needs to be preserved or regenerated prior to or as part of dental implant placement.

As previously stated, dental implant position in three dimensions influences biologic width and height of bone and soft tissue. This remains true in the functional zone as well as the aesthetic zone. Ultimately sound treatment planning and site preparation will prevent complications. Similar mechanical and functional concerns from angled load generation on the implant abutment interface, inadequate occlusal force distribution, and food trapping will also alter the predictability and patient satisfaction in the posterior maxilla and mandible (Figure 4.19).

Complicating factors such as side-by-side dental implant placement is more tolerable than in the anterior. The loss of papilla is less problematic as it is not an aesthetic concern. In some cases, a patient will benefit from additional implant support in the posterior maxilla and mandible.

Ideal implant placement in the posterior maxilla and mandible can be accomplished by treatment planning from the restoration down (see Figure 4.20). Placement parameters include the following:

- 3 mm of space is needed between dental implants with a matched platform and abutment to prevent the horizontal aspect of crestal bone remodeling from eliminating the bone between dental implants.
- 2.1 mm of space is needed between dental implants with a dental implant platform that is wider than the restorative abutment.
- 1.5 mm of space is needed between dental implants and natural teeth so as not to compromise the bone supporting the adjacent tooth.
- Screw access in the middle of the occlusal table.
- Platform depth 3 mm deep or less to the zenith of the facial gingival margin.
- Plan and place the widest implant possible.

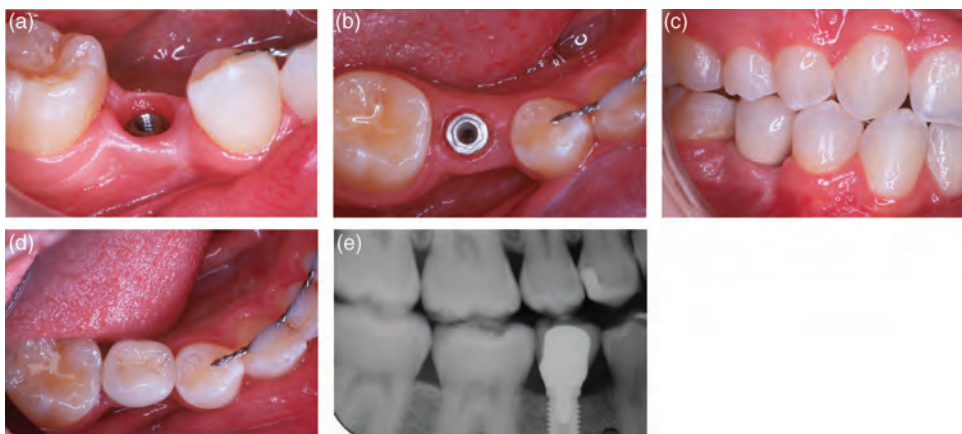


Figure 4.18 Mandibular right second premolar is replaced with a dental implant, custom abutment, and crown. The area was not grafted horizontally, leaving a defect relative to the adjacent teeth. The gingival emergence is chronically irritated.

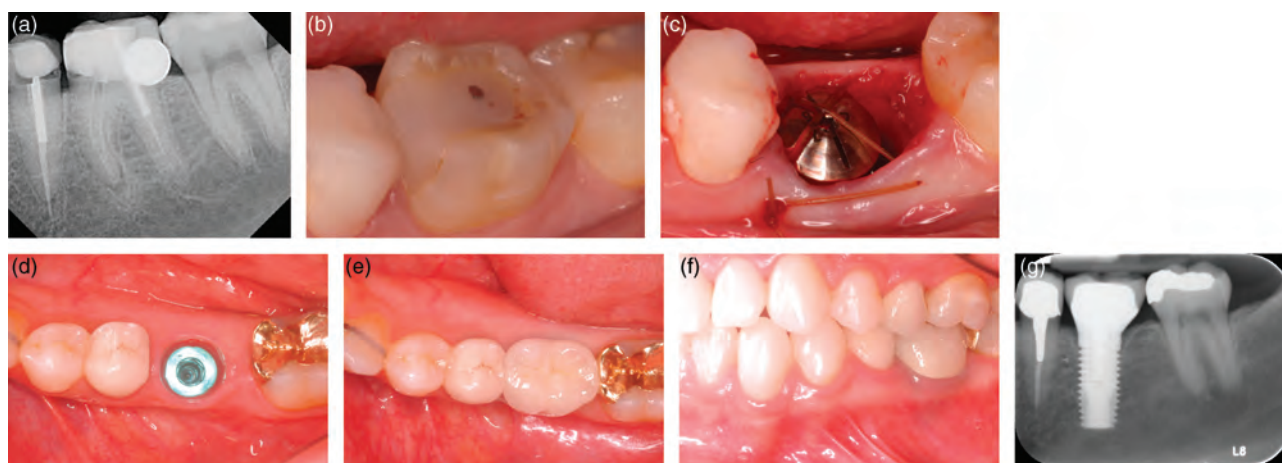


Figure 4.19 (a–g) Mandibular left first molar is fractured and not restorable. The tooth was extracted and dental implant immediately placed. Once integrated, a custom abutment was digitally fabricated and PFM crown placed to restore the implant. The need for horizontal ridge augmentation was prevented by the immediate placement of the dental implant. Ideal emergence was achieved with this technique.



Figure 4.20 (a) Pre-op radiograph. (b) Orthodontic site preparation. (c) The ridge is deficient buccally. (d, e) Ridge augmentation procedure to provide adequate width for dental implant placement. (f–h) Dental implant placement. (i–l) The dental implants area restored. (m) 8 year follow up clinical image.

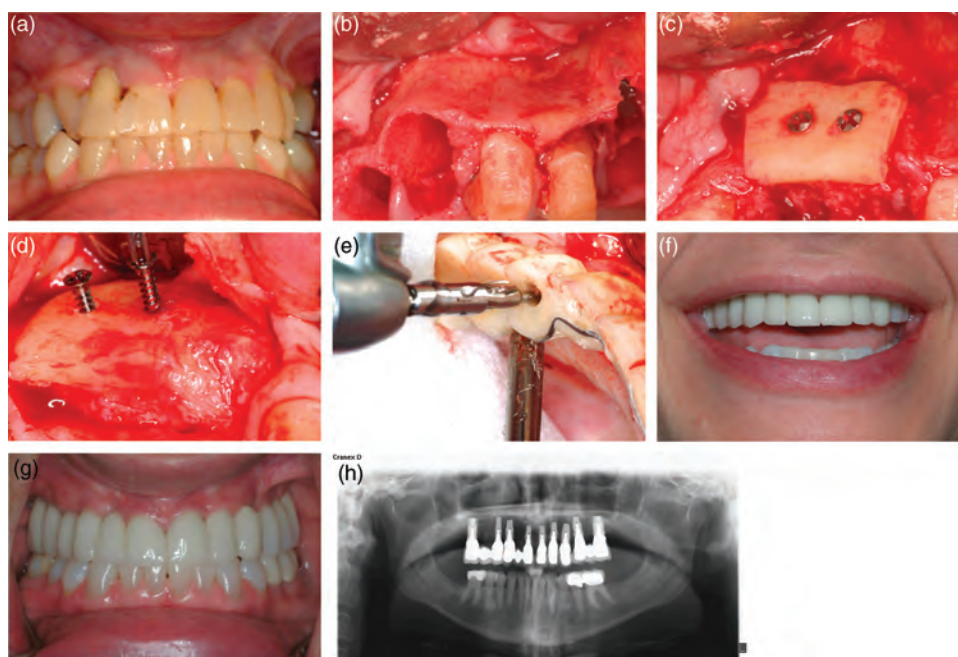


Figure 4.21 (a) Pre-treatment clinical photographs of a failing maxillary dentition. (b, c) Extracting and block bone grafting. (d, e) Dental implant placement. (f-h) 24-month follow-up.

C: Prosthetic evaluation and treatment planning of the completely edentulous patient

When a patient presents to the surgeon restorative team for the replacement of their entire dentition in the maxilla, mandible, or both, they often do not have a clear understanding of the options available to them. When asked many will desire to have a fixed, non-removable dentition. Others will opt for the convenience of a

removable overdenture prosthesis supported by a bar from the standpoint of cleansability and others may need the additional facial support of a flange. Due to finances, some may choose freestanding dental implants with stud attachments. The joint decision on how to accomplish this goal is based ultimately on their desires to replace their teeth and their clinical needs. The patient wishes to replace their teeth in a predictable manner. They want the teeth to look

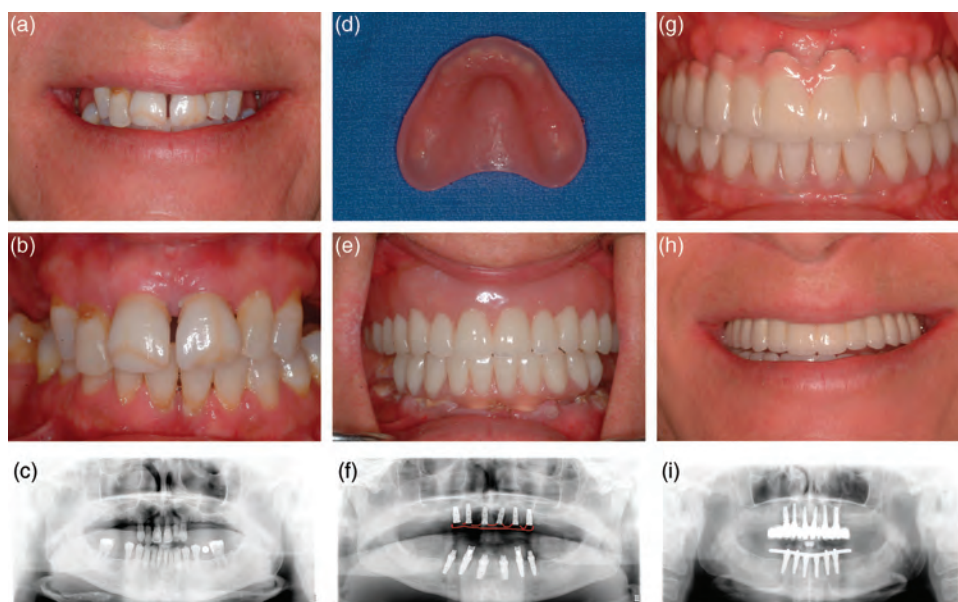


Figure 4.22 (a-c) This patient presents with a failing maxillary and mandibular dentition. The maxilla will require grafting prior to dental implant placement. (d) The interim maxillary immediate denture is fabricated with short and thin flanges to accommodate the graft. (e) The maxillary immediate denture in place. The mandibular immediate denture is attached to the dental implants and loaded immediately. (f) Mid-treatment radiograph. (g) Final implant restoration. The maxillary arch is restored with a porcelain-fused-to-metal (PFM) fixed bridge. The pink porcelain is used to create artificial papilla and normal tooth dimensions. The margins are set equally at the gingival level and for hygiene. (h, i) Final smile and radiograph.

natural and function as if they are their own. The type of restoration chosen will determine the proposed position of dental implants. Recommendations for the placement of dental implants to support fixed crown and bridge restorations on six implants, whether it be with sinus elevation and vertical bone augmentation to accommodate the position of the dental implants or the use of angled implants, have been well described in the literature. The need to graft horizontally is determined by the design of the restoration and implant position necessary to provide adequate support [34,35].

Crown and bridge restoration

Edentulous patients who desire a crown and bridge restoration often lack the support needed both vertically and horizontally. In these cases a staged approach often works best (Figure 4.21). Working from the restoration to the apex, the implant prosthetic platform should be 9 mm to 11 mm from the incisal edge. The platform needs to be of adequate width to properly support the occlusion. The bone must be able to accommodate the proper platform diameter. Ridge width augmentation is needed to allow for

the labial/facial surfaces of the restoration to be in the proper orientation to the facial plane. Without, a small ridge lap may be needed to create the proper facial plane parallelism.

If the vertical bone support calls for artificial gingiva in order to create teeth of a proper dimension, ridge width augmentation may be needed in conjunction to implant placement to allow for proper implant support beneath the restoration. This can be done in a staged approach (Figure 4.22). Great concern must be given to the design of the provisional denture. The flanges must be short of the vestibule and allow for adequate relief on the buccal surface so as to not pressure the healing graft.

Implant supported overdentures and implant supported fixed complete dentures

In the case where a patient requires a hybrid or overdenture, ridge width augmentation is often created by subtracting the thin alveolar ridge to create an adequate housing for the implants (Figure 4.23). This is especially true in the anterior mandible. Although fixed

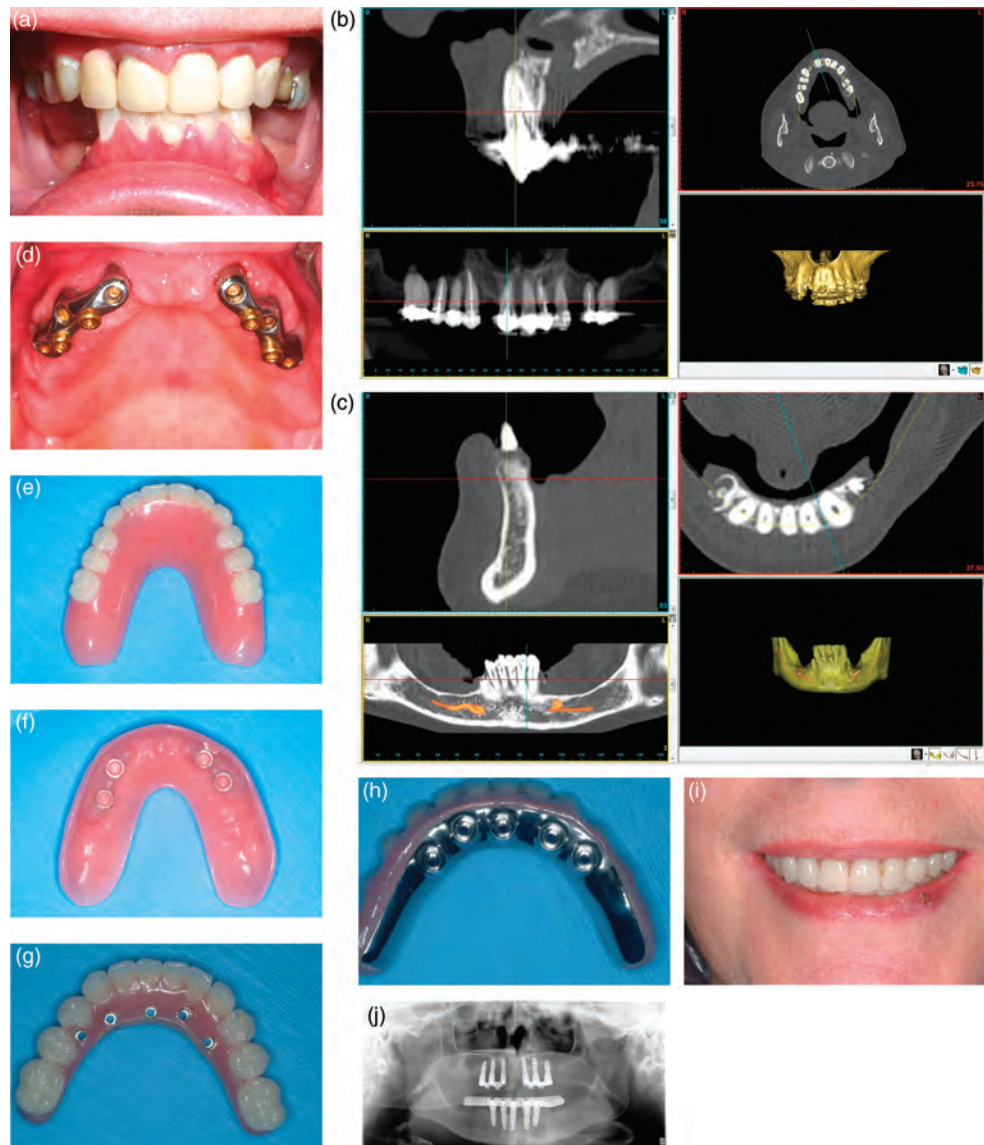


Figure 4.23 A split bar overdenture supported by six dental implants is used to restore the maxillary dentition. The mandibular teeth are replaced with an implant supported fixed complete denture supported by six dental implants.

implant restorations supported by four dental implants are successful, studies show greater prosthetic success when hybrid prostheses are restored on five or six dental implants [36,37].

Implants set more posteriorly in the maxilla allow for greater anterior-posterior spread and allow for avoidance of the bar crossing the anterior maxilla, keeping the prosthesis thinner, increasing comfort, and improving speech by decreasing the horizontal thickness of the restoration in this area. Studies suggest equal success rates when bars are split on six implants set more posteriorly or when four dental implants are placed between the maxillary sinuses [38].

Conclusion

The restoration of a dental implant patient is a multidisciplinary specialty. Coordination of efforts in diagnosis and treatment planning can be the difference between success and failure on many levels. Long-term predictability, patient satisfaction, and implant-restorative success rely on the communication between the surgical specialist, restorative dentist, and laboratory technician. Coordination of diagnostic information, goals of restoration, implementation of procedures, and delivery of prosthetics, as well as long-term maintenance, must be outlined in advance.

Acknowledgments

To my surgeons who partner with me to provide the best care possible for my patients.

To my wife Shelley and children Taylor and Austin, for their love, inspiration, and for making me complete. To the memory of my son Aiden who is always with me in my heart. To the memory of Ethan Wolfe. Both Aiden and Ethan taught us of the blessing of unconditional love that is experienced from children with special needs and to the bravery and will to live they exhibited. To the memory of Dr. Charles M. Johnson, my mentor and friend, whom I think of daily. To my parents for their love, and support.

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Orthodontic Implant Site Development

Ugo Macca,¹ Agatino Davide Mirabella,² and Francesco Amato³

¹CAGS in Prosthodontics, Boston University, Boston, Massachusetts, USA, and Private Practice, Siracusa, Italy

²Department of Orthodontics, University of Ferrara, Italy, and Private Practice, Catania, Italy

³Private Practice, Catania, Italy

Introduction

In contemporary interdisciplinary treatment planning, forced eruption [1–3] is a valid therapeutic option [4] to correct osseous and gingival levels in a compromised environment and to prevent post-extraction ridge deficiency [5]. Forced eruption of single-rooted teeth is considered predictable even in those cases when active periodontal disease is present [6]. For multirrooted teeth, though not sufficiently reported in the literature, our experience is highly positive. The outcome of pre-extractive orthodontic therapy is a more favorable ridge for dental implant placement [7] and for the pontic area as well [8]. Hopeless but not “useless” [5] teeth can be used to fill bone defects, extend gingival surfaces, and improve the extraction site, overbuilding it to compensate for post-extraction remodeling (Figure 5.1).

Sometimes an implant can be effective from an “osseointegration” standpoint (Figure 5.2) but a failure from an esthetic point of view (Figure 5.3). Most of the time, what makes the difference is the lack or the presence of an adequate tissue surrounding the crown.

How can we prevent this kind of failure?

- (a) Surgical options.
- (b) Orthodontic implant site development (OISD) [9] (Figure 5.4).

What is orthodontic forced eruption?

It is the therapeutic induction of a natural phenomenon, starting with the permanent teeth appearance in the mouth until a stable occlusal contact is established and continuing through life to compensate for grinding and occlusal abrasion. Light and uniform [10] extrusive forces stretch gingival fibers during eruption so that tension is applied to the bone surrounding the tooth, stimulating bone apposition at the alveolar crest. The entire alveolar bone housing follows the tooth in its movement [11].

Orthodontic treatment can also treat some clinical difficulties that cannot be solved by surgery alone, improving the whole scenario around the implant site: the mesiodistal dimension of the edentulous space, root proximity, positions and periodontal topography of the teeth adjacent to the edentulous area and the occlusal scheme [4].

Description of the technique

Treatment protocol [12]

- Diagnosis of the defect (Figure 5.5).
- Endodontic treatment.
- Periodontal therapy.
- Orthodontic appliance application.
- Two weeks perio and occlusal checks.
- Two/three months stabilization.
- Immediate implant placement flapless.
- Immediate provisional crown insertion.

The treatment starts by collecting clinical data (X-rays, probing chart, pictures, and stone models) in order to make a diagnosis of a failing tooth suitable for orthodontic extrusion (see Figures 5.6 to 5.14). The first step is root canal therapy to eliminate any sensitivity following periodontal treatment or occlusal reduction. Teeth with pocket depths ranging between 1 mm and 5 mm are treated with scaling and root planning in combination with topical antibacterial treatment (chlorhexidine 0.2% rinse three times daily). In the case of teeth with pockets that are 5 mm or deeper the treatment is followed 1 month later by an open flap debridement (modified Widman flap) in combination with topical antibacterial treatment (chlorhexidine 0.2% three times daily for 2 weeks). Immediately after periodontal treatment, orthodontic brackets are applied and tooth alignment, if needed, is obtained with a 0.016 inch heat-activated nickel–titanium archwire.

The OISD technique is defined as the “Slow Rate Biologic Technique”. It starts with this initial “periodontal activation” [13], after which a 0.018 inch stainless steel archwire is placed. A vertical-forward step of 1 mm is bent to obtain 1 mm of extrusion along the tooth’s long axis and is increased by the same amount monthly. Therefore a very light force (“interrupted continuous forces”) [13] will produce a bone apposition in accordance with the same rate of 1 mm per month described in the literature.

Alternatively, a 0.019 inch × 0.025 inch beta-titanium archwire with a 1 mm vertical step and palatal root torque can be used. The bends are deepened at each appointment at 1 month intervals.

The very key to treatment success can be compressed in this statement: the tooth during its movement must follow its long

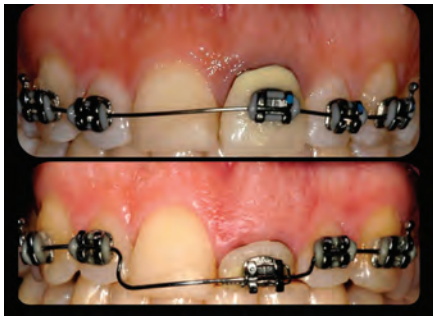


Figure 5.1 Pre-extractive orthodontic extrusion improves the future implant site. Overbuilding is necessary to compensate for post-extraction remodeling.

axis [12] (Figure 5.15). This can be achieved by putting a step down and forward in the orthodontic arch in order to keep the root away from the buccal cortical plate. It is important to point out that strong contact between the root and the buccal cortical plate could cause bone dehiscence. In that respect, it is the authors' conviction that most failures in obtaining bone augmentation are likely to be related to improper biomechanics.

It is assumed that the amount of extrusion would be equal to the total millimeters of activation; at each visit, the incisal edge and any occlusal contact area of the extruding tooth is ground with a diamond bur (1 or 2 mm each time), and the amount of shortening should also correspond to the tooth extrusion. Patients are monitored every other week to ensure that the extruded tooth is kept out of occlusion and to confirm good hygienic conditions in the area to prevent inflammation. The alveolar bone coronal movement is monitored by periodic periapical radiographs. The goal is to exceed

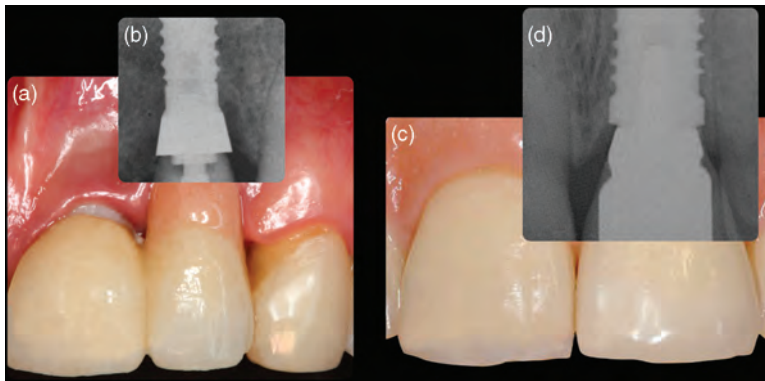


Figure 5.2 Osseointegration is obtained.

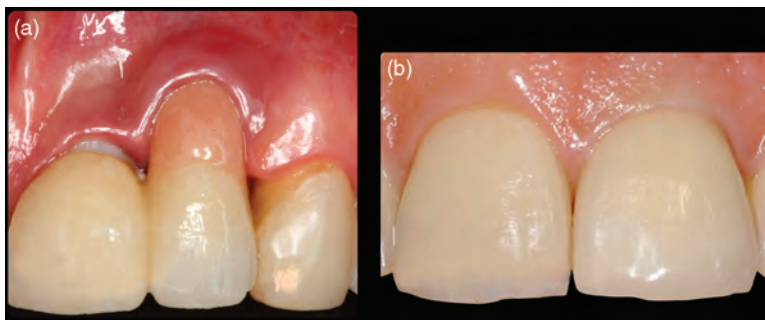


Figure 5.3 Esthetic failure due to inadequate hard and soft tissue.

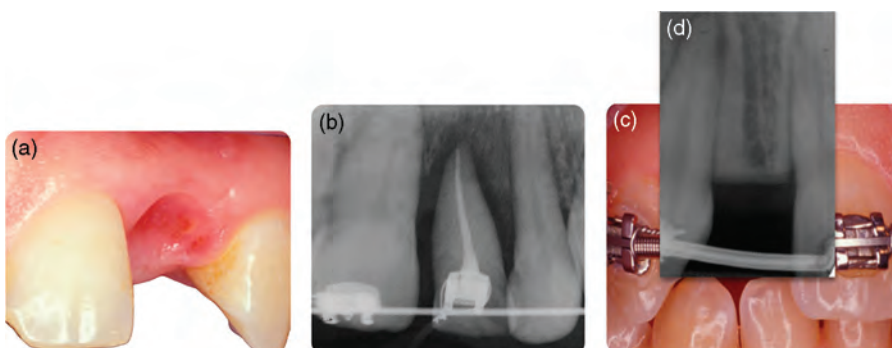


Figure 5.4 Role of orthodontics in improving implant sites: (A) soft tissue profile improvement, (B) hard tissue volume increase, (C) space distribution.

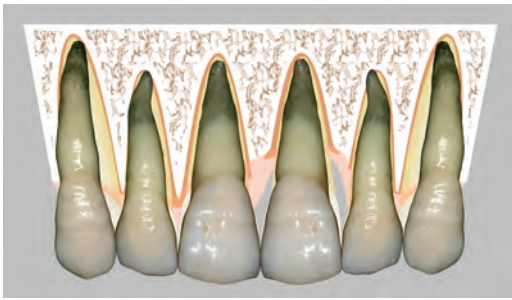


Figure 5.5 Treatment protocol.

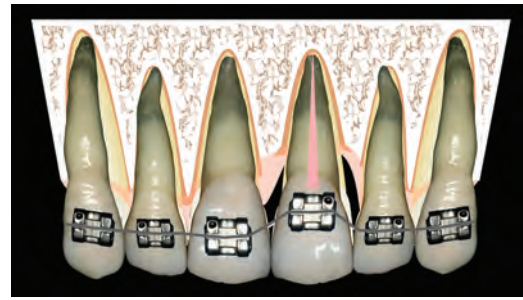


Figure 5.9 Orthodontic application.

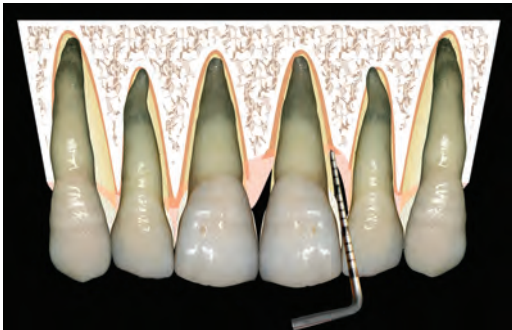


Figure 5.6 Diagnosis of the defect.



Figure 5.10 Two weeks of perio and occlusal monitoring.

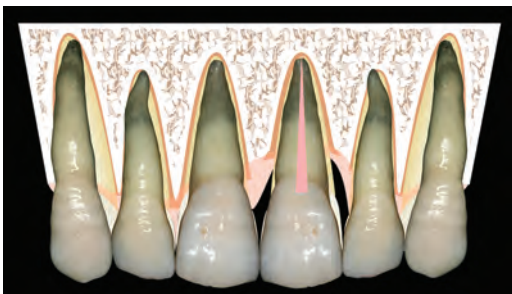


Figure 5.7 Endodontic treatment.



Figure 5.11 Two months stabilization.

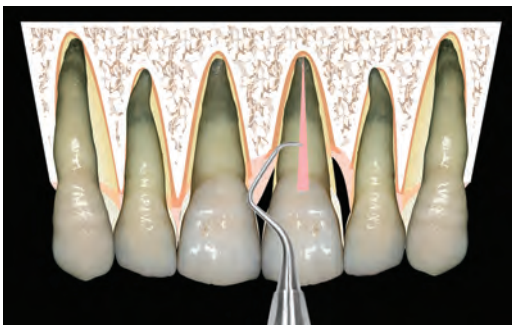


Figure 5.8 Periodontal therapy.

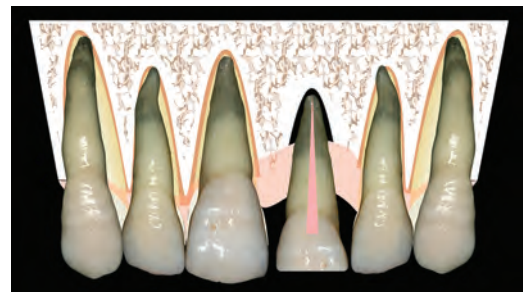


Figure 5.12 Tooth extraction.

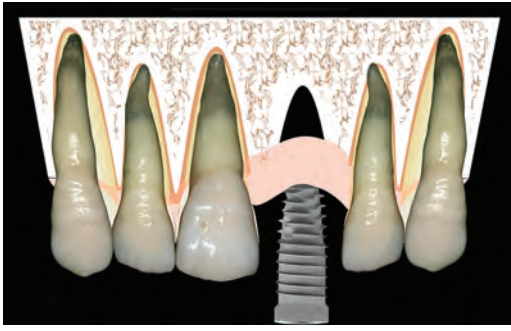


Figure 5.13 Immediate implant placement (flapless, if possible).

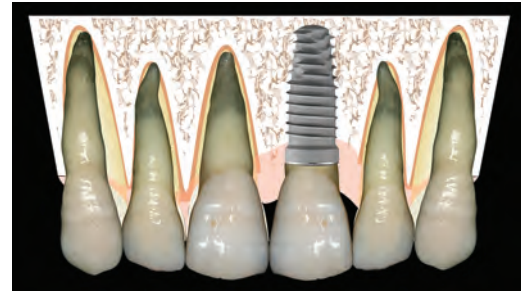


Figure 5.14 Immediate temporary crown placement.

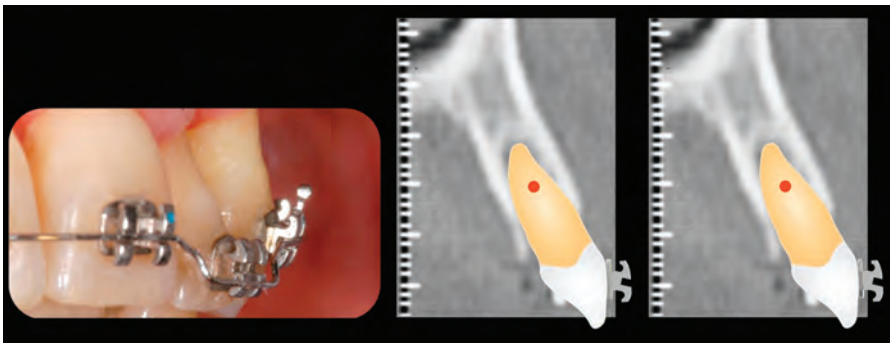


Figure 5.15 Extrusion must occur along the long axis of the tooth.

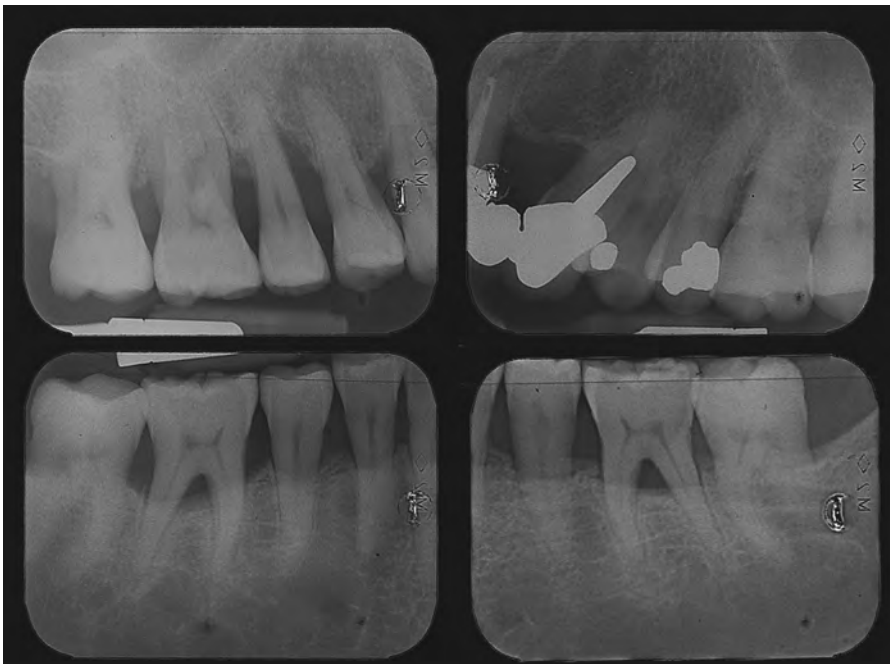


Figure 5.16 Pre-treatment radiographs.

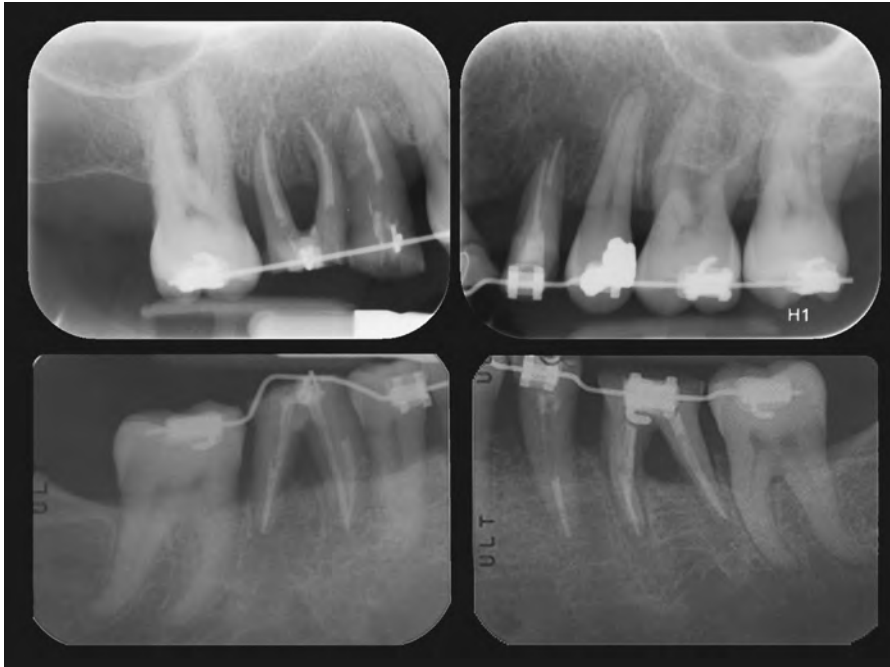


Figure 5.17 Radiographs at the completion of orthodontic treatment.

by at least 2 mm the bone level of the contralateral tooth, which acts as a reference. At this point, extrusion is ended and a period of 2 to 3 months of orthodontic stabilization is applied to allow mineralization of the newly formed bone matrix. Two days before implant placement a final, rapid extrusion is applied. This helps to widen the periodontal ligament space and makes extraction easier and less traumatic.

The patient is prescribed antibiotic prophylaxis (amoxicillin tablets, 1 g every 12 hours) and antibacterial mouth rinse (chlorhexidine 0.2%) starting 24 hours before surgery.

The implants are inserted preferably flapless, the provisional abutments are connected, and the screw-retained provisional

crowns must be placed out of occlusion. Although there is ample evidence that insertion of an implant into a fresh extraction socket does not prevent alveolar bone resorption [14–16], regardless of whether a crown is placed immediately or after a delay [17], the immediate placement and provisionalization helps in supporting and maintaining soft tissues, especially papillae [18].

Posterior teeth

OISD is effective on molars and premolars too (Figures 5.16 to 5.18). As described for front teeth, it is possible to improve bone width and height with a thicker and higher attached gingiva. On multirooted teeth a “guided bone regenerative effect” is shown



Figure 5.18 Radiographs at the completion of the entire treatment.



Figure 5.19 Orthodontic “guided bone regenerative effect” in interradsular area.

(Figure 5.19) since not only the attachment apparatus follows the root in their eruptive movement but also the inter-rooted area is filled with new formed bone that makes the implant positioning easy and safe.



Figure 5.20 Pre-treatment clinical situation.

3D bone remodeling [19]

In a very advanced case where the buccal bone crest is completely gone and a deep pocket (>8 mm) is present, it is still possible to utilize OISD effectively using medial, distal, and especially palatal bone to fill the defect completely (Figures 5.20 to 5.28). The first steps of treatment are the usual extrusion protocol previously described, but open-flap debridement is chosen to treat the active pocket (Figure 5.29).

When forced extrusion is completed, a buccal root torque is activated, using a 019 $\times$ 025 B-titanium wire, to pursue the filling of the alveolus, thanks to the residual palatal bone (Figure 5.30).

Discussion

Results

In interdisciplinary treatment plans, orthodontics plays an effective role in achieving success and the desired esthetic outcome. As far as it concerns implant site development by orthodontic forced extrusion, early clinical results are highly promising (Table 5.1).

A significant increase in quantity and quality of hard and soft tissue is possible to achieve, provided that the operator uses the proper technique and is aware of contraindications and limitations.



Figure 5.21 Pre-operative and intraoperative clinical photos demonstrating deep pockets (probing >10 mm) with the buccal bone completely missing up to the apex. A full-thickness flap is raised and an accurate debridement is accomplished before initiation of the orthodontic treatment.

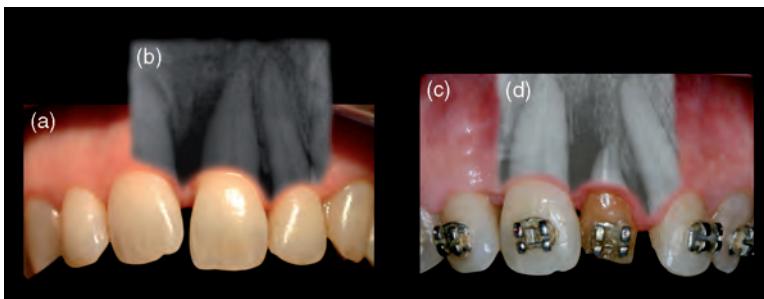


Figure 5.22 The extrusive movement of the left central incisor that fills the bone defect vertically.

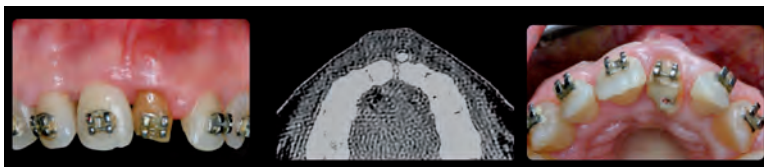


Figure 5.23 The tooth movement is completed (with a buccal root torque) that fills the defect horizontally. The root apex is buccally positioned and perforates the soft tissue. It appears in front of the buccal crest on the computed tomography (CT) axial image.

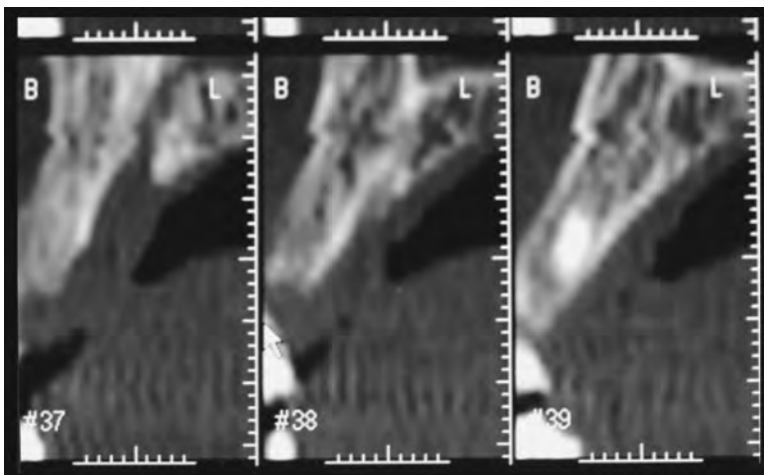


Figure 5.24 The CT scan slice shows the amount of newly formed bone palatal to the root apex.

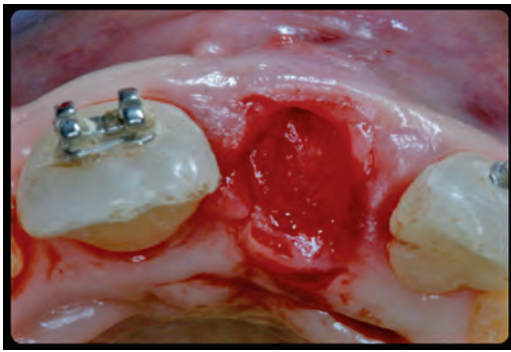


Figure 5.25 Post-extraction alveolus is very small, which is ideal for the implant placement.



Figure 5.26 Immediate temporary emergence profile is checked out of the mouth to determine the soft tissue shape.



Figure 5.27 Temporary crown is inserted on the same day as the implant placement (flapless) to maintain or improve the soft tissue contour.



Figure 5.28 Final crown placement.

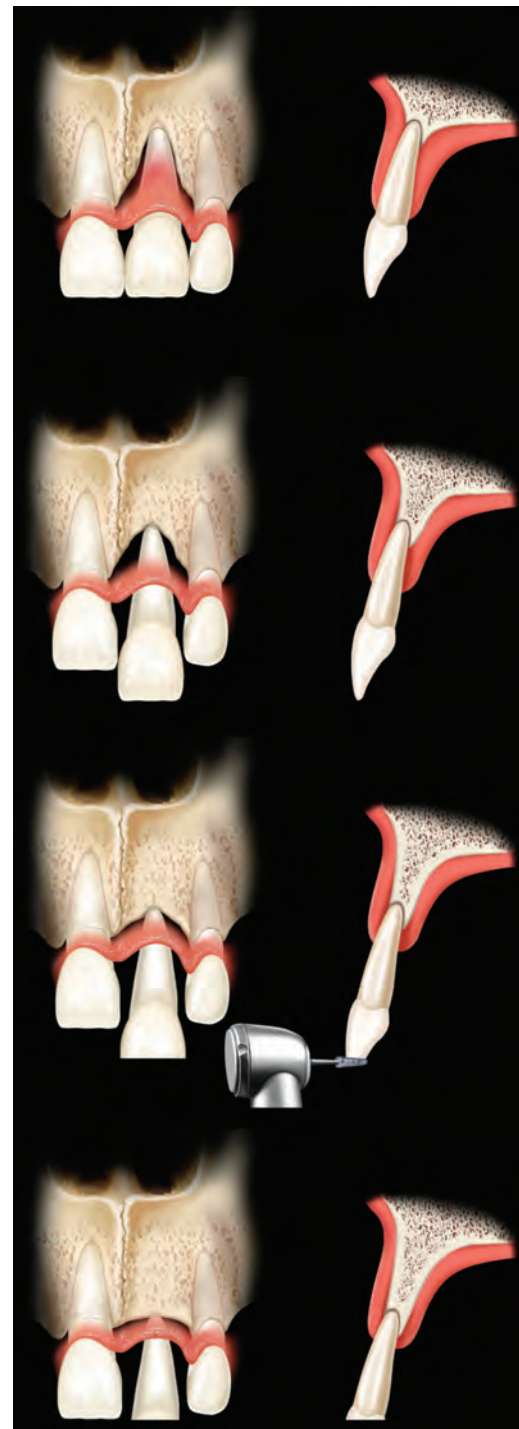


Figure 5.29 The first orthodontic phase consists of extrusive movement. The tooth must be shortened in advance to avoid traumatic contacts.

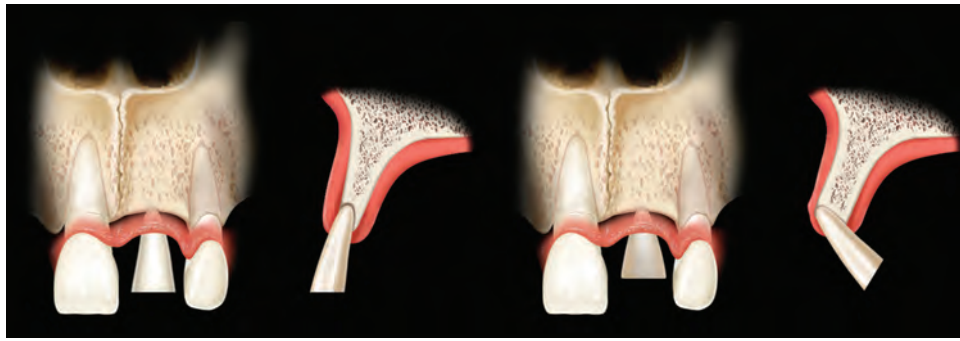


Figure 5.30 The second phase consists of the buccal root torque.

Table 5.1 Summary of the clinically relevant results from the Amato et al. article [12].

Implant Site Development by Orthodontic Forced Extraction: A Preliminary Study

- 5 years
- 13 pts consecutively treated
- 32 Orthodontically Extracted teeth
- 27 Implant sites, 5 pontic sites
- Evaluation of hard and soft tissue

- Orthodontic Extrusion $5.2\text{mm} \pm 1.4$
- Bone Augmentation $4\text{mm} \pm 1.4$
- Gingival augm $3.9\text{mm} \pm 1.5$
- MGJ movement $2.1\text{mm} \pm 1.3$
- Keratinized gingiva augm $1.8\text{mm} \pm 1.1$
- Recession $1.8\text{mm} \pm 1.2$
- Pocket depth reduction $1.8\text{mm} \pm 0.9$
- Gingival thickness augm $0.7\text{mm} \pm 0.4$
- Bone augm/Ortho Eruption $68.9\% \pm 17.3$
- Gingival augm/Ortho Eruption $65.2\% \pm 19.9$

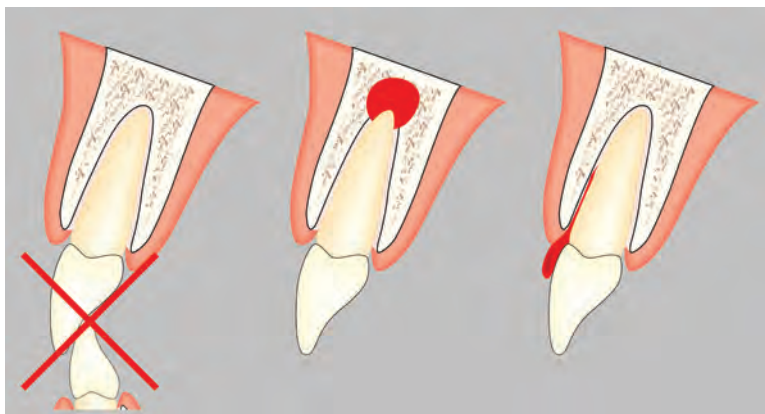


Figure 5.31 Contraindications to extrusive tooth movement: (A) occlusal traumatic contacts have to be avoided to achieve bone apposition, (B) periapical lesions can become larger during the extrusion, (C) active periodontal pockets must be treated before initiation of the orthodontic treatment.

Contraindications

During the whole extrusive movement the tooth must avoid any occlusal contact against the opposite tooth, both static and dynamic (see Figure 5.31). This kind of traumatic contact, contrary to the tooth movement, would prevent the new apposition of bone that usually occurs during extrusive movements. To prevent any contact,

the extruding tooth will be shortened by 1 mm incisally and at the cingulum at every appointment.

When a periapical endo lesion is present, the extrusion of the affected tooth will enlarge it dramatically. However, on the coronal side, there will be gingival and bone augmentation with esthetic improvement even in the presence of a wider periodical lesion that

Table 5.2 Main clinical advantages of the OISD technique.

Measurement	Mean	SD	Range
OE	6.2	1.4	3 to 10
BA	4	1.4	0.6 to 8
KGA	1.8	1.1	-1.5 to 3.8
MGJM	2.1	1.3	0.4 to 5.0
GA	3.9	1.5	1.7 to 7.7
R	1.8	1.2	0.2 to 5.7
GTA	0.7	0.4	0.2 to 1.7
PDR	1.8	0.9	0 to 4
BA/OE%	68.9	17.3	10 to 97
GA/OE%	65.2	19.9	28 to 100
BA/GA%	115.3	50.0	22.2 to 285.7

SD = standard deviation; OE = orthodontic extrusion; BA = bone augmentation; KGA = keratinized gingival augmentation; MGJM = mucogingival junction movement; GA = gingival augmentation; R = recession; GTA = gingival thickness augmentation on the facial side; PDR = pocket depth reduction; BA/OE% = bone augmentation/amount of orthodontic movement ratio (efficacy); GA/OE% = gingival augmentation/amount of orthodontic movement ratio (efficacy); BA/GA% = bone augmentation/gingival margin ratio.

may be completely filled spontaneously after the extraction. If possible, endo treatment or retreatment or, if necessary, apicectomy are the treatments of choice before starting orthodontics.

Periodontal lesions should not be active (no bleeding and no suppuration). Plaque control is recommended. Mobility is not a factor, except for patient discomfort. Control of inflammation is accomplished immediately prior to beginning the orthodontic treatment by means of surgical or non-surgical debridement.

Limitations

OISD allows a favorable pre-implant edentulous site to be obtained eventually, but the positive result is definitely technique-sensitive. Plaque control has to be constantly perceived. Treatment protocol must be followed carefully. It consists of multiple visits and frequent monitoring, so the patient's compliance is needed. The overall treatment before implant placement can be long (6–9 months). Some minor toothache can be present as in any adult orthodontic treatment. The “along the treatment” esthetic compromising aspect,

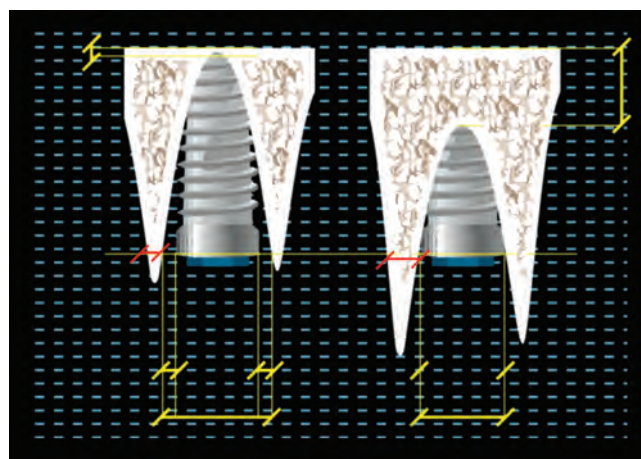


Figure 5.32 Main mechanical advantages for the implant treatment of an orthodontically developed site are: (A) greater amount of basal bone useful for primary implant stability, (B) reduced implant–alveolar gap at the head of the implant, (C) increased buccal ridge thickness to avoid complete post-extractive resorption.

due to progressive shortening of the tooth and enhancement of pink tissue, is the main discomfort.

Advantages

As described in the literature by other authors [11] there are many good reasons to utilize the OISD technique. Table 5.2 and Figure 5.32 demonstrate the main clinical advantages of the OISD technique and Table 5.3 shows a complete OISD data analysed by the authors of this chapter.

Conclusion

In selected cases and using the proper technique, forced extrusion represents a valid alternative to surgical techniques. The obtained results show stability along the years. (Fig 5.33–5.36) Although few questions still remain opened (bone quality and its stability in time, which is the orthodontic extrusion rate that assures the most predictable results, and what is the best timing for implant placement after orthodontic treatment), OISD technique might be a valuable treatment option to regenerate hard tissue for implant site development in many patients.

Table 5.3 Complete data [12].

Advantages		
Biologic	Esthetic	Mechanical
Coronal movement of crestal bone	Vertical increase of papillae dimension	Easier tooth extraction (bone preservation)
Coronal movement of gingival margin	Increase of gingival thickness	Increase of basal bone
Increase of keratinized gingiva	Increase of buccal bone thickness at impl head	Reduced implant–alveolar gap
		Alveolar diameter reduction



Figure 5.33 The left central incisor is not restorable and must be extracted. The OISD technique is performed to improve hard and soft tissues in anticipation of post-extraction remodeling.

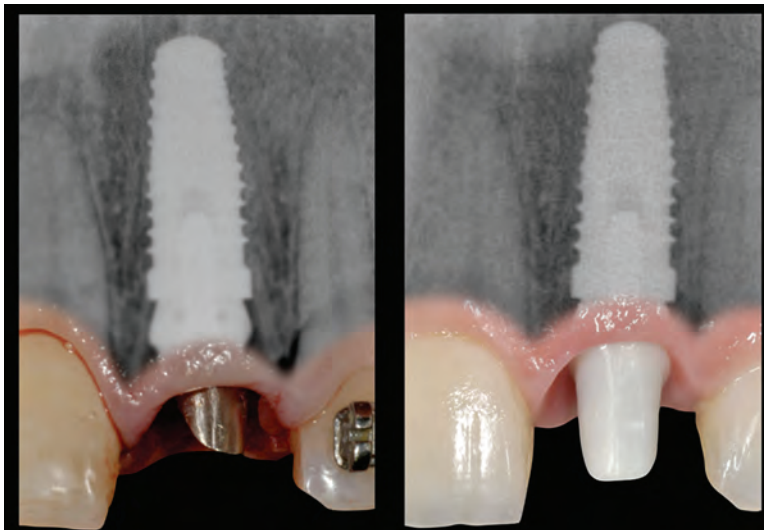


Figure 5.34 Osseointegration is achieved and implant platform switching helps in maintaining the bone level: (A) day of insertion: a temporary abutment is used, (B) 6 months later: the gingival contour is established and a zirconia abutment is chosen.



Figure 5.35 Final restoration: a ceramozirconia crown is cemented on the zirconia abutment of the implant and a laminate restoration is cemented on the other central incisor.

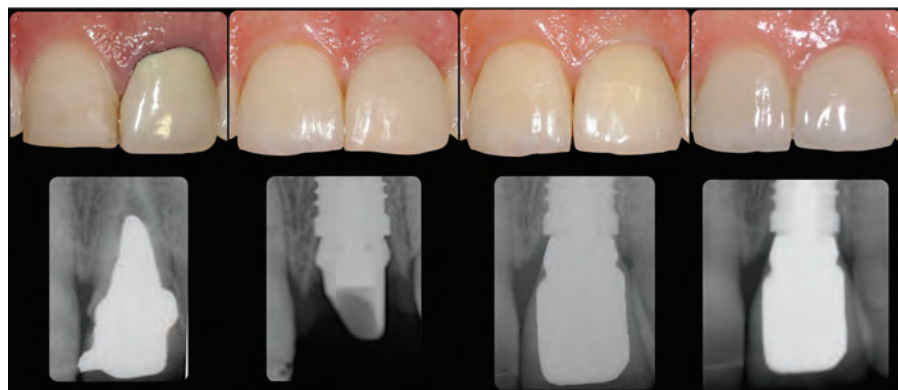


Figure 5.36 The result is long-lasting. The gingival and bone levels are the same at the initial placement, 3 years later, and 7 years post-treatment.

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CHAPTER 6

Radiographic Evaluation of the Alveolar Ridge in Implant Dentistry. CBCT Technology

Shikha Rath and David Hatcher

Private Practice, Diagnostic Digital Imaging, Sacramento, California, USA

Introduction

Radiography plays a pivotal role in the diagnosis and treatment planning required for the successful placement of an endosseous implant. Implant imaging goals must include determining bone height, width, quality, jaw shape and orientation, identification of anatomical boundaries, and ruling out pathology. Two-dimensional (2D) radiographs, such as panoramic and intraoral periapicals, have been traditionally used for preoperative implant-site assessment. They are widely available, inexpensive and well tolerated by patients. However, like all plain film radiographs, they are subject to anatomic superimposition, geometric distortion, and sensitive to positioning errors. Each examination has specific indications and limitations.

Periapical radiography

The paralleling technique for periapical radiographs presents a fairly reliable estimation of the object being examined in the vertical and mesiodistal dimension. It provides high-resolution images with fine bony detail of the area being examined. Accuracy of linear measurements may be increased by calibration with a radiographic marker or metal grid of known dimensions [1]. The technique, however, permits only a limited area of the dentoalveolar region to be visualized and no cross-sectional (buccal-lingual) information is provided. Superimposition of anatomic structures can sometimes lead to an erroneous interpretation due to lack of information in the third (buccal-lingual) dimension (Figure 6.1a shows a periapical radiograph and Figure 6.1b and c show CBCT images of the corresponding region). Periapical radiographs can be used for preliminary evaluation of an implant site and is indicated in the postoperative assessment of the bone-implant interface to evaluate for the presence of lack of osseointegration or bone loss due to peri-implantitis.

Panoramic radiography

Panoramic radiography gives a general overview of the jaws and relevant anatomic landmarks and can aid in the identification of gross pathologic abnormalities in the jaws (Figure 6.2). They can provide an estimate of the ridge height at a specific location when a radiographic marker of known dimensions is used. Measurements from panoramic radiographs, however, have limited reliability and accuracy (Figure 6.3a and b). Panoramic radiographs are associated

with differential magnification and geometric distortion, mainly in the horizontal (mesiodistal) direction; this varies in different regions of the jaws and from one equipment to another. Errors may also be associated with patient positioning and discrepancies between the curvature of the dental arch and the focal trough of the machine. Accurate reproduction of the images is difficult and inconsistent. Panoramic radiographs also only provide information of the vertical and mesiodistal dimensions of a region and do not offer cross-sectional (buccal-lingual) information. In cases of bony undercuts or knife-edged ridges, measurements from these images can be misleading (Figures 6.4a and b and 6.5). Due to its many inherent limitations, panoramic radiography is considered sub-optimal as a single imaging source for preoperative implant site assessment [2–4].

Occlusal radiography

Occlusal radiographs provide information of the general shape of the dental arch and its *maximum* buccal-lingual dimension. However, no information of bone morphology, angulation, or undercuts is provided. Maxillary images are inherently oblique and therefore distorted. Occlusal radiographs may offer limited usefulness in post-operative assessment of implant positioning in the buccal-lingual dimension.

Cone beam computed tomography (CBCT)

The introduction of *cone beam computed tomography* (CBCT) has overcome the shortcomings of conventional radiography and has established a new era of implant imaging [5–8]. The technology has improved diagnostic information and treatment outcomes due to visualization of the anatomy at potential implant sites in three dimensions (3D) with submillimeter accuracy [9]. Software programs permit versatile reformatting capabilities that allow slicing of the scan to be performed in any plane; this can be performed to obtain sectional images in the optimum orientation for implant site assessment. Interactive treatment simulation software also enables virtual implant planning that can be transferred to a surgical guide to be used in executing the treatment plan at surgery. More recently, CBCT data have been integrated with surgical navigation systems to perform a computer-guided implant placement without the use of surgical guides. This chapter emphasizes the role and applications of CBCT in the planning and placement of implants.

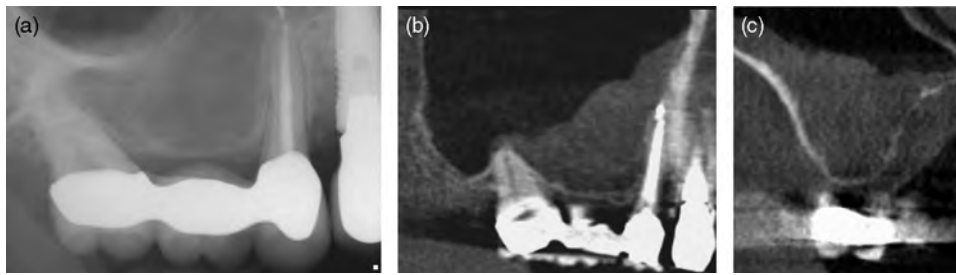


Figure 6.1 (a) Periapical radiograph of the right posterior maxilla with indistinct margins of the floor of the maxillary sinus and the alveolar crest in the region of 3. (b) Sagittal view CBCT of the region showing marked atrophy of the alveolar ridge and pneumatization of the right maxillary sinus with soft tissue collection within it. (c) CBCT cross-sectional (buccolingual) view of the area showing no residual ridge height and presence of sinus pathology. Superimposition of anatomic structures in conventional 2D radiographs can mask pathology and make interpretation of landmarks difficult.

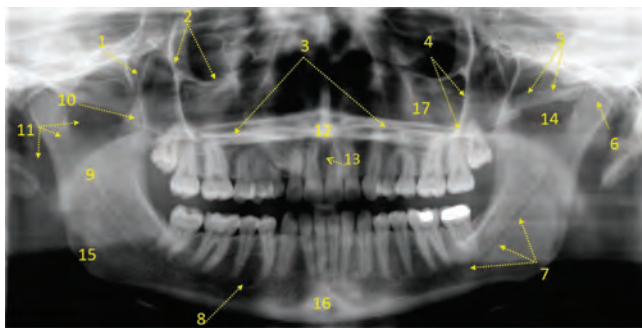


Figure 6.2 Panoramic anatomic landmarks: (1) Pterygomaxillary fissure, (2) orbital floor, (3) hard palate, (4) zygomatic process of the maxilla (malar process), (5) zygomatic arch, (6) condyle, (7) mandibular canal, (8) mental foramen, (9) mandibular foramen, (10) coronoid process, (11) pharyngeal air space, (12) anterior nasal spine, (13) incisive canal, (14) mandibular notch, (15) mandibular angle, (16) genial tubercles, and (17) maxillary sinus.

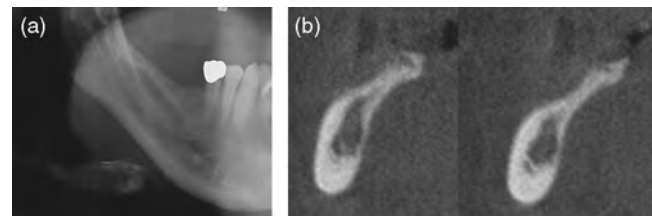


Figure 6.4 (a) A cropped panoramic of the right posterior mandible with missing teeth 30–32. (b) CBCT cross-sections in the region of 30 and 31. Note lingual projection of the narrowed ridge and large lingual undercut representing the submandibular fossa. The major limitation of panoramic radiography is that buccolingual assessments cannot be made.

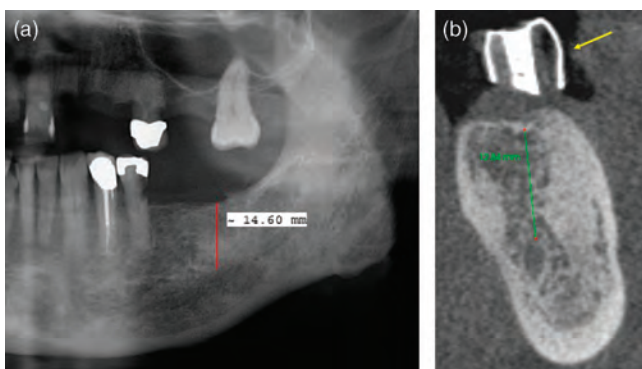


Figure 6.3 (a) A cropped panoramic image showing vertical bone measurement (of 14.6 mm) from the alveolar crest to the superior border of the mandibular canal in the region of 18. Inconsistent magnification associated with the panoramic techniques makes measurements made on them unreliable. (b) A CBCT cross-section of the same region showing a measurement of 12.84 mm. Arrow points to the radiographic marker indicating the position and trajectory of the proposed implant.

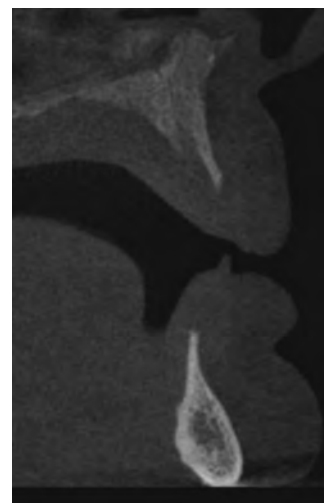


Figure 6.5 CBCT cross-section of the anterior maxilla and mandible showing the knife-edged ridge. Panoramic and periapical radiographs only provide information of the bone height but not of the bone width.

Anatomic and architectural considerations for treatment planning

Pre-operative treatment planning necessitates obtaining a thorough knowledge of anatomical appearance, location, dimensions, and variations of critical structures that are routinely encountered during implant placement. This information is crucial in determining implant length, size, and angulation for long-term implant function and esthetics and to lower the risk of complications. In addition to evaluation of internal anatomy, consideration should be given to jaw shape, orientation, and boundaries; this assessment is necessary since the clinical examination may not reveal the underlying osseous contours. The canine fossa on the labial surface of the anterior maxilla and the submandibular fossa on the lingual surface of the posterior mandible are common normal anatomic depressions; however, shallow or deep facial and lingual fossae may be present in any area of the jaws. The vertical long axis of the mandible has a lingual angulation that is more pronounced in the posterior regions (Figure 6.3b). Atrophy of the alveolar ridge occurs to a greater extent in the mandible than in the maxilla and atrophy reduces bone width more than bone height. Cross-sectional imaging is essential in the visualization of anatomic structures and morphological changes to the residual ridges [5]. Implant placement beyond the anatomic boundaries may result in neurovascular injuries that can lead to inflammation and infection with ultimate loss of implant, compromised or complete loss of sensation, and even life-threatening events. Some of the anatomic structures that are commonly encountered during implant site assessment are discussed below.

Anterior maxilla

Nasopalatine (incisive) canal

The nasopalatine canal (NPC) is located at the anterior midline of the maxilla, posterior to the central incisor teeth (Figure 6.6a to d),

and is formed by the union of the two palatal processes of the maxilla. The nasopalatine canal transmits the nasopalatine nerve (V2 sensory branch) and the terminal branch of the nasopalatine artery. The canal extends from the nasal floor and emerges on the hard palate through the nasopalatine (incisive) foramen. In this foramen, the orifices of two lateral canals are usually visible; these are the canals of Stensen (Figure 6.6e). Occasionally, two additional minor canals, the canals of Scarpa, are seen in the mid-line; they serve as passageways for the nasopalatine nerves.

The diameter of the nasopalatine foramen is typically below 6 mm; when it exceeds 8–10 mm, pathological conditions such as the nasopalatine duct cysts should be considered. The average length of the canal is reported to be ~8–10 mm and it is situated ~7.4 mm from the labial surface of an unresorbed ridge [10]. The nasopalatine canal tends to enlarge in all dimensions with increasing age and progressive ridge atrophy after tooth loss in the anterior maxilla [11]. Perforation of the incisive canal by dental implant may happen intraoperatively if the canal is enlarged and is encroaching on to the central incisor space (Figure 6.6f). Pre-operative analysis of the CBCT scan prior to surgery helps to avoid this complication.

Canalis sinuosus

The anterior maxillary region also contains the anterior superior alveolar (ASA) nerve and artery in a bony canal named the canalis sinuosus (Figure 6.7a). Along with the nasopalatine nerve and vessels, these supply the incisors and canines, as well as the adjacent soft tissues. The canal is present along the lateral nasal wall and follows the curve of the narial margin. A palatine extension of the canalis sinuosus may sometimes be present in the anterior region of the palate [12]. Figure 6.7b shows a para-sagittal view CBCT showing perforation of the posterior superior alveolar (PSA) canal by dental implant in the left posterior maxilla.

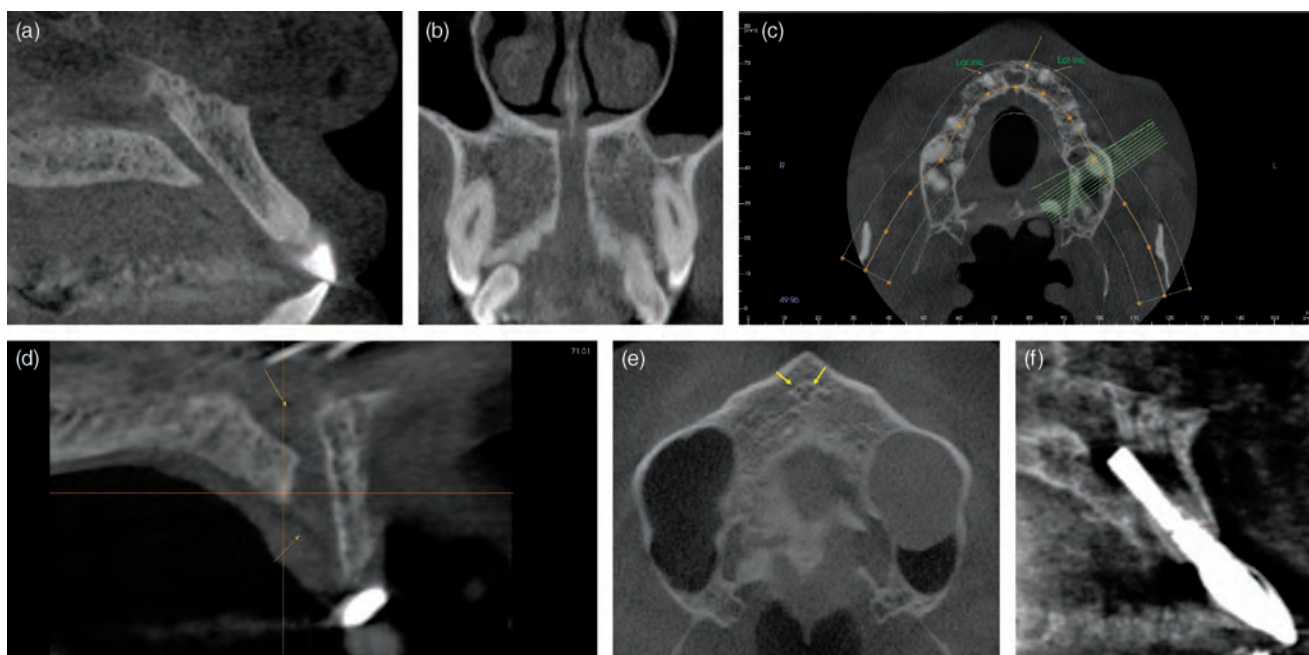


Figure 6.6 (a) Mid-sagittal view CBCT showing the incisive canal located palatal to the maxillary central incisors. (b) Coronal view CBCT showing the incisive canal extending from the floor of the nasal cavity to the incisive foramen. (c) Axial view CBCT showing an enlarged nasopalatine canal (NPC). (d) Mid-sagittal view CBCT showing an enlarged incisive canal. (e) Two lateral canals within this incisive foramen, on each side of the mid-line (arrows). These represent the foramina of Stensen, which transmit the nasopalatine nerves and the terminal branch of the descending palatine artery. (f) Sagittal view showing perforation of the incisive canal by implant.

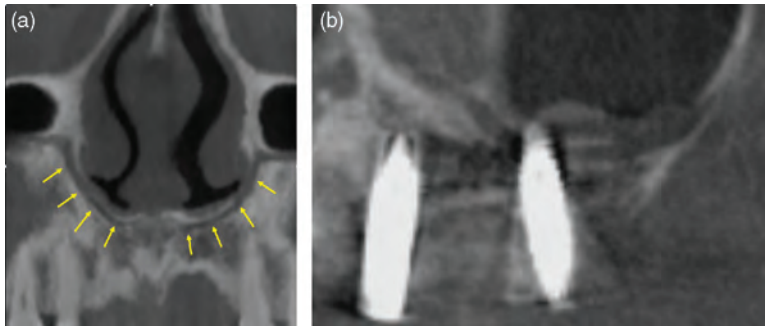


Figure 6.7 (a) Coronal view CBCT showing the location of canalis sinuosus containing the anterior superior alveolar canal (arrows) along the lateral walls of the nasal cavity. (b) Para-sagittal view CBCT showing perforation of the posterior superior alveolar (PSA) canal by implant in the left posterior maxilla.

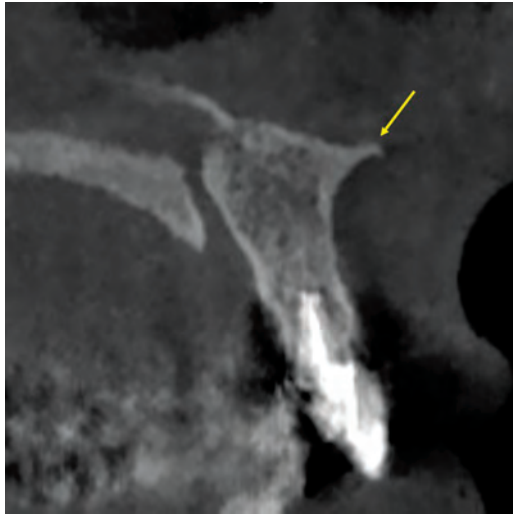


Figure 6.8 Mid-sagittal view CBCT showing the ANS in the mid-line on the anterior-inferior aspect of the nasal cavity.

Anterior nasal spine and nasal floor

The anterior nasal spine (ANS) is a sharp bony projection formed by the forward elongation of the maxillae in the mid-line at the anterior and inferior aspect of the nasal cavity (Figure 6.8).

The floor of the nasal cavity is a curved bony landmark located apical and palatal to the roots of the maxillary anterior teeth. Perforation of the nasal floor by an implant (Figure 6.9a and b) may cause difficulty in nasal breathing and infection.

Pattern of ridge atrophy in the anterior maxilla

Atrophy of the anterior maxilla progresses from initial development of a labial concavity with development of a bulbous alveolar crest. It proceeds to uniform thinning of the alveolar ridge until the residual ridge crest becomes knife-edged (Figures 6.5 and 6.10a). There is simultaneous progressive loss of bone height until the ridge involves the basal bone. In advanced cases, there may be resorption of the anterior nasal spine and exposure of the nasopalatine foramen at the residual ridge crest. The buccal cortical plate is often thin to begin with (Figure 6.10b) and becomes more resorbed with age, history of trauma (bike accidents, etc.), and loss of maxillary incisors and canines. This often leads to the necessity of bone grafting of the anterior maxilla if implant treatment is contemplated. Therefore, severely resorbed maxilla atrophies superiorly and posteriorly and maxillomandibular relations with loss of teeth and bone often becomes Class III.

Posterior maxilla

Maxillary sinus

The maxillary sinus is the largest of all the paranasal sinuses and is pyramidal in shape. The sinus ostium is the opening of the sinus to the middle meatus of the nose (ostiomeatal complex, or OMC) and is located on the medial wall of the superior aspect of the maxillary sinus (Figure 6.11). The mean distance from the most inferior point of the sinus floor to the ostium is 28.5 mm [10]. Evaluation of the patency of the osteomeatal complex is important during pre-surgical planning for sinus augmentation since a pre-existing sinusitis with an obstructed ostium (outflow) could increase the likelihood of a flare-up or graft failure after a sinus lift surgery

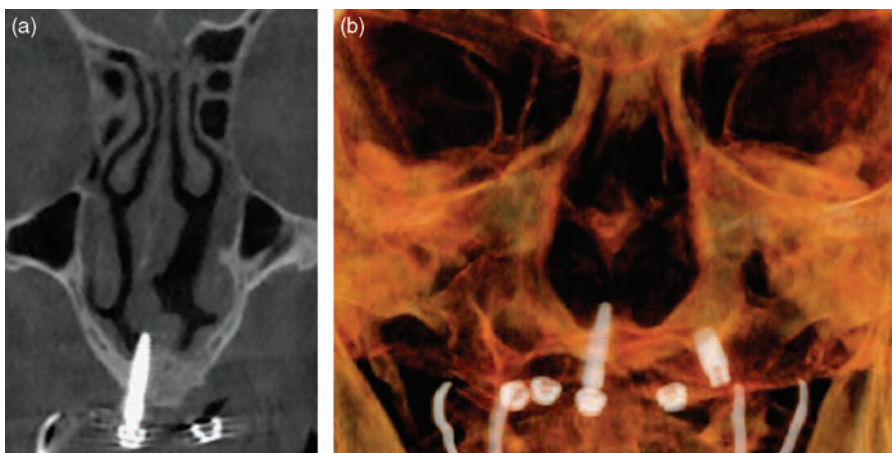


Figure 6.9 (a) Coronal view CBCT showing perforation of the floor of the right nasal cavity by implant. (b) Volume rendered image of the same case.

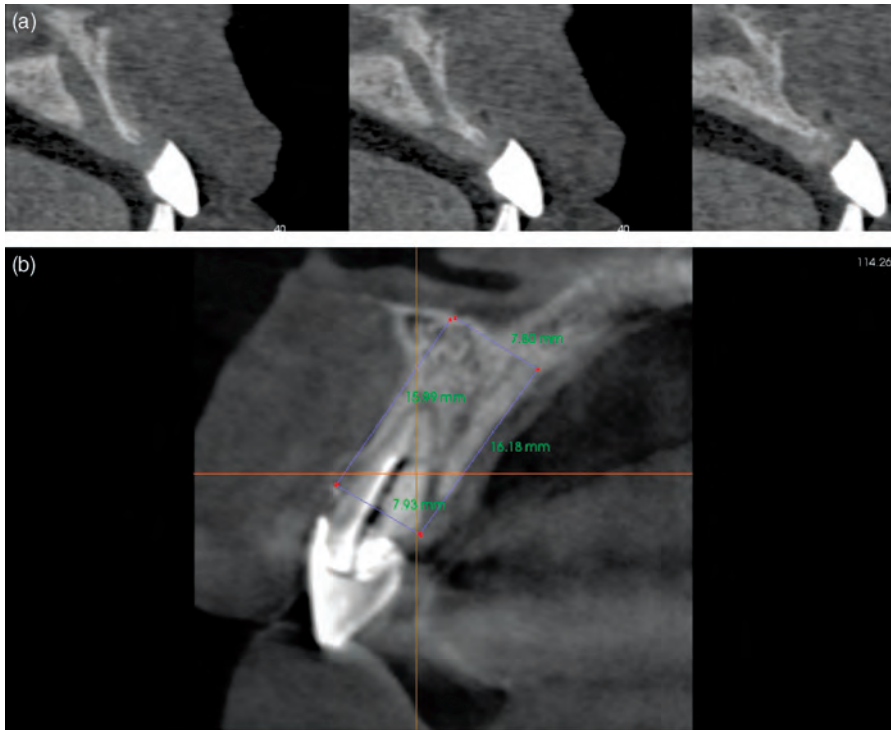


Figure 6.10 (a) CBCT cross-sections showing atrophy in the anterior maxilla. Note the marked labial resorption of the ridge with development of a labial undercut and a knife-edged crest. (b) Sagittal CBCT view showing thinning of the buccal cortical plate adjacent to the failing central incisor.

(Figure 6.12). The normal width of the Schneiderian membrane is 0.3–0.8 mm [10]; sinus floor membrane thickening >5 mm has been reported to be associated with a progressively increased risk for ostium obstruction. Membrane perforations occur in 10–60% of cases and are usually not significant. The risk for complications increases when the perforation is greater than 2 mm. Implant protrusion into the sinus (Figure 6.13) often does not cause sinus inflammation but may exacerbate a pre-existing sinusitis or result in new infection (Figures 6.14a and b).

The sinus floor may be flat or oblique and also may extend between the roots of the maxillary posterior teeth. Sinus septation may be present on the sinus floor and they frequently tend to get larger as they proceed medially. A sinus lift surgery should proceed

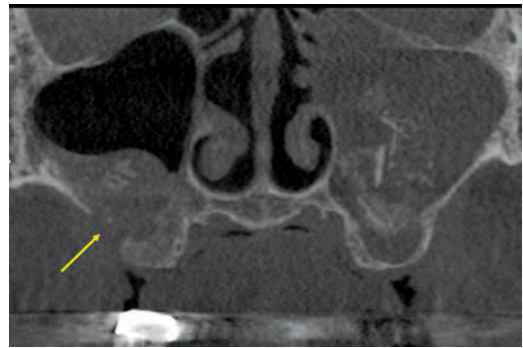


Figure 6.12 Coronal view CBCT showing dislodgement of the graft into the maxillary sinuses and resultant sinus infection, more pronounced on the left. Perforation of the sinus floor can be seen on the right side (arrow).



Figure 6.11 Coronal view CBCT showing paranasal sinuses with a patent osteomeatal complex (arrows) on both sides. The complex is located on the superior-medial aspect of the maxillary sinuses and provide a pathway for drainage from the maxillary sinuses to the nasal cavity.



Figure 6.13 Sagittal view CBCT showing no sinus reaction in spite of three implants protruding into the maxillary sinus. Implant protrusion into the sinus cavities often does not result in sinus inflammation. The dark areas adjacent to the implants represent a beam hardening artifact. The presence of these artifacts limit evaluation of the peri-implant bone on a CBCT.

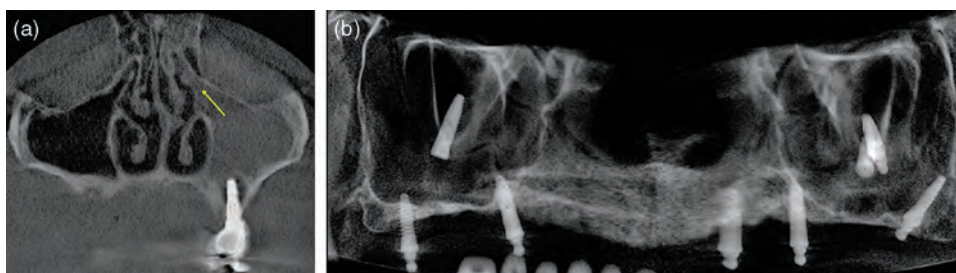


Figure 6.14 (a) Coronal view CBCT shows infection of the left maxillary sinus and obstruction of the osteomeatal complex (arrow) due to implant perforation. (b) CBCT-generated panoramic showing dislodgement of three implants into the maxillary sinuses and perforation of the sinus floor by other implants.

laterally to medially over a partial septum instead of anteriorly to posteriorly so as to avoid a membrane perforation. When large or multiple longitudinal septa are present, more than one lateral window may be created anterior and posterior to them as part of the antral opening. Mucous retention pseudocysts are commonly found arising from the sinus floor; when small, these are not considered a risk factor for sinus surgery (Figure 6.15a shows a large pseudocyst that can obstruct the OMC during a sinus lift surgery). Other sinus pathology that can requires ENT evaluation includes acute (Figure 6.15b) and chronic (Figure 6.15c) rhinosinusitis, fungal sinusitis (Figure 6.15d), mucocoele (Figure 6.15e), sinonasal polyp (Figure 6.15f), and malignancy (Figure 6.15g and h).

The posterior superior alveolar (PSA) canal is present within the posterolateral wall of the maxillary sinus and contains the posterior superior alveolar nerve and blood vessels that supply the maxillary sinuses, alveolar bone, teeth, and surrounding soft tissues. In 20% of patients, the diameter of the PSA canal is >1 mm, large enough to cause bleeding and/or paresthesia if damaged during implant surgery [13] (Figure 6.7b shows perforation of the PSA canal by an implant in the left posterior maxilla).

Greater palatine foramen

The greater palatine foramen is located on the palatal aspect of the third molar, halfway between the alveolar ridge crest and the

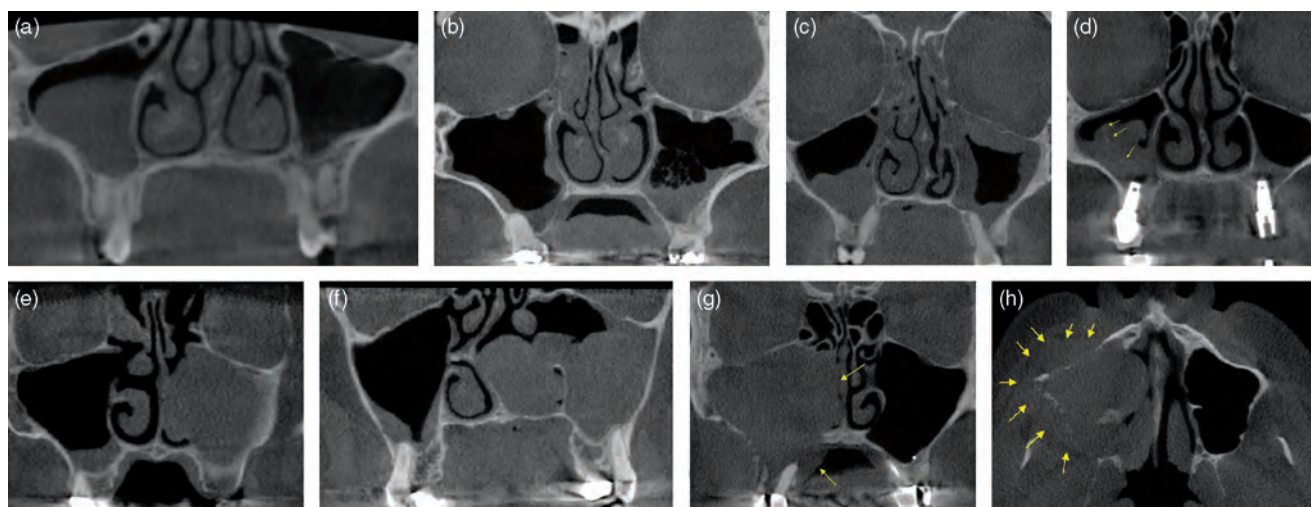


Figure 6.15 (a) Coronal view CBCT showing a large mucous retention pseudocyst in the right maxillary sinus. These can be raised to obstruct the osteomeatal complex during a sinus lift procedure. (b) Coronal view CBCT showing acute rhinosinusitis with air bubbles in the left maxillary sinus. Acute rhinosinusitis presents with air–fluid levels, mucosal thickening, and air bubbles within the sinuses. (c) Coronal view CBCT showing chronic rhinosinusitis with soft tissue collection in the maxillary sinuses and in the ethmoid air cells. Chronic rhinosinusitis presents with thickened sinus mucosa, opacification, and/or sclerosis of the sinus walls. The degree of mucosal thickening is considered normal (2–3 mm), mild (3–5 mm), moderate (5–10 mm), or severe (>10 mm). (d) Coronal view CBCT showing fungal sinusitis in the right maxillary sinus. Fungal sinus often presents with polypoid soft tissue mass with diffuse, scattered calcifications within (arrows). Expansion, remodeling, sclerosis, thinning, or erosion of the sinus walls may be present. The osteomeatal complex of the involved sinuses are almost always present. (e) Coronal view CBCT showing mucocoele in the left maxillary sinus that invades into the left nasal cavity. Mucocoeles are mucus-containing expansile lesions that are capable of bony destruction and compromise of surrounding structures. (f) Coronal view CBCT of a polypoid lesion that extends from the left maxillary sinus into the left nasal cavity (antrochoanal polyp). Sinonasal polyposis demonstrate rounded, polypoid masses causing partial to complete sinus opacification and thickening/remodeling of sinus walls. (g, h) Coronal view and axial view CBCTs of a mucosal melanoma in the right maxillary sinus. Sinus malignancies are associated with destruction of the sinus walls with little or no expansion. Often there is infiltration into the adjacent soft tissues (arrows) through sieve-like penetrations in the sinus walls.



Figure 6.16 Coronal view CBCT showing the greater palatine foramen (arrows) located on the palatal aspect of the third molars.

median palatal raphe (Figure 6.16). The greater palatine artery and nerve emerge from the foramen and traverse the palate anteriorly to reach the incisive canal. Severing the palatal artery close to the foramen may retract the artery into the bone, thereby making its ligation during surgery difficult.

Pattern of ridge atrophy in the posterior maxilla

Atrophy of the posterior maxilla progresses from the initial loss in bone width from the buccal aspect of the cervical third of the alveolar crest to loss in ridge height from the alveolar crest and concomitant pneumatization of the maxillary sinus into the alveolar bone (Figure 6.1b). There is a tendency for a decrease in bone height and an increase in bone width from the premolar to the molar regions. With the progression of bone remodeling, there can be complete effacement of the alveolus with only a thin layer of cortex separating the sinus and the alveolar mucosa (Figure 6.1c). Therefore, severely resorbed maxilla atrophies superiorly and posteriorly and maxillomandibular relations with loss of teeth and bone often becomes Class III.

Anterior mandible

Mandibular incisive canal

The incisive canal is present anterior to the mental foramen and typically narrows as it approaches the mid-line, usually terminating apical to the lateral incisor (Figure 6.17). The size of the canal is typically less than 1 mm, and as such it does not pose a risk for osteotomies that penetrate the canal.

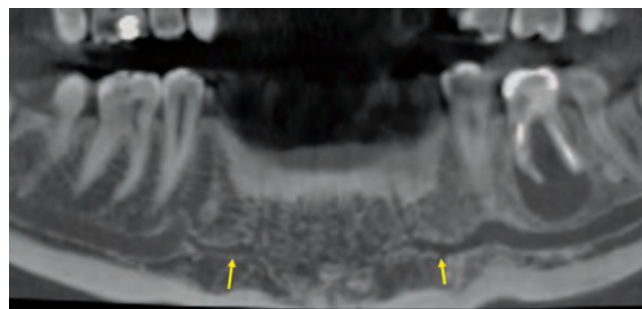


Figure 6.17 CBCT-generated panoramic section showing the mandibular incisive canal (arrows) extending anteriorly from the mandibular foramen towards the mid-line.

Lingual foramen and lateral canals

Small vascular canals are often present at or near the mid-line of the mandible; a mid-line lingual foramen is present in 99% of cases (Figure 6.18a and b). Sublingual arteries can extend into the anterior mandible, perforating the lingual cortex and providing blood supply for the anterior mandibular bone. Canals larger than 1 mm pose a risk for excessive bleeding during surgery. In addition, accessory foramina may be present in the lingual cortical plate of the anterior mandible through which branches of the sublingual and submental arteries may enter the mandible. These vascular channels do not have resilient walls that are common for arteries traveling in the soft tissue. Implant placements into the anterior mandibular bone, for example, that extends far down to these sublingual vessels or inadvertent penetration into the floor of the mouth through the lingual cortex can cause arterial trauma, thereby resulting in a sublingual or submandibular hematoma. The development of a hematoma can displace the tongue superiorly and posteriorly, thereby potentially causing an airway obstruction [14,15].

Genial tubercles

The genial tubercles are small, bony projections on the lingual surface of the inferior aspect of the mandible, on either side of the mid-line (Figure 6.19a and b). There are two superior and two inferior tubercles and they serve as points of attachment of the genioglossus and the geniohyoid muscles, respectively. The genioglossus muscle should not be completely reflected during flap

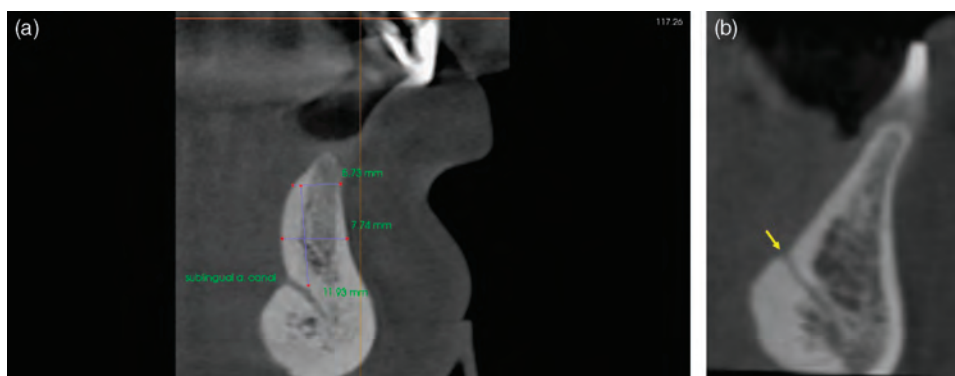


Figure 6.18 (a, b) Sagittal view CBCT of the anterior mandible demonstrating the lingual canal and foramen (arrow) in the mid-line for sublingual arteries.

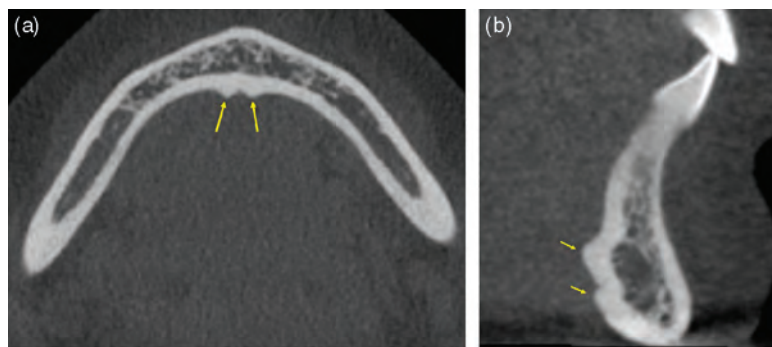


Figure 6.19 (a) Axial view CBCT showing two superior genial tubercles on either side of the mid-line in the anterior mandible (arrows). (b) Sagittal view of the anterior mandible demonstrating the superior and inferior genial tubercles (arrows).

elevation because the tongue may retract to the posterior part of the throat and obstruct the airway.

Pattern of ridge atrophy in the anterior mandible

Bone loss causes progressive thinning of the alveolus labiolingually in the anterior mandible. The alveolar crest may become knife-edged (Figure 6.5) and is typically shifted labially due to the forces exerted by the tongue. Loss in bone height also occurs with gradual flattening of the crest. In advanced cases, the lingual canal and the superior genial tubercle may become exposed to the ridge crest. Therefore, severely resorbed mandible atrophies inferiorly and anteriorly and maxillomandibular relations with loss of teeth and bone often becomes Class III.

Posterior mandible

Inferior alveolar (mandibular) canal

The inferior alveolar nerve (IAN), a branch of V3, enters the mandibular canal through the mandibular foramen on the medial surface of the ramus and exits through the mental foramen. The canal is ~3.4 mm wide and houses the nerve (~2.2 mm thick) along with an artery, vein, and lymphatic vessels [10]. The IAN crosses from the lingual side of the mandible to the buccal and is usually located midway buccolingually in the first molar region. Canal bifurcation is seen in ~1% of patients (Figure 6.20) [10]. Injury to the IAN may occur when the canal is compressed or perforated (Figure 6.21) during implant surgery or placement. Complications range from hypoesthesia or paresthesia (reduced sensation) to anesthesia (complete loss of sensation). Painful (unpleasant) sensation can also occur and is called dysesthesia. The IAN terminates into the mental and incisive nerves in the premolar region [16]. The

mental nerve exits the mental foramen and the canal continues anteriorly as the incisive canal.

Mental foramen

The mental foramen is located on the buccal aspect of the mandible, at the apical region of the second premolar or between the premolars (Figure 6.22a to c). The foramen is usually inferior to the apex of the premolars, but may be present superior to the apex or at its level [17]. It is typically located halfway between the alveolar crest and the lower border of the mandible [18].

The IAN may course anteriorly and inferiorly to the mental foramen and then loops back to emerge from the foramen. The anterior loop of the canal can be up to 4 mm in length.

Submandibular and sublingual fossae

The submandibular fossa is a medial/lingual depression on the posterior aspect of the mandible and inferior to the mylohyoid line; it houses the submandibular gland (Figures 6.4a and b and 6.23a and b). The sublingual fossa is a shallow depression in the canine-premolar region superior to the mylohyoid line and houses the sublingual gland (Figure 6.24a to c). The resultant lingual undercut gets deeper as it progresses distally from the premolar to the second

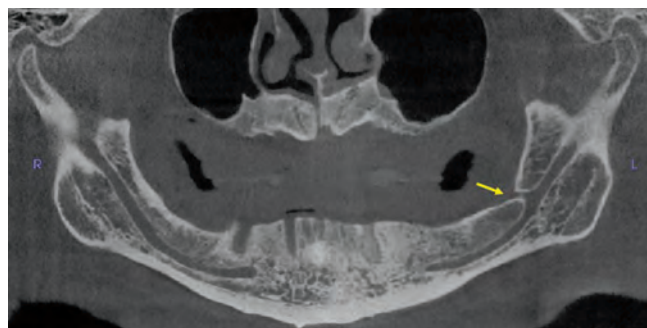


Figure 6.20 CBCT-generated panoramic cross-section showing an accessory branch of the mandibular canal (arrow) exiting at the alveolar crest.

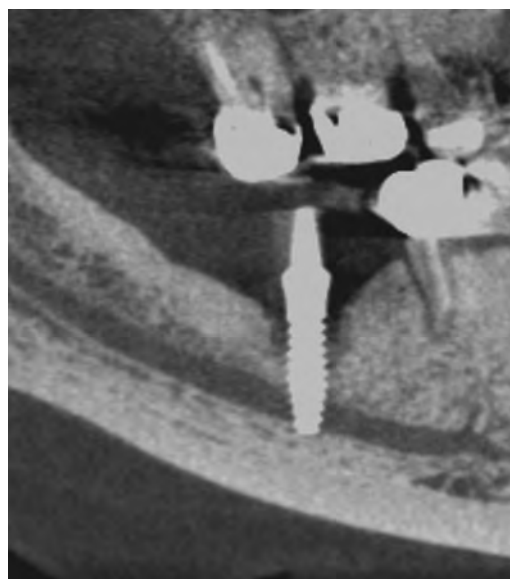


Figure 6.21 CBCT showing an implant interrupting the superior and inferior borders of the mandibular canal. Perforation of the canal may result in mandibular nerve injury that could cause pain and paresthesia.

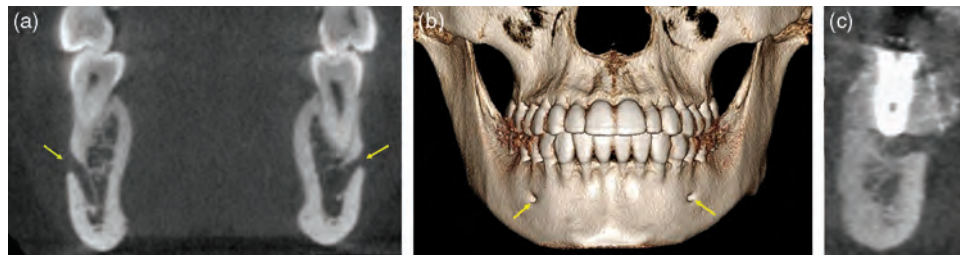


Figure 6.22 CBCT of the mental foramen on the apical aspect of the mandibular premolar exiting the bone on the buccal aspect: (a) coronal view and (b) 3D volume rendered view. (c) CBCT cross-section showing perforation of the superior aspect of the IAN as it exits the mental foramen.

molar region. It poses a risk for perforation of the lingual cortex and resultant hemorrhage during implant surgery.

Lingual nerve

The lingual nerve is a branch of the mandibular nerve (V3) and provides sensory innervation to the mucous membranes of the anterior two-thirds of the tongue and to the lingual tissues. It is usually located 3 mm apical to the alveolar crest and 2 mm medial to the lingual cortical plate. In 15–20% of cases, it may be located at or above the crest lingual to the third molars. In 22% of cases, the lingual nerve may contact the lingual cortical plate [19].

Pattern of ridge atrophy in the posterior mandible

Bone loss results in thinning of the alveolar ridge in the buccolingual dimension and the ridge may become knife-edged. Lingualization of the crest may also occur, which can become more pronounced if the

buccal plate of the alveolar bone is fractured during tooth extraction (Figure 6.4). Atrophic loss in ridge height ensues, which could extend down to the superior border of the mandibular canal and cause an eventual exposure of the mental foramen (Figure 6.25a and b). As a rule, severely resorbed mandible atrophies inferiorly and anteriorly and maxillomandibular relations with loss of teeth and bone often becomes Class III.

Imaging considerations for CBCT utilization

Technical considerations

The *field of view* (FOV) on a CBCT scan for implant imaging should extend beyond the implant site to include adjacent structures that could affect implant surgery. The selection should, however, be limited to the smallest field of view (FOV) necessary to minimize the radiation dose to the patient [20,21].

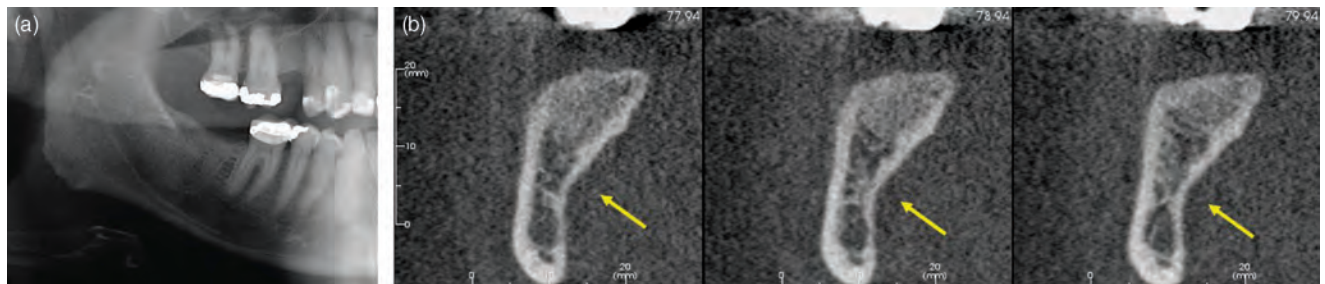


Figure 6.23 (a) Panoramic radiograph of the right side, (b) CBCT cross-sections in the region of 31 showing a lingual undercut representing the submandibular gland fossa.

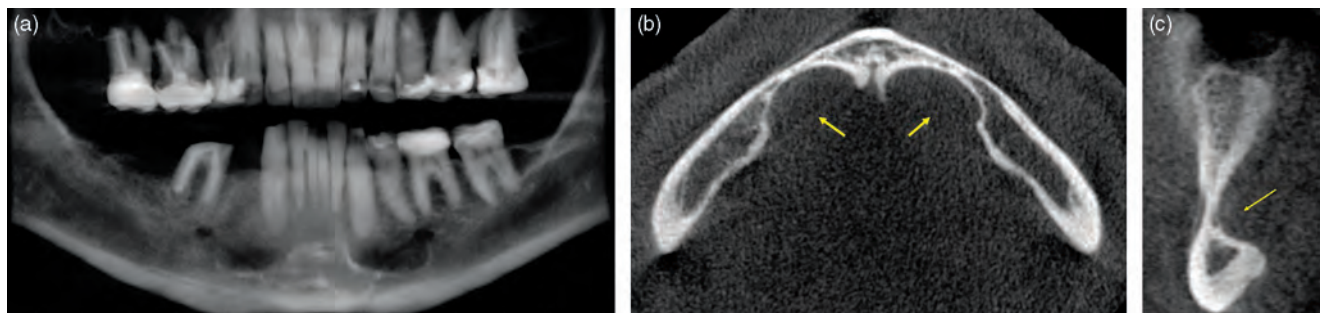


Figure 6.24 Bilateral large sublingual salivary gland depressions seen on CBCT: (a) panoramic reformat, (b) axial view showing anterior sublingual gland depressions (arrows), and (c) cross-sectional view in the region of 27 showing the lingual depression (arrow).

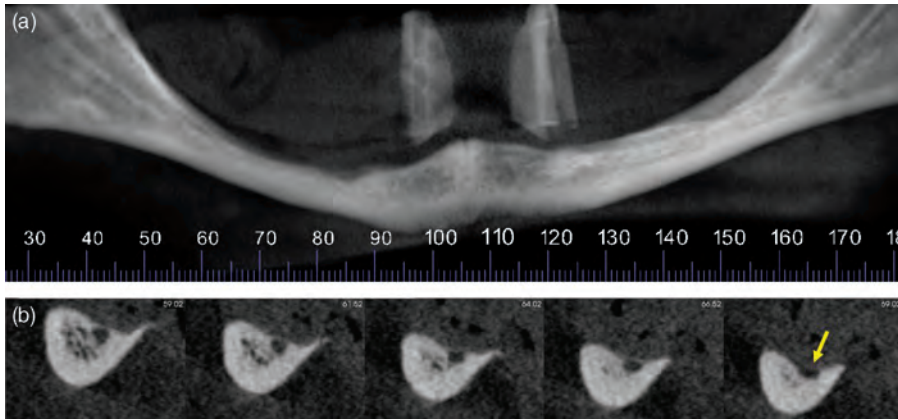


Figure 6.25 (a) CBCT panoramic of a severely atrophic mandible and (b) cross-sections of the right posterior mandible exhibit loss in bone height that extends to the superior cortex of the mandibular canal. Note exposure of the mental foramen at the alveolar crest (arrow).

The *voxel size* of a scan is the primary determinant of spatial resolution; the smaller the voxel size, the greater the scan resolution. A low scan resolution can reduce the accuracy of measurement and the visualization of the adjacent anatomic boundaries. Selection of a smaller voxel size is typically associated with an increase in radiation dose due to an increase in mA (tube current) or scan time required to maintain adequate image quality. A voxel size of 0.2–0.3 mm is considered a good compromise between image quality and radiation dose for implant scanning [22].

All CBCT scans are subject to *artifacts* emerging from dense materials such as implants, cast restorations, and gutta percha that degrade image quality in the affected area. *Beam hardening* artifacts appear as dark bands adjacent to the high-density object. Bone or tooth structures adjacent to the high-density areas may appear “burned out” or missing (Figure 6.13), which may mimic disease [23]. *Streak artifacts* appear as light and dark lines arising from a dense source object (Figure 6.26). The presence of these metallic artifacts limits the evaluation of trabecular bone in the adjacent region during pre-surgical assessment, and also limits the evaluation of peri-implant bone defects or osseointegration during post-surgical assessment. For this reason, intraoral periapical radiographs should often be utilized for post-op implant evaluation for osseointegration [24].

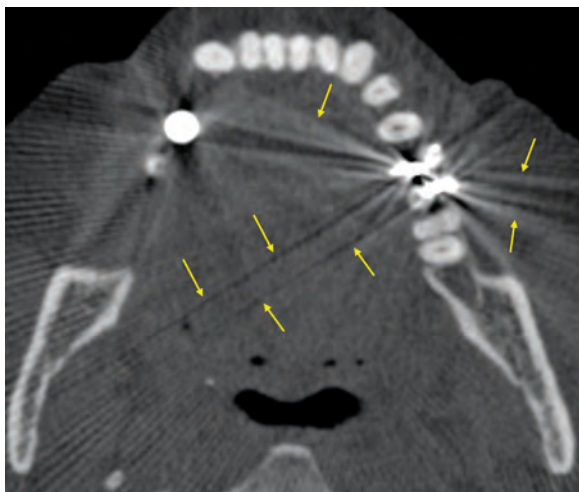


Figure 6.26 Axial view CBCT showing metallic streak artifacts that appear as light and dark lines arising from a dense object (arrows).

Bone quality and bone density assessment

Bone quality comprises the thickness of cortical bone as well as the characteristics and patterns of trabecular bones and contributes to the stability of implants [25]. Successful implant integration is dependent upon the type and density of bone at an implant site. The mean bone density is greatest in the anterior mandible, followed by the anterior maxilla, and is the least in the posterior maxilla. For implant placement, the most critical area for bone density assessment is the crestal 7–10 mm of bone, since this is the region where stresses are applied to the bone–implant interface. Hounsfield units (HUs) are standardized objective measurements in medical CT that represent the relative density of bony tissues according to a calibrated gray-scale level. Density numbers measured in CBCT represent the gray-scale level and do not directly correspond to HU. They are influenced by exposure parameters, image artifacts, and increased level of scatter in CBCT scans; for these reasons, *density measurements are unreliable in CBCT* and evaluation is only subjective [26].

Pathology detection

Successful implant placement and retention may be compromised in the presence of a disease process or an abnormal condition involving the implant site. These may include retained root fragments, inflammatory processes, fibro-osseous lesions, cysts, neoplasms, dense bone islands, and systemic conditions causing abnormal bone density. In addition, anomalies involving other significant maxillofacial structures, such as maxillary sinuses and TMJs, may interfere with or be exacerbated by implant placement. Due to its high accuracy and precision in portraying bony detail, CBCT can identify or rule out the presence of osseous pathology or abnormality at an implant site (Figure 6.15a to h demonstrates various types of sinus pathology).

Radiation Dose

Radiation dose from CBCT scans varies considerably depending on the scanner used and the imaging protocols selected. With continuing development of technology, radiation doses are steadily declining. Further dose reduction during a scan can be done by limiting the FOV to the area of interest or by reducing the mA (tube current) or scan time. Increasing the voxel size indirectly reduces the radiation dose [27–30]. A careful selection of exposure protocols should be made dependent on patient size, age, and the image quality required. In recent years, the media has highlighted the

Table 6.1 Comparison of effective radiation doses.

Examination	Effective dose
CBCT – small and medium volumes (FOV <10 cm)	11–674 μ Sv (median value: 61 μSv)
CBCT – large volumes (FOV >10 cm)	30–1073 μ Sv (median value: 87 μSv)
Panoramic	9–26 μ Sv
FMX – PSP plates/F-speed film, rectangular collimation	34.6 μ Sv
FMX – PSP plates/F-speed film, round collimation	170.7 μ Sv
FMX – D-speed film, round collimation	388 μ Sv
Medical CT	280–1410 μ Sv
Daily background radiation in US	8 μ Sv

potential danger of radiation exposure from dental imaging. This has served to remind the community that the ALARA (“as low as reasonably achievable”) principle with dose reduction strategies should be applied whenever possible while maintaining diagnostic image quality.

Table 6.1 compares the effective radiation dose from different imaging modalities and background radiation [27–30]. The data in Table 6.1 include some of the higher dose CBCT machines that have now been discontinued. It also does not take into account the variability in CBCT dose introduced due to technique selection. Limiting the FOV and adjusting the scan protocol for patient size and age can significantly reduce the CBCT dose without a considerable effect in the image quality.

Interactive implant treatment planning

The concept of implant placement in the area of maximum bone volume over the last 20 years has been replaced by a prosthetically driven (crown-to-bone) approach of implant placement in order to incorporate the functional, restorative, and esthetic requirements into overall implant diagnosis and treatment planning. Radiographic guides with markers (constructed from a preplanned wax-up of the shape of the final restoration on a diagnostic cast) can be used during scan acquisition to transfer the prosthetic plan to the CBCT scan (Figure 6.3b). The marker aids in accurate

localization of the desired placement position and angulation of an implant on a CBCT scan, and permits assessment of the bone availability and adjacent anatomic boundaries in the area. In this way, the need for bone augmentations or other treatment modifications can be determined pre-surgically in order to allow restoratively optimal implant placement and an accurate emergence profile.

The preliminary step in implant planning on a CBCT scan is *proper scan orientation* so as to create accurate cross-sections in the area of implant placement. This is required so that assessment can be performed perpendicular to the long axis of the planned implant. Cross-sections that are not correctly reformatted can lead to erroneous measurements at the proposed implant site [31]. Accurate implant site evaluation requires that scan orientation be based on the following principles:

- The axial and coronal planes of the scan should be aligned with the patient’s mid-line.
- The sagittal plane of the scan should be oriented such that the occlusal plane of the implant arch is parallel anteroposteriorly to the horizontal axis (axial plane) (Figures 6.27a and b and 6.28a to d).
- The sagittal plane should also be adjusted so that the roots of the adjacent teeth are parallel to the long axis of the implant site and to the coronal plane.
- Cross-sections should be created to be perpendicular to the curve of the arch (Figure 6.29a and b).
- The cross-section in the center of the interdental space, level with the implant trajectory, should be used for measurements.

The use of a radiographic guide during image acquisition facilitates the correct scan orientation and creation of appropriate cross-sections for measurements.

CBCT-reconstructed panoramic images may be distorted since they represent curved 3D anatomy; hence measurements on these may be incorrect. They can, however, be used to cross-reference the location of a cross-sectional image in the mesiodistal dimension (Figure 6.25a and b).

Three-dimensional volume renderings can give misinterpretations of the jaw boundaries and the location of the cortical bone. Improper threshold or brightness settings can cause the false appearance of a periodontal bone defect. 3D renderings can be used as an adjunct to cross-sectional images in order to visualize

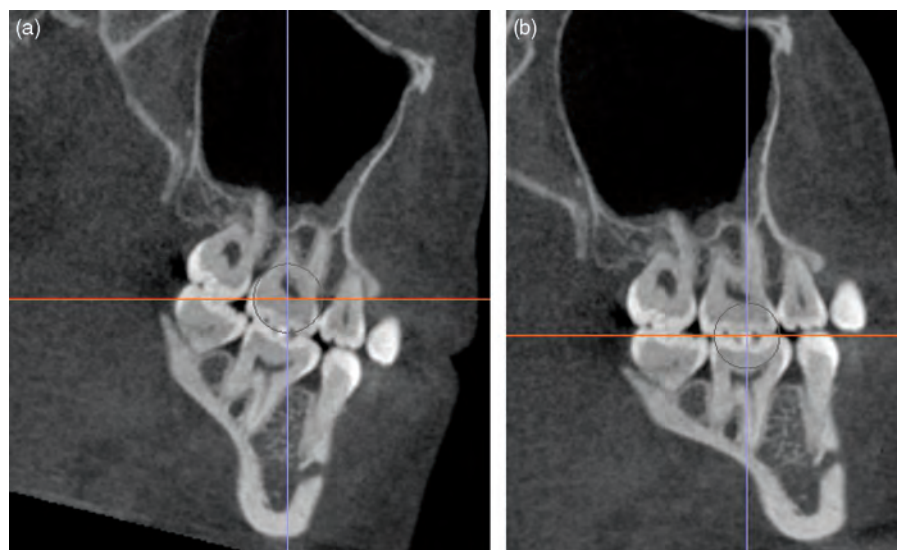


Figure 6.27 Orienting the sagittal tilt on a CBCT scan. (a) Sagittal view showing an incorrect scan orientation due to the sagittal tilt tipped forward (chin down), resulting in an occlusal plane that is not parallel to the horizontal axis. (b) Sagittal view showing the correct scan orientation with the occlusal plane parallel to the horizontal axis.

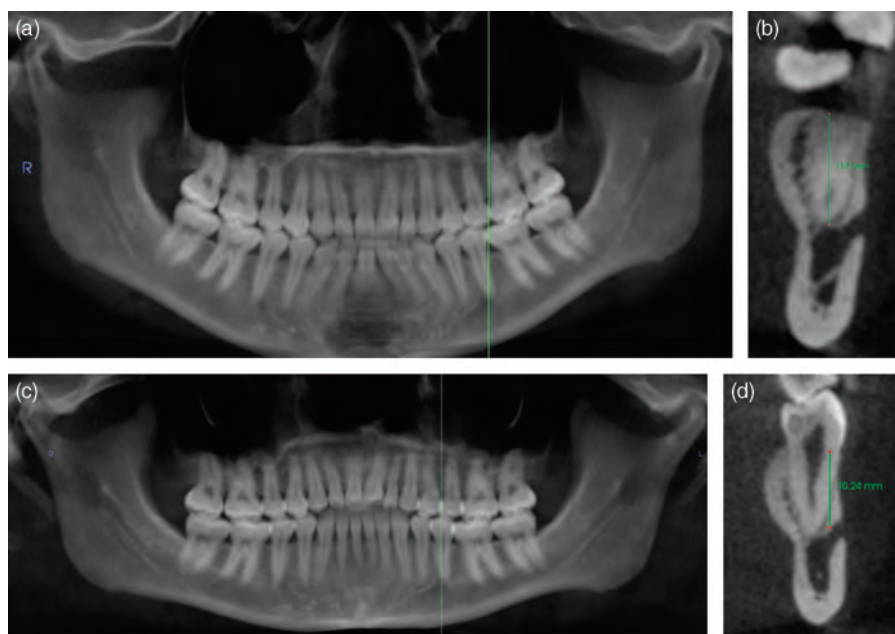


Figure 6.28 (a) CBCT generated panoramic with incorrect sagittal tilt (corresponding to the image in Figure 6.27a) that results in a cross-section in the region of 20 having greater bone height (of 11.71 mm) (b). (c) CBCT generative panoramic with corrected sagittal tilt (corresponding to the image in Figure 6.27b) that results in a cross-section in the region of 20 having the correct bone height (of 10.24 mm) as it cuts in the same trajectory as the long axis of tooth 20 or of an implant that would be planned in the region.

implant trajectories, bone orientation, and the relationship of the planned implant to adjacent anatomic structures (Figure 6.30).

Current implant planning software offers a variety of tools that further aid in implant treatment planning and surgery. Depending on the specific software capabilities, realistic models of implants can be virtually placed along with the corresponding virtual restorations or prosthetics (Figures 6.30 and 6.31). These can be selected from an implant library in the software, which has specifications from popular implant manufacturers, or a generic implant with flexible design parameters may be used. When intraoral optical scans or CBCT scans of stone models are available (to depict the precise locations of crown and soft tissue contours that are often masked in CBCT scans because of metal artifacts), they can be fused with the CBCT scan of the patient to allow for planning of the desired restorative outcome along with the surgical planning (Figure 6.32).

Some software permits bone graft planning along with tools for volume measurement so that the precise location and amount of augmentation material that is required for surgery can be calculated. A ridge reduction-planning tool is provided in some software that can aid in the fabrication of ridge reduction guides, which can be used along with surgical guides during implant surgery. A comparison of pre- and post-operative scans can be done by superimposition capabilities that allow the two scans to be overlaid on top of each other so that surgical changes can be assessed.

Surgical guides

The transfer of the virtual treatment plan on a CBCT software can be facilitated by computer aided manufacture (CAM) surgical guides that can be used at the time of the implant surgery (Figure 6.33a to h). These surgical guides are used with implant-specific

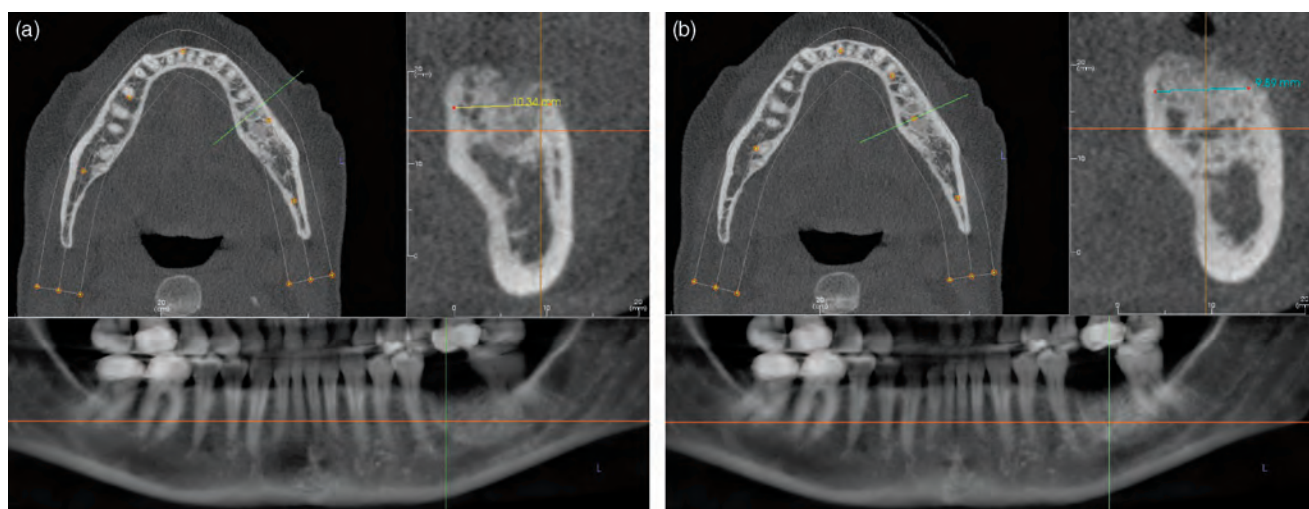


Figure 6.29 Cross-section generated for the bone width measurement should be perpendicular to the dental arch. (a) Incorrectly created focal trough on an axial view can give an impression of greater bone width (of 10.34 mm) than is actually present. (b) CBCT images showing a correctly traced focal trough on an axial image resulting in a cross-section that accurately represents bone width (9.89 mm) at an implant site.

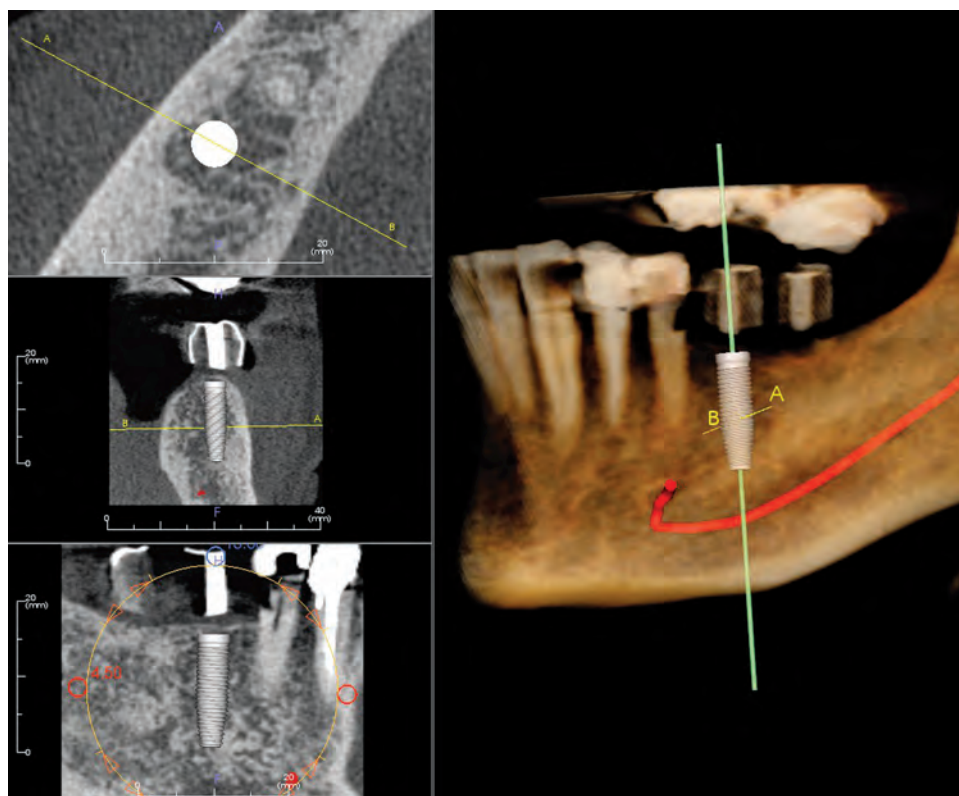


Figure 6.30 CBCT multiplanar reformat showing the trajectory of a planned implant. The 3D reformation is used as an adjunct to sectional images and shows the relationship of the planned implant with the adjacent anatomic structures. The course of the mandibular canal is marked in red; note the presence of an anterior loop of the canal.

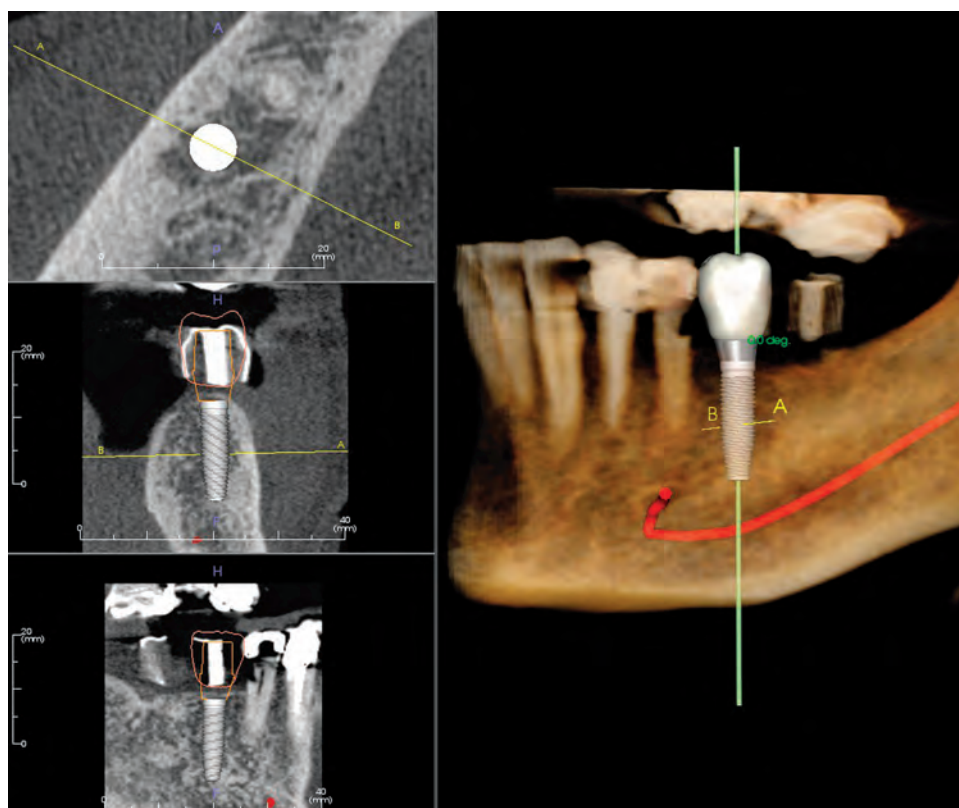


Figure 6.31 Same images as in Figure 6.30 but showing placement of a virtual restoration on the planned implant.



Figure 6.32 Fusion of an intraoral optical scan with the CBCT scan of the same patient.

drilling instruments to place the planned implants in the same position, depth, and angulation as the virtual plan. They allow for accurate and predictable implant placement and can significantly reduce surgical time.

Depending on the type of tissue that provides intraoral stability to a surgical guide, the guides may be:

- **Tooth-borne.** These offer great stability of the surgical guide but are limited to partially edentulous cases. Periodontally compromised mobile teeth may result in an inaccurate guide position (Figure 6.33a to h).
- **Soft tissue-borne.** These are typically used in completely edentulous cases for flapless implant placement. Anchor pins may be used to increase the stability of the guide.
- **Bone-borne.** These are typically used in completely edentulous cases with full thickness tissue flaps. Bone modeling for surgical guide fabrication is not a precise technique and therefore these guides may not provide an accurate fit during surgery. Anchor pins may be used to increase the stability of the guide.
- **Combination tooth–bone-borne.** These allow for a portion of the guide to rest on teeth and another portion to rest on the bone above the surgical site with a flap.

Based on the system selected, surgical guides can provide control of the pilot drill, drill sequence, and/or depth control. Certain implant manufacturers require specific protocols and radiographic guides for surgical guide fabrication. Accuracy of the surgical guide fit may be compromised in the presence of patient movement and metallic artifacts. Use of intraoral optical scans or a CBCT of the stone model that is fused with a patient's CBCT scan enables creation of a surgical guide with better accuracy. The guide fit may also be compromised if a change in intraoral tissues (such as extractions, new restorations or displacement of adjacent teeth) occurs between the scan capture and surgery.

Implant analogs for pre-made provisional restorations can be used to guide the placement of a restoration with surgical guides.

Navigation surgery

Navigation surgery offers the opportunity to achieve the planned implant placement simply, efficiently, effectively, with cost control, and with a reduced time cycle between planning and surgery. There are several surgical navigation schemas allowing surgical control of osteotomy position, angle, and depth (Figure 6.34).

In general, the navigation process begins with a CBCT scan acquired with a fiducial marker in place, followed by implant planning of one or more implant sites (Figure 6.35). The plan informs the computer of the proposed implant length, angle, and position and as a result the computer can now be used to guide the surgery. The surgical procedure begins with re-securing the fiducial markers in the mouth and then calibrating the surgical headpiece into the surgical field, thus achieving 3D localization of the bur tip and shaft orientation (Figure 6.36). Using computer vision (close range stereophotogrammetry) the position of the handpiece can be tracked during surgery in real time with 6 degrees of freedom (x, y, z , yaw, pitch, and roll) (Figure 6.37). The surgeon can view the simulated position of the hand on a computer monitor that is simultaneously showing the CBCT volume and proposed plan (Figure 6.38). There is feedback incorporated into the display

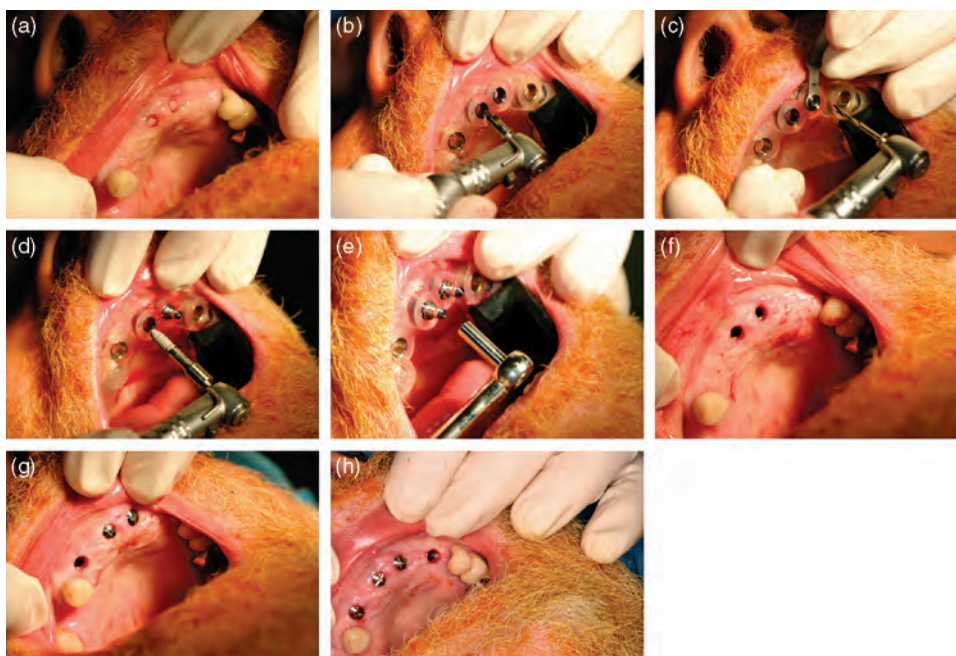


Figure 6.33 (a–h) Clinical intraoperative photographs of a surgical guide. The surgical guide transfers the virtual implant planning performed on a CBCT scan and is worn by the patient during surgery.



Figure 6.34 The X-Guide Machine tracks the handpiece in real time during surgery with 6 degrees of freedom (x, y, z, yaw, pitch, and roll) and provides a real time, 360 degree view of the simulated implant position, drill movements, and anatomy on a single display. Supplied by X-Nav Technologies, LLC, 1555 Bustard Road, Suite 75, Lansdale, PA 19446, USA.



Figure 6.36 Registration of the drill to the X-Guide system to enable real time tracking.

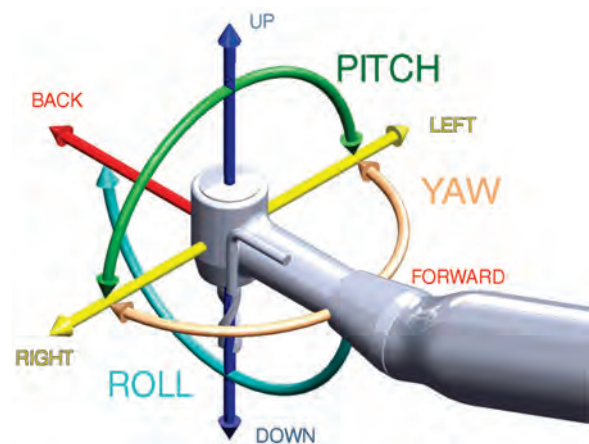


Figure 6.37 Graphic illustrating the dimensions of drill bit control with 6 degrees of freedom (x, y, z, yaw, pitch, and roll).

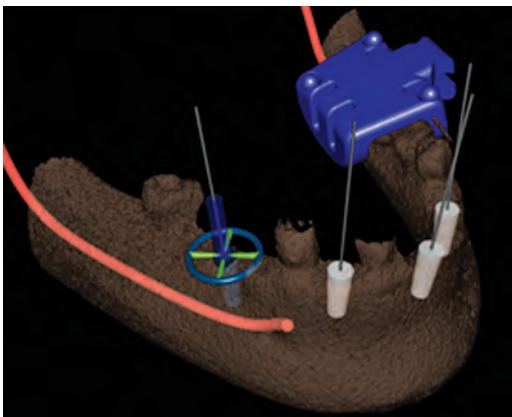


Figure 6.35 Shows virtual plan on the CBCT scan. The mandibular canal is marked for visualization. X-Point in the right mandibular bicuspid region is the target point for placing the drill bit. An X-clip is fastened to the dental arch and is used to calibrate the clinical scene.

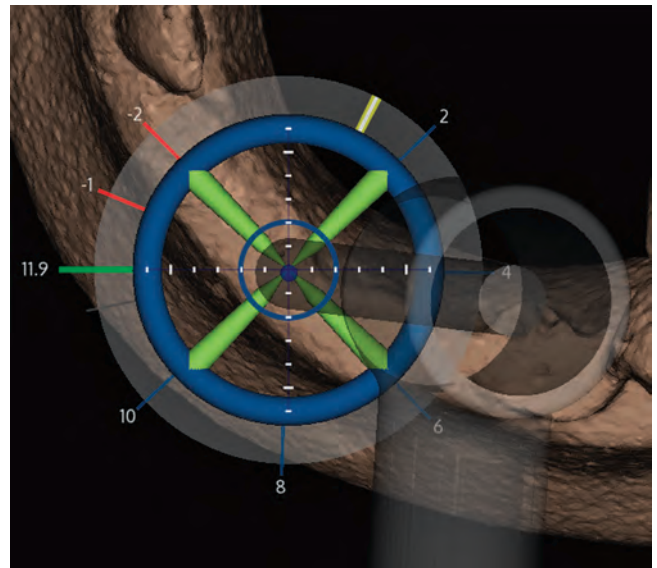


Figure 6.38 Tracking system indicates that the drill bit tip is correctly placed on the target point. The partially transparent image of the headpiece attitude in space reminds the clinician to align it.

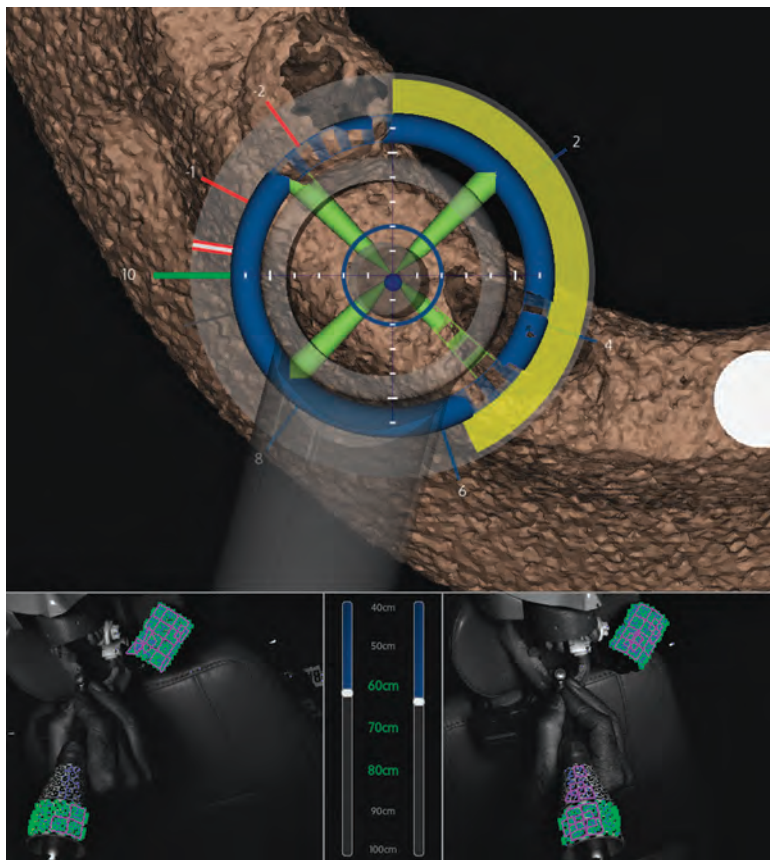


Figure 6.39 Shows the hand piece properly aligned. The yellow arch is depth control tracking, indicating that nearly 6 mm of drill depth has been completed. The images at the bottom of Figure 6.39 are stereo views of the headpiece in the surgical field along with tracking targets on the headpiece and in the mouth.

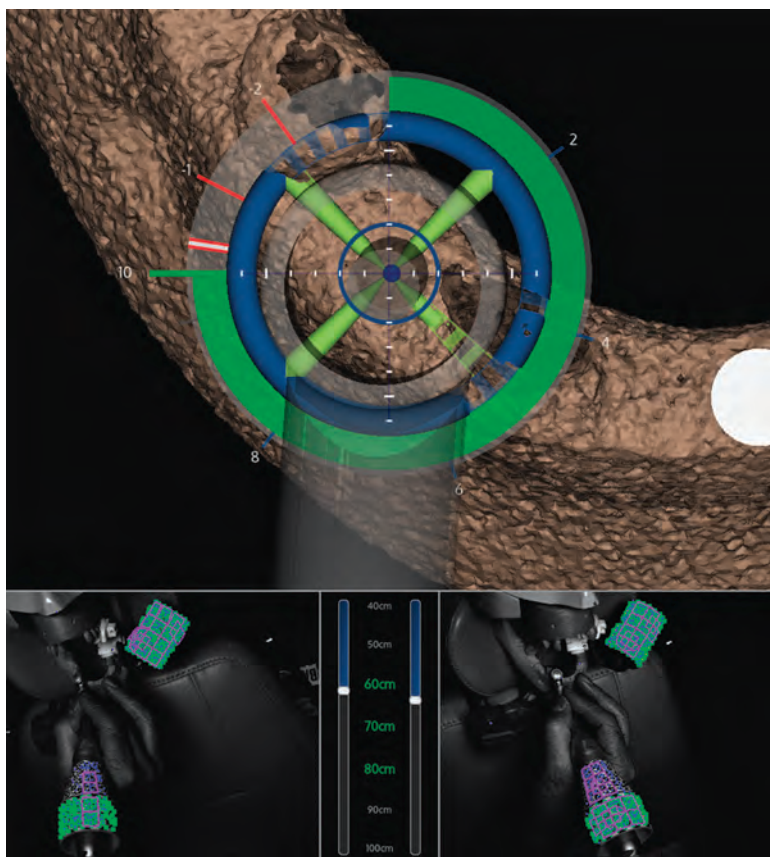


Figure 6.40 Same as Figure 6.39 but the green ring indicates that the drill bit tip has reached the planned depth.

software to inform the surgeon in real time of the position, angle, and depth of the bur relative to the plan (Figures 6.39 and 6.40).

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Classification of Alveolar Ridge Defects in Implant Dentistry

Patrick Palacci

Brånemark Osseointegration Center, Marseille, France

Introduction

In 1985, Lekholm and Zarb [1] presented a classification of the jawbone based on shape and quality to be used to analyze implant anchorage. They described five groups of mandibular and maxillary cross-sectional shapes (Figure 7.1):

- A. Most of the alveolar ridge is present.
- B. Moderate residual ridge resorption has occurred.
- C. Advanced residual ridge resorption has occurred (only basal bone remains).
- D. Some resorption of the basal bone has started.
- E. Extreme resorption of the basal bone has occurred.

The authors also described four groups of bone quality:

- 1 Almost the entire jawbone is composed of homogenous compact bone.
- 2 A thick layer of cortical bone surrounds dense trabecular bone.
- 3 A thin layer of cortical bone surrounds a core of dense trabecular bone.
- 4 A thin layer of cortical bone surrounds a core of low-density trabecular bone.

In addition to this classification, the thickness of the ridge mucosa also has to be considered. The classification of Lekholm and Zarb [1] helps to clarify the relationship between the surgical techniques to be used and jaw bone shape and quality. This classification determines the position and number of implants to be placed, as well as the need for additional surgeries in order to optimize implants positioning.

For example, in the presence of a Class A group an implant can be placed slightly forward while additive surgery is needed in order to be able to optimally place an implant in a Class D case.

Concerning bone quality, the surgeon has to focus on initial stability and needs to avoid any excess heat during drilling and implant insertion. This is why under or over preparation and the use of different implant diameters are considered.

According to Seibert [2,3], ridge defects in edentulous regions can be divided into three classes (Figure 7.2):

- 1 Class I: loss of tissue in the buccolingual direction with normal height in the apical-coronal direction.
- 2 Class II: loss of the tissue in the apical-coronal direction, with normal width in the buccolingual direction.

- 3 Class III: a combination of Class I and Class II (loss of both height and width).

In the anterior maxilla, the position of the lip line (high or low), as well as the lip mobility, has to be considered. The architecture of the lip line, in combination with the mobility of the lip, determines the need for additional surgical procedures for an optimal aesthetic outcome [4].

Implant treatment becomes more challenging in the presence of a high lip line and significant lip mobility.

Implant position, shape, color, texture of the soft tissue (the presence or absence of interdental papillae), and quality of the final prosthetic restoration are of a great importance for the overall final result.

The interdental papilla is the part of the periodontal soft tissue between crowns of two teeth (Figure 7.3). The contact relationship between the teeth, the width of the proximal tooth surfaces, and the course of the CEJs define papilla's shape. Thus, in the anterior regions of the dentition, the interdental papilla assumes a pyramidal or conical shape.

Two major types of gingival architecture have been described in the literature (for example, Olsson and Lindhe, 1991 [5]; Olsson et al., 1993 [6]; and Seibert and Lindhe, 1997 [2]), namely the "scalloped-thin" and the "flat-thick" gingival architecture (Figure 7.4a and b, respectively). The gingival architecture is determined by many genetic and local factors, including the anatomy of the teeth and position and size of the contact surfaces of the teeth.

Palacci-Ericsson classification of the alveolar ridge

The use of a classification of the overall shape of the anterior maxilla (including the soft tissues) will help the practitioner to evaluate the anatomical conditions in implant treatment. This classification of the alveolar ridge is based on the amount of vertical and horizontal loss of soft tissue, hard tissue, or both, and can also be applied to other parts of the jaws. It is divided into four classes according to the vertical dimension and into four classes according to the horizontal dimension [7–9].

Based on *vertical* loss, Class I has intact or slightly reduced papillae (Figure 7.5). Class II has limited loss of the papillae

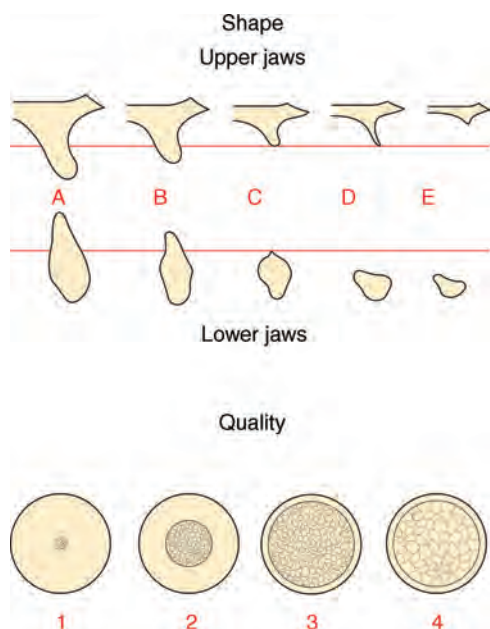


Figure 7.1 Bone shape and bone quality classification according to Lekholm and Zarb (1985) [1].

(Figure 7.6). Class III has severe loss of the papillae (Figure 7.7), and Class IV represents absence of the papillae (Figure 7.8).

Based on *horizontal* loss, Class A shows intact or slightly reduced buccal tissue (Figure 7.9). Class B has limited loss of buccal tissue (Figure 7.10). Class C has severe loss of buccal tissue (Figure 7.11). Finally, Class D has extreme loss of buccal tissue, often in combination with a limited amount of attached mucosa (Figure 7.12). Of course, many combinations of the different classes occur, and each patient must be viewed as unique.

A good final outcome depends on the clinician's understanding of the complexity of the overall treatment. The anterior maxilla classification should be used to document the anatomical condition before treatment and will guide the clinician in choosing proper treatment options to reach the expected final result. Some treatments (for example, Class IA) normally require only proper implant placement and minimal soft tissue handling.

In a Class IA case, we are in the presence of intact and healthy papillae and an intact ridge. The keys to success in implant therapy are:

- optimal implant positioning,
- minimal invasive surgery,

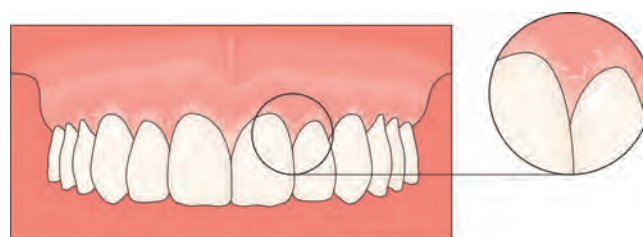


Figure 7.3 The interdental papilla.

- respect of the per-implant soft tissue,
- no additive surgeries are needed

Class IA cases are rare; most of the time hard and soft tissue resorption follows teeth extraction and after a few weeks we are more likely to be in presence of a Class IIB, where hard and soft tissues surgeries are needed.

However, in the presence of a simultaneous extraction and implant placement we can consider being in presence of a Class IA, where:

- atraumatic extraction of the teeth,
 - ridge preservation technique,
 - optimal positioning of the implants,
 - additive soft tissue procedures (connective tissue grafts),
 - optimal temporary restoration,
 - optimal emergence profile respecting the blood supply,
 - careful control of occlusal forces.
- are all needed for the success of the case.

Case 1: Figures 7.13 to 7.18

A fifty-seven years old female presents with an advanced periodontal disease with severe hard and soft tissue loss, more precisely in the anterior maxilla. There is a need for aesthetic and if possible an immediate temporary fixed restoration [10].

Four anterior incisors are carefully extracted using a periosteal elevator trying to avoid any ridge fracture or alteration. Three implants are inserted and the site of the upper left central incisor filled with biomaterial and connective tissue graft in order to preserve ridge volume [11,12].

Voids between implants and alveolas are also filled with biomaterial in order to minimize the risk for bone resorption and maintain soft tissue volume as well as overall aesthetics of the case [13].

A reinforced temporary restoration is then placed (screw retained) with sufficient embrasures to maintain a soft tissue blood supply between the implants and papillae. Final restoration is in place four months later, allowing optimal hygiene maintenance

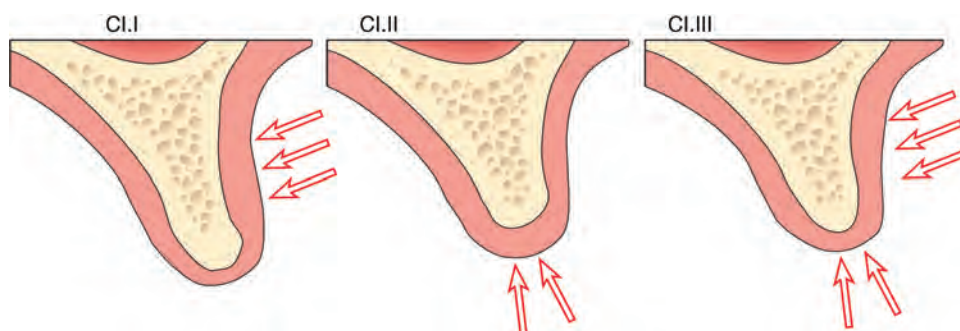


Figure 7.2 Ridge defect classification according to Seibert (1983) [3].

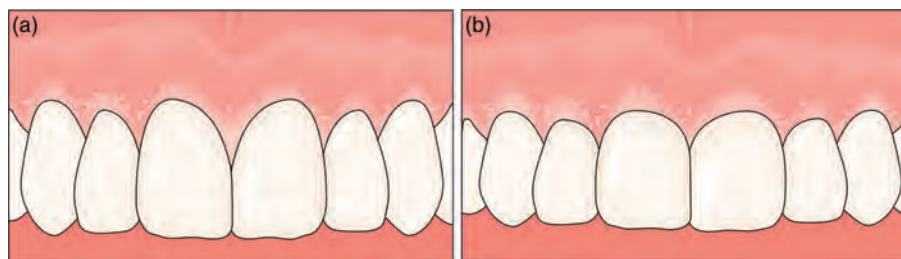


Figure 7.4 (a) “Scalloped-thin” gingival architecture. (b) “Flat-thick” gingival architecture.



Figure 7.5 Class I.



Figure 7.6 Class II.



Figure 7.7 Class III.

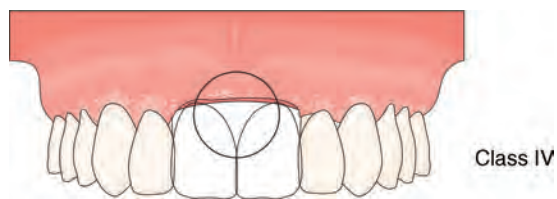


Figure 7.8 Class IV.

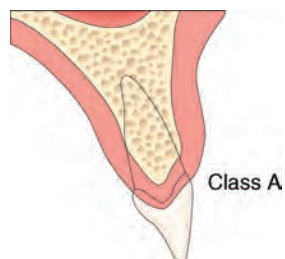


Figure 7.9 Class A.

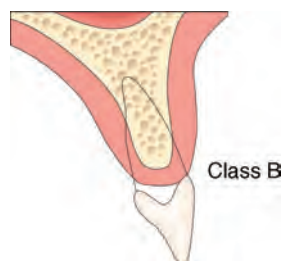


Figure 7.10 Class B.

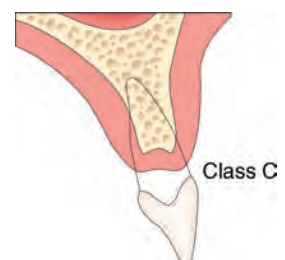


Figure 7.11 Class C.

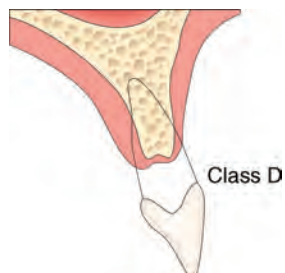


Figure 7.12 Class D.

and aesthetics. Occlusion, extremely important, has to be carefully checked in order to maintain long-term osseointegration.

Acceptable results in Class IV, in contrast, may require additional hard and soft tissue surgical procedures prior to, at the time of, or after implant placement.



Figure 7.13 High lip line, high lip mobility, and high aesthetic expectations are the main characteristics of this case. Note the soft tissue loss following the periodontal disease.

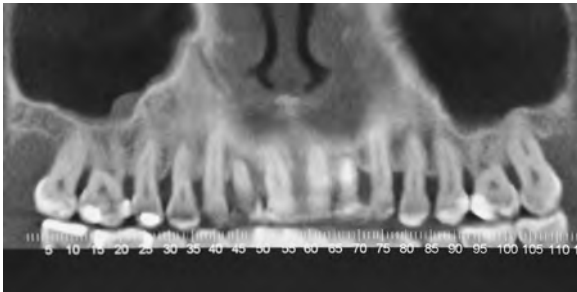


Figure 7.14 Radiographic examination. Note the significant hard tissue loss around the incisors.



Figure 7.15 Flapless surgery performed in order to minimize tissue trauma. Site preservation technique combined with biomaterial filling and a connective tissue graft in the upper left central incisor region.



Figure 7.16 Temporary restoration in place. Note the presence of papillae two weeks post-op and the emergence profile emerging directly from the implants.

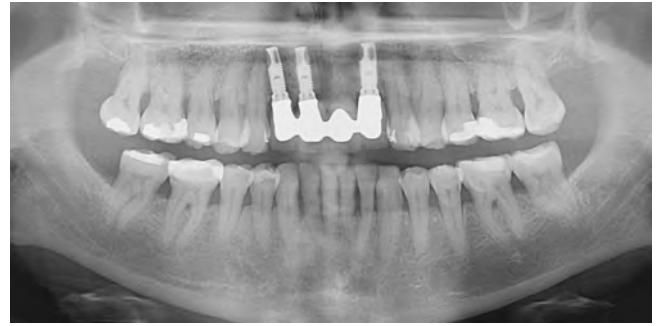


Figure 7.17 Radiographic examination of the final case.



Figure 7.18 Clinical results after six years. Note the stability of the tissues.

Case 2: Figures 7.19 to 7.27

A forty-five years old man presents with a fractured upper right central incisor root resulting in an acute abscess and significant bone loss. The extraction of the root results in a ridge loss associated with the loss of the existing papillae [14,15].

An autogenous bone graft (harvested from the chin) is performed as well as a connective tissue graft placed into the internal side of the flap at the time of implant installation in order to get enough soft tissue to be manipulated (papillae regeneration technique – Palacci) [6–10] at the time of abutment placement [16,17]. A ceramic crown is then placed on a zirconia abutment in order to achieve a reliable aesthetic result.

This case, which could be presented as a Class IA before extraction, became a Class IIIC after extraction and bone resorption. It is almost impossible to jump from Class IIIC to Class IA in one step. Bone ridge has to be augmented first in order to go from Class IIIC to Class IIB; then with placement of an implant one can go from Class IIB to Class IA by soft tissue augmentation.

The benefits need to be noticed of, for example, a 2 mm gain by bone addition, and/or a 2 mm gain by soft tissue manipulation, and/or a 1–2 mm gain by crown lengthening of the adjacent teeth that makes a 5–6 mm gain of tissue that can make a significant difference.

This difference is extremely important in the aesthetic zone, being a key factor for the final aesthetic result.

No scientific evidence for the absolute need for attached mucosa from a functional or survival point of view has been presented (Wennström et al., 1994 [18]). However, from an esthetic and oral hygiene point of view, an adequate zone of attached peri-implant mucosa is preferable.

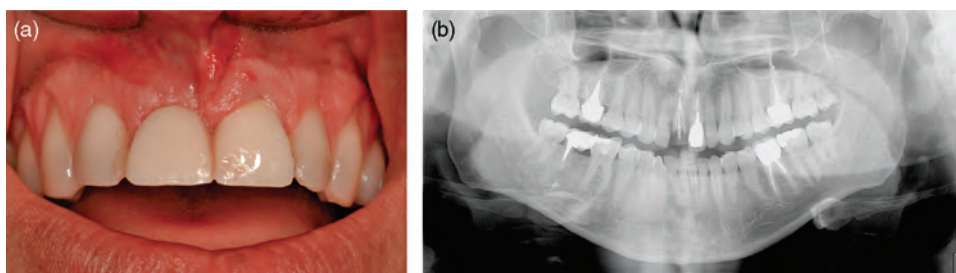


Figure 7.19 Upper right central incisor extracted. Radiographic examination showing fracture of the root.



Figure 7.20 Result of the extraction. Loss of the ridge and papillae.

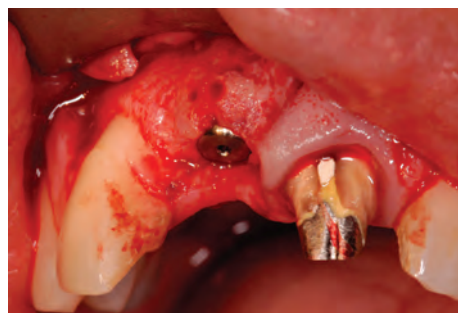


Figure 7.23 Optimal positioning of the implant.



Figure 7.21 Clinical situation. Loss of the labial plate of bone and need for ridge augmentation.

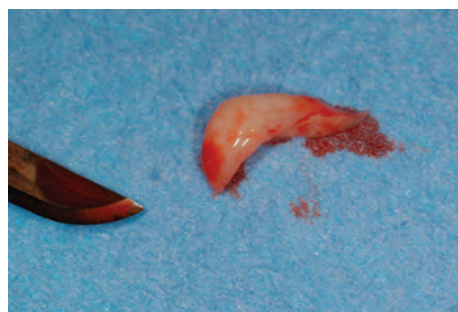


Figure 7.24 A connective tissue (CT) graft is harvested from the tuberosity region and then situated into the desired position.



Figure 7.22 An autogenous bone graft is placed, recreating the initial anatomy.

Thus, the final aesthetic and functional outcome is related to three main factors: the jawbone, the soft tissue, and the design of the prosthetic reconstruction. The replacement of missing teeth is only one part of the treatment, especially in the anterior maxilla. Another part is the replacement of the lost portion of the alveolar process, the

covering soft tissue, or both. The re-creation of a normal alveolar contour is an important key to aesthetic success.

Understanding the anterior maxilla classification will guide the clinician to find adequate solutions to obtain consistent and predictable treatment results from a functional and aesthetic point of view.

Precision in implant placement

A straightforward implant placement can be performed without any additional surgery. However, at the time of implant placement, minor hard tissue augmentation may be needed to add support to the peri-implant mucosa. In other situations, soft tissue must be added to enhance the final result and thus facilitate soft tissue maintenance [19,20].

Both hard and soft tissues must be considered when planning optimal placement of the implants as well as reconstruction of the new papillae. All the different elements have to be perfectly correlated in order to achieve final success [21]:

- hard tissue management,
- soft tissue management,

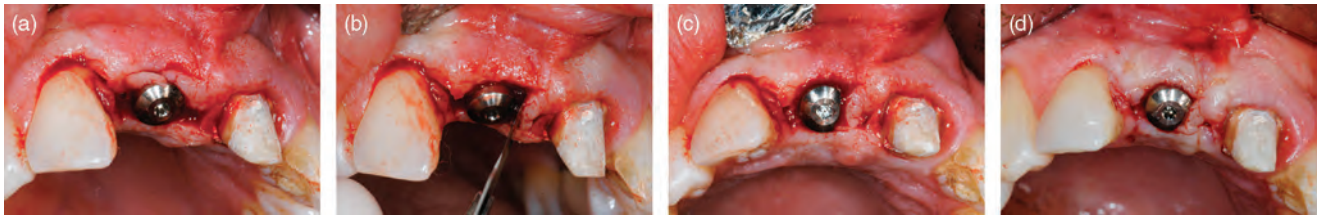


Figure 7.25 (a) Pedicle grafts, papillae regeneration technique (Palacci) allowing the recreation of the lost papillae: pedicle flaps are created on the buccal side of the placed implant and the healing abutment and the blood supply is preserved at the base of both flaps from the intact adjacent gingiva. (b) Distal pedicle flap is flipped to re-create the papilla. (c) Mesial pedicle flap is flipped to form the papilla. (d) Resorbable sutures are placed to secure buccal tissue to the palatal.



Figure 7.26 Temporary restoration is placed.

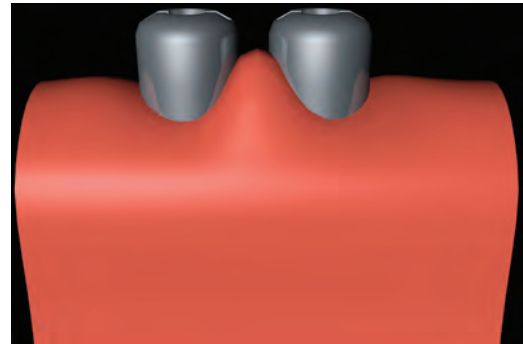


Figure 7.28 Optimal placement between two implants: 7–8 mm from center to center, 2–3 mm from edge to edge of the abutments. The papilla can be present and stable.



Figure 7.27 Final restoration seven years later: (a) intraoral photograph showing the re-created papillae; (b) extraoral frontal photograph of a patient with a high lip line, showing the re-created papillae as well as the final aesthetic outcome.

- the quality of the prosthetic restoration,
- aesthetic factors.

In addition to all of these emerges the vital concept of precision in implant positioning:

- If the angulation of implants in mesiodistal and buccal-lingual (palatal) directions are optimal, soft tissues will find a way to live, develop, and proliferate between the future prosthetic elements (Figure 7.28).
- The space between two implants must be adequate (7 mm between centers of two implants, 2 mm minimum between two abutments).
- If the implants are too close, no surgical technique will allow the papillae to prosper between the implants. It is obvious that less than 2 mm between abutments will never be enough to ensure sufficient blood supply vertically, meaning that the maximum papilla height will not exceed 2–3 mm above the bone level (Figure 7.29).
- However, if the implants are too far from each other, no papilla will grow between them (Figure 7.30).

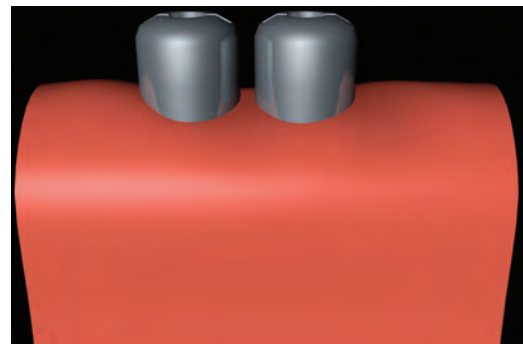


Figure 7.29 Not enough space between two implants: insufficient blood supply resulting in the loss of the papilla as well as hard tissue.

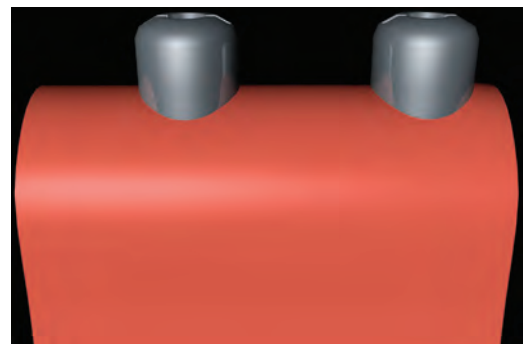


Figure 7.30 More than 4 mm between abutments: no support for the papilla, which will become flat.

- In a similar way, if an implant is placed buccally, a very thin ridge will remain beneath the soft tissues. Knowing that the maximum stress is located at the base of the implant, a labial plate that is too thin may not support the stress, resulting in recession and consequently the loss of the adjacent papillae.

Two implants that are placed in an overly pronounced angulation (one towards the other) will also result in:

- Two convergent crowns and the impossibility for soft tissue to develop between these crowns (Figure 7.31).
- Two divergent crowns with insufficient support for the papillae (Figure 7.32).

In order to understand treatment objectives and the way to achieve them, one should be able to evaluate the clinical situation at the very start of the treatment.

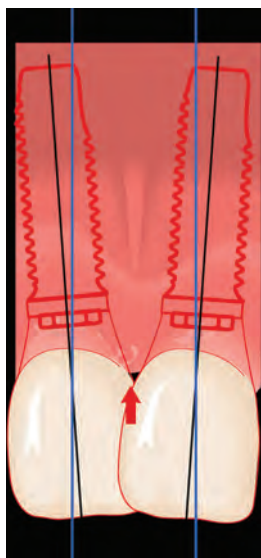


Figure 7.31 If implants are too convergent, the emergence profile will be altered and the papilla is compromised.

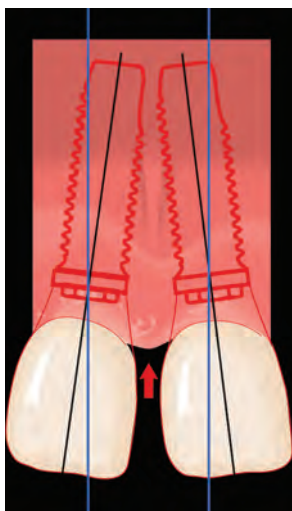


Figure 7.32 Too divergent implants will result in a large embrasure and consequently the loss of the interdental papilla.

Class IVD

In this situation the main objective is to place implants into the residual bone with or without hard tissue augmentation. We know that, in most of cases, “restitutio ad integrum” will be extremely difficult to be obtained, maybe impossible.

Papillae need hard tissue support to exist and vertical ridge augmentation is one of the most challenging treatment options. A patient should be informed prior to any treatment of the objectives to be reached. Sometimes, it is wise to tell the patient that the best way in this case to obtain an optimal final result is to include prosthetic (acrylic or porcelain) papillae into the prosthetic restoration. The patient, understanding the challenges of problems to be solved, can accept the compromise more easily knowing that without this kind of prosthetic solution he/she will end up with long teeth and black triangles between them. (Figures 7.33 to 7.39).

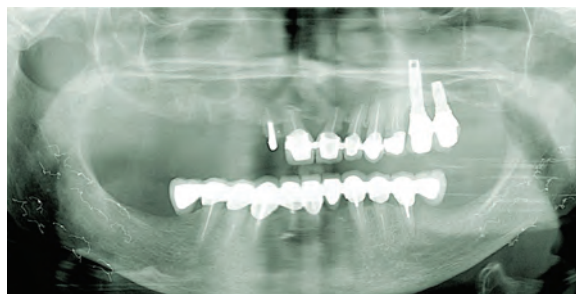


Figure 7.33 Radiographic examination of the edentulous upper ridge area, failing upper incisor, canine and premolars to be extracted, perfectly integrated implants placed several years prior.



Figure 7.34 Clinical view of the Class IVD in the upper right region seems to be a Class IIIC but bone loss is such that it will become immediately a Class IVD after extraction of these teeth.

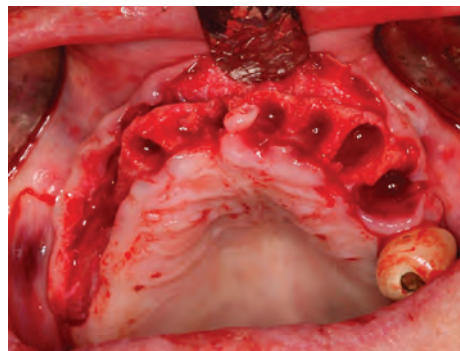


Figure 7.35 Extraction of the interior teeth and preparation of the implant site.

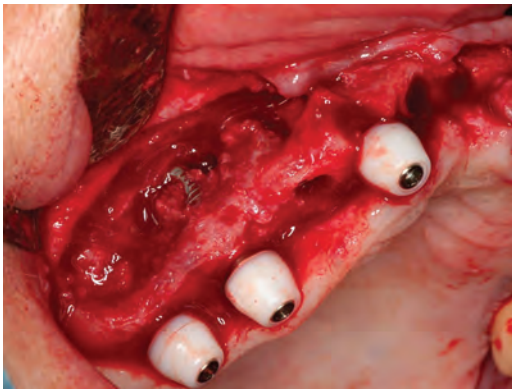


Figure 7.36 Sinus elevation plus implant placement.

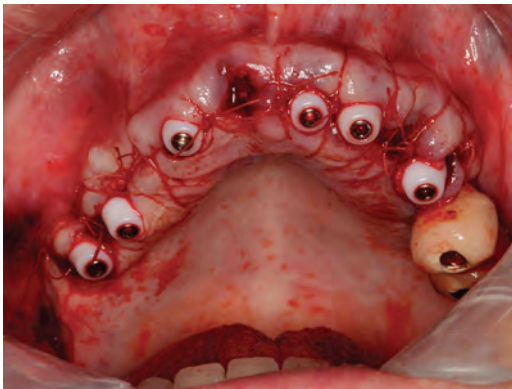


Figure 7.37 Implants are placed, abutments into position.



Figure 7.38 Panoramic radiograph of the case.

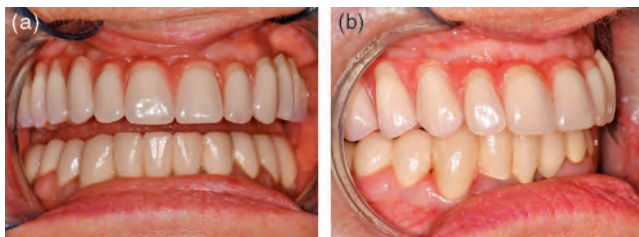


Figure 7.39 (a) Intraoral frontal photograph and (b) intraoral lateral photograph. Note the presence of acrylic (artificial) gingiva included in the restoration to solve functional, esthetic, phonetic, and comfort problems.

Table 7.1 Palacci and Ericsson classification.

Vertical loss		Horizontal loss	
Class I	Intact and healthy papillae	Class A	Intact/slightly reduced buccal tissue
Class II	Limited loss of the papillae less than 50% loss	Class B	Limited loss of the buccal tissue
Class III	Severe loss of the papillae more than 50% loss	Class C	Severe loss of the buccal tissue
Class IV	Absence of papillae (edentulous areas)	Class D	Extensive loss of buccal tissue associated with limited amount of attached mucosa

Discussion

For decades, implant treatment was used to treat edentulous patients where esthetics was not the main goal. Function was recreated by placing fixed anchor bridges with a metallic framework and acrylic teeth mounted on to pink acrylic. The esthetic needs became more obvious with time and after many esthetic failures.

The above-mentioned classification, shown in Table 7.1, gives the clinician the initial diagnostic guideline and also a recommendation for the different treatment sequences needed.

Conclusion

A careful evaluation of the clinical situation has to be done before any implant treatment. The presented classification will help the practitioner to evaluate this situation more precisely in the anterior maxilla or other parts of the jaws and can be a useful guide for the overall treatment with respect to the biological parameters.

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CHAPTER 8

Alveolar Ridge Augmentation: An Algorithmic Approach

Alan S. Herford, Katina Nguyen, and Ayleen Rojhani

Oral and Maxillofacial Surgery Department, Loma Linda University, Loma Linda, California, USA

Introduction

Loss of teeth is associated with a significant change in the alveolar bone, leading to bone remodeling and loss of bone volume. The most significant change occurs during the first three months following tooth extraction and can continue over time with an additional loss of 11% of volumetric bone over time [1]. A study by Ashman showed that there is an average loss of 40% to 60% of the total bone height and width within the first two to three years [2]. The greatest bone resorption occurs in the horizontal plane, which leads to considerable loss of alveolar width. Patients who desire restoration of their dentition with implants and implant supported prostheses who lack adequate bone may be candidates for bone augmentation procedures. There are a variety of successful techniques that can regenerate new bone such as: guided bone regeneration, the osteoperiosteal split ridge technique, distraction osteogenesis, and block grafting. Aghaloo and Moy [3] performed a systemic review to determine which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement. They found that maxillary sinus augmentations have long-term success rates, regardless of the type of graft material used, whereas alveolar augmentation techniques may be more technique sensitive and implant survival may be a function of residual bone supporting the implant rather than the grafted bone.

Important characteristics of the defect include the location, geometry, and size of the defect. This information is helpful in determining the preferred technique as well as the location for graft harvest depending on the quantity of graft material needed. Many of these defects have both a hard and soft tissue deficit. It is important to consider the implications of bone augmentation on the surrounding soft tissue, as it may create a defect that affects esthetics.

Patient selection and preparation

The decision to graft is prosthetically driven. It is important to determine what the patient's current condition is and decide on the feasibility of various treatments. The treatment plan should consider whether the patient desires a fixed implant restoration or rather an overdenture fabrication. This has direct consequences on how much bone is required as well as how much interarch space is

required for the prosthesis. The prosthetic plan must be in place prior to alveolar grafting.

The most significant complication associated with bone augmentation procedures is infection, which may lead to delayed healing and possibly rejection of the graft or inadequate bone formation. An important factor in selecting patients to undergo this procedure is to make sure that they have excellent oral hygiene, with an attempt at reducing the bacterial load within the oral cavity prior to grafting. Patients should be instructed to avoid tobacco use and any systemic diseases should be well controlled. Patients should also be informed that continued smoking as well as any poorly controlled systemic diseases that are associated with poor wound healing are risk factors that are associated with an increased incidence of complications.

In the evaluation of the patient, a step-wise clinical exam noting the location of the defect as well as the type of defect is necessary to determine the preferred technique and graft material to ensure the best possible outcome [4]. The size of the defect can vary from a localized minimal defect to a more generalized complex defect. Patient stone models and computer guided 3D models may be helpful in the pre-operative planning of the graft and implant placement. Radiographic images using cone-beam CT (CBCT) radiographs for complex defects are often useful in determining the volumetric amount of bone available and missing and what bone augmentation technique will be needed.

The soft tissue should also be evaluated for amount and thickness of keratinized tissue and presence of scar tissue. It may be preferable to correct soft tissue problems prior to grafting if the soft tissue deficit is severe and there is minimal soft tissue to provide coverage for the bone graft.

Types of defects

Defects requiring alveolar augmentation can be categorized based on their characteristics. This will in turn aid in the selection of a technique that has the highest predictability for success. Alveolar defects can present in various shapes and sizes. Defects may be narrow (horizontal deficit) or be deficient in height (vertical). Some patients will present with different types of defects present in the same jaw and treatment should be individualized for each defect (Figure 8.1). Defects that have walls around them generally respond

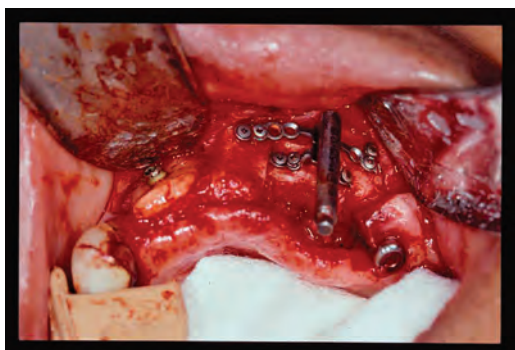


Figure 8.1 Showing two separate techniques. Pictures showing different defects in a patient: vertical that is being corrected with the distraction osteogenesis technique (on the right side of the photograph) and horizontal, with an onlay block graft (on the left side).

better to grafting than those that are not contained. The teeth adjacent to the defect should also be evaluated to determine if there is bone loss with exposed root surfaces. It is difficult to predictably regain bone height adjacent to exposed root surfaces of teeth. In some patients it is better to remove the adjacent tooth in order to more predictably graft the area.

The alveolar defect may be present in the maxilla or the mandible (Figures 8.2 and 8.3). The maxilla has less dense bone than the mandible. The bone can also be classified based on the quality of bone (types 1 to 4) [5].

Maxillary alveolar defects can be categorized as being anterior or posterior. In the maxilla the anterior esthetic zone may require augmentation in an anterior and vertical direction because of the pattern of resorption resulting in a Class III relationship with the lower jaw. The posterior maxilla resorbs in a pattern that narrows the maxilla so augmentation will often require lateral augmentation. The position of the maxillary sinuses is another consideration involving the posterior maxilla. The vertical position of the maxilla should be evaluated and a severely resorbed maxilla (severe generalized alveolar resorption) may benefit from inferior and anterior movement (Le Fort I) of the maxillary alveolar process in order to create a better (Class I) maxillomandibular relationship with the lower jaw (Figures 8.4 and 8.5).

The mandible has unique anatomical characteristics that are important to consider when choosing a type of grafting procedure. The defects are categorized as being anterior (between the mental foramen) or posterior to the mental foramen. For posterior deficits, the amount of alveolar resorption and position of the inferior alveolar nerve are important determinants for the type of reconstructive technique. An important question to ask is “How much bone is above the nerve?” If there is only a few millimeters above the nerve then techniques such as a “tunneling” procedure to place a graft just above the residual alveolar ridge may be an option as well as consideration of a guided bone regeneration type of procedure. Care should be undertaken to avoid placing screws that could possibly damage the nerve. Techniques such as block grafts or osteotomies (i.e. distraction, sandwich technique) should be avoided for those cases where the nerve is very close to the crest of the ridge. There are more options for anterior defects because these defects lie between the mental foramen.

Types of procedures

1. Guided bone regeneration

Guided bone regeneration (GBR) is one of the best-documented and widely used procedures for augmenting localized alveolar ridge defects. GBR techniques utilize a particulate graft with an overlying membrane that promotes stabilization of the graft material and protects the healing graft from competing with non-osteogenic cells, like fibroblasts and epithelial cells (Figure 8.6). The membrane may be resorbable or non-resorbable. For horizontal bone augmentations, the use of membranes combined with particulate autogenous bone has led to increased thickness of the alveolar ridge [6,7]. Vertical augmentations are more technique sensitive and less predictable and for larger, more complex alveolar defects, onlay grafting is likely to be more predictable [8,9]. GBR with titanium mesh can also be used for localized ridge augmentation [10] (Figures 8.7 and 8.8).

Advantages

The use of either a resorbable or non-resorbable membrane helps prevent the migration of non-osteogenic cells into the graft site, so there is more predictable bone formation. The GBR technique is well documented in the literature and reports a high success rate of 93% in a 12.5-year follow-up study after implant placement [11].

Disadvantages

Instability of the membrane may cause delayed healing and formation of fibrous tissue rather than bone due to the lack of conversion of mesenchymal cells into osteogenic cells.

Collapse of the membrane will lead to inadequate bone formation and possibly fibrous growth. It is necessary to maintain adequate space under the membrane to allow migration of cells and the ingrowth of new blood vessels. Large defects may require support with particulate bone and possibly titanium mesh.

Guided bone regeneration is a well-documented technique that has been in use by surgeons for over two decades and has predictable outcomes. Current research is focused on improving available biocompatible resorbable membranes that can meet the ever-increasing demands of esthetics and the ability to create and enhance alveolar bone.

2. Osteoperiosteal flap ridge-split procedure

The osteoperiosteal flap ridge-split technique is performed for horizontal augmentation of narrow ridges that otherwise would not be suitable for implant placement. This technique consists of splitting the facial or buccal cortical plate from the lingual or palatal and further opening the space with osteotomies [12–14]. This technique may be done anywhere in the mouth, but it is recommended for use in the esthetic zone and posterior mandible. The osteoperiosteal flap ridge-split technique has had a success rate of 98% to 100% according to some studies [15].

Advantages

Fewer disturbances to the osteogenic periosteum allows greater resistance to resorption and remodeling of the grafted site. A major advantage is access to the endosteal marrow, which provides a rich vascular network for acceptance of the new graft. There is improved continuity of the crestal gingivoalveolar form, which is a great advantage when used in esthetic areas.

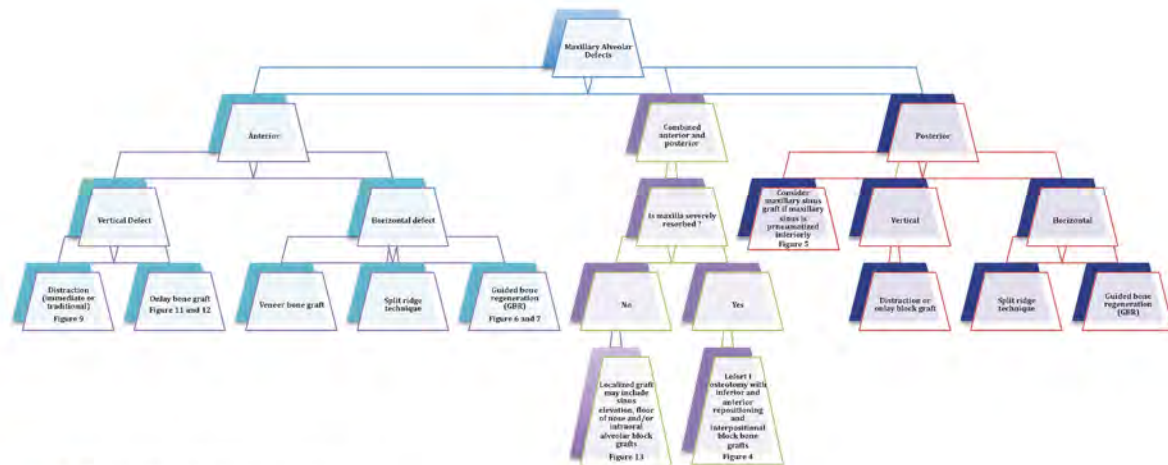


Figure 8.2 Maxillary algorithm of alveolar bone augmentation.

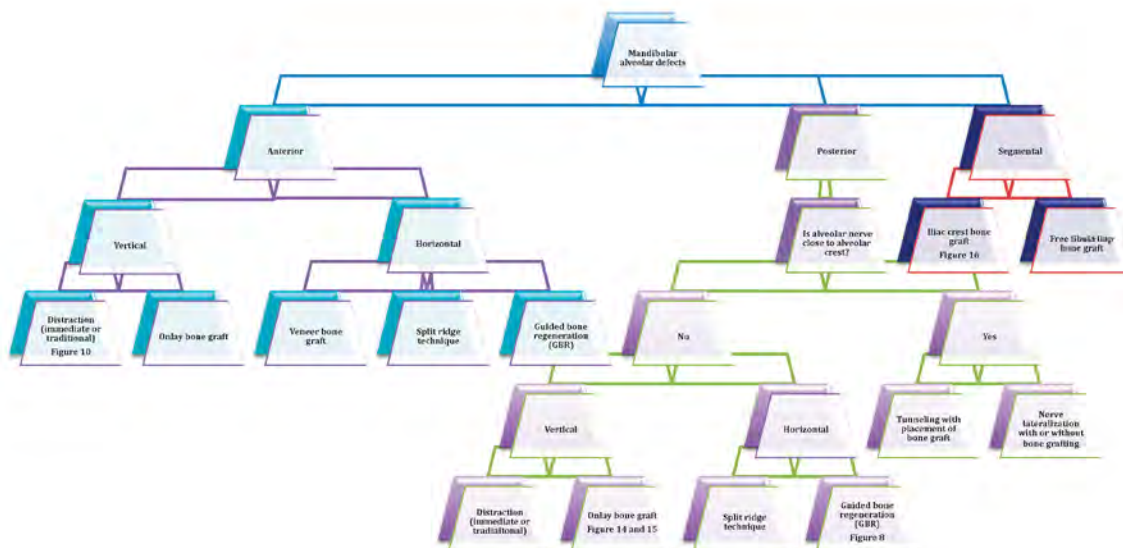


Figure 8.3 Mandibular algorithm of alveolar bone augmentation.

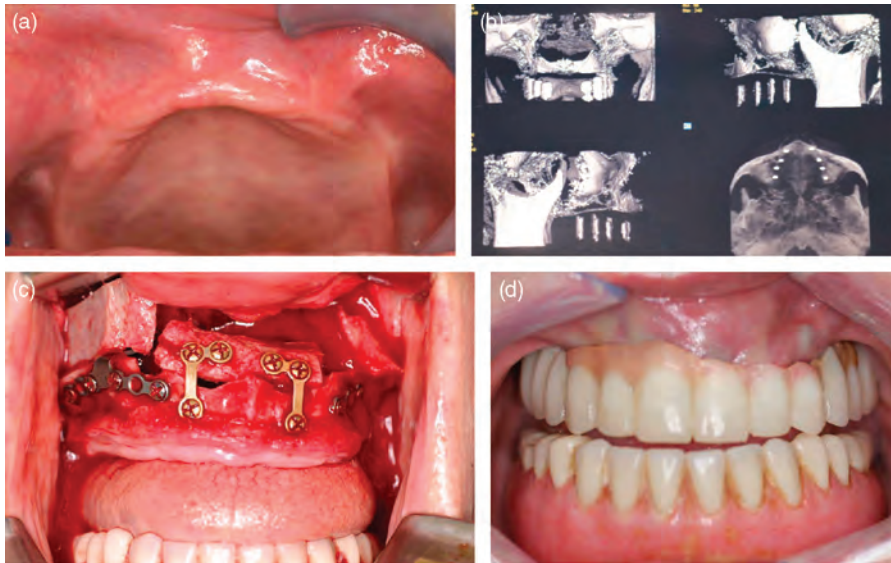


Figure 8.4 Le Fort I osteotomy and interpositional bone grafting: (a) severe max atrophy, (b) radiograph showing severe bone resorption, (c) Le Fort I osteotomy with interpositional bone graft, (d) temporary prosthesis in place.

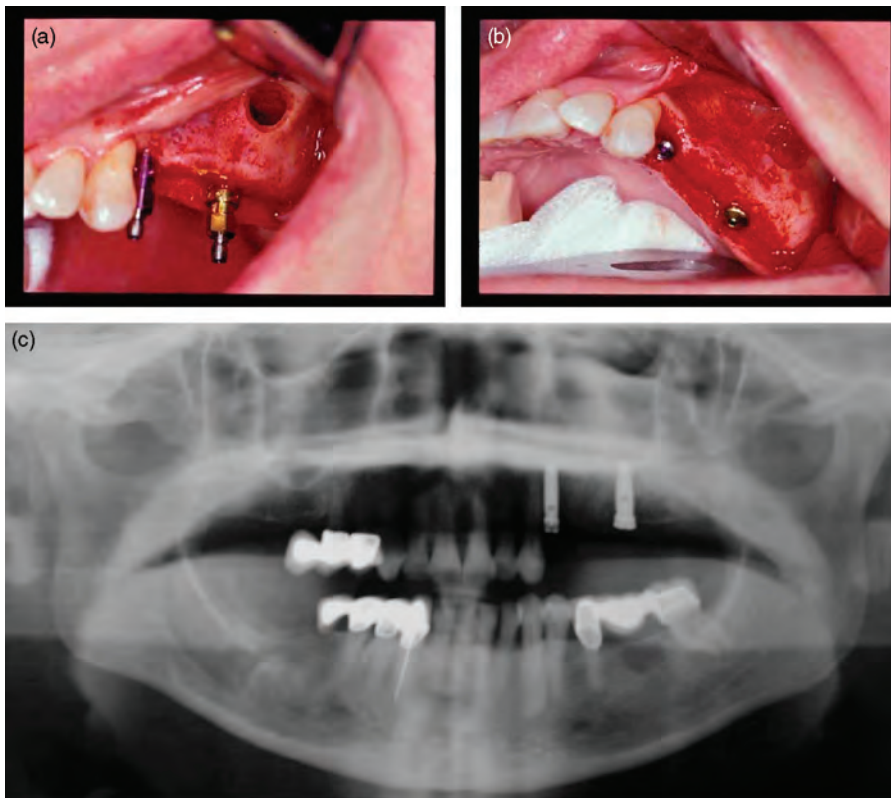


Figure 8.5 Maxillary sinus lift with particulate graft: (a) maxillary sinus lift, (b) placement of bone graft and implants, (c) post-operative radiograph.

Disadvantages

For very thin alveolar ridges this technique is more difficult and is unable to address significant vertical height challenges.

3. Distraction osteogenesis

Distraction osteogenesis (DO) can be used to regenerate missing hard and soft tissue [16,17] (Figures 8.9 and 8.10). Distraction osteogenesis relies on the body's ability to generate bone as two segments of bone are "distracted" apart. The osteotomies are created and the distraction device is placed. Typically, there is a latency

phase of one week where a fibrovascular bridge is formed in the osteotomy site. This provides a template to generate new bone as the segments are distracted apart during the activation phase. Once the desired distraction has occurred, the device is left in place for a period of time. Once consolidation (typically 2 to 6 months) has occurred, the distraction device can be removed and implants can be placed. Chiapasco compared GBR to DO and found that both are equally effective in alveolar bone augmentation for implant placement and further stated that the long-term prognosis of vertical bone gain in DO is more predictable [18].

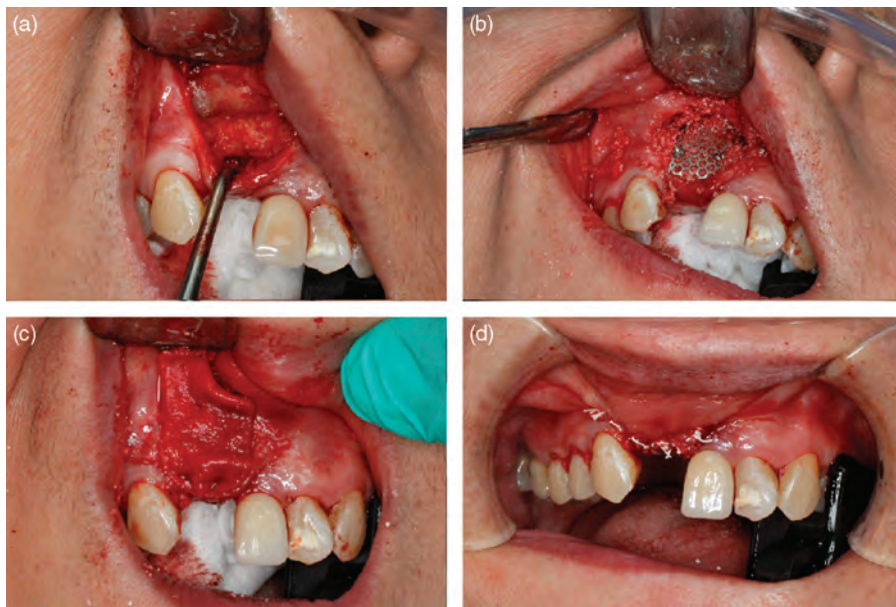


Figure 8.6 Anterior maxilla: localized guided bone regeneration (GBR): (a) localized maxillary anterior defect, (b) particulate graft contained with titanium mesh, (c) placement of collagen membrane over mesh, (d) tension-free closure over graft.

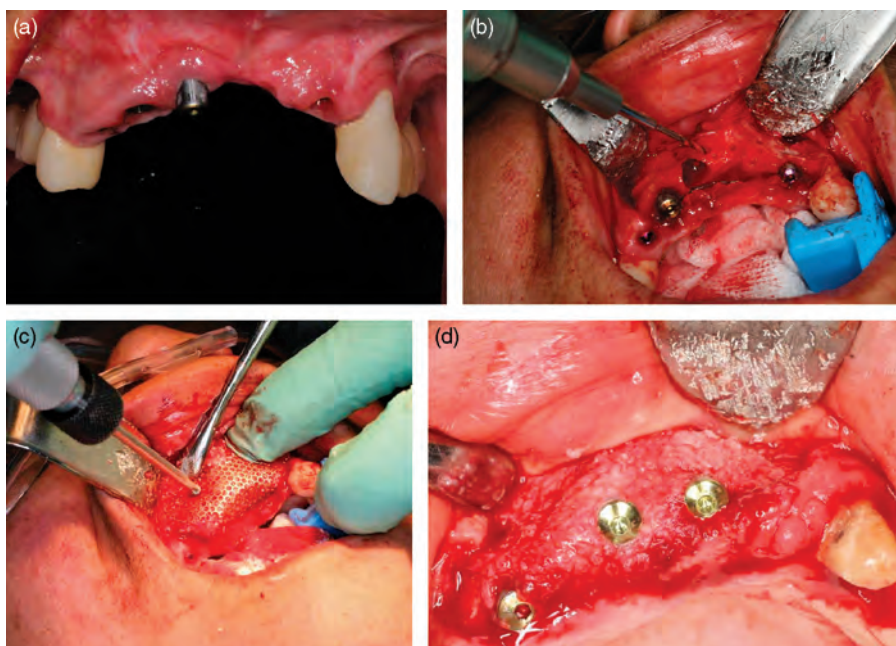


Figure 8.7 Anterior maxilla: GBR: (a) anterior maxillary defect with failing implant, (b) maxillary defect, (c) placement of titanium mesh and particulate graft, (d) placement of titanium implants in reconstructed bone.

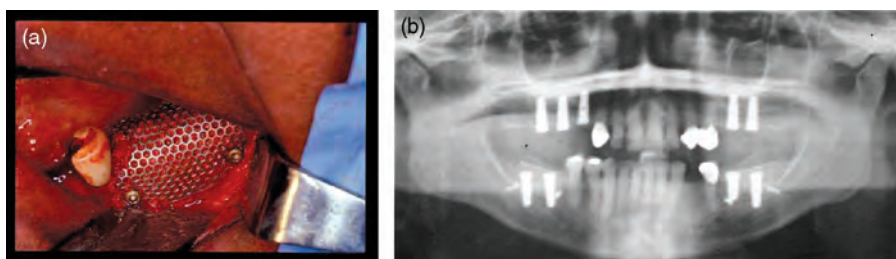


Figure 8.8 Posterior mandible: GBR: (a) titanium mesh and particulate graft, (b) implant placed.

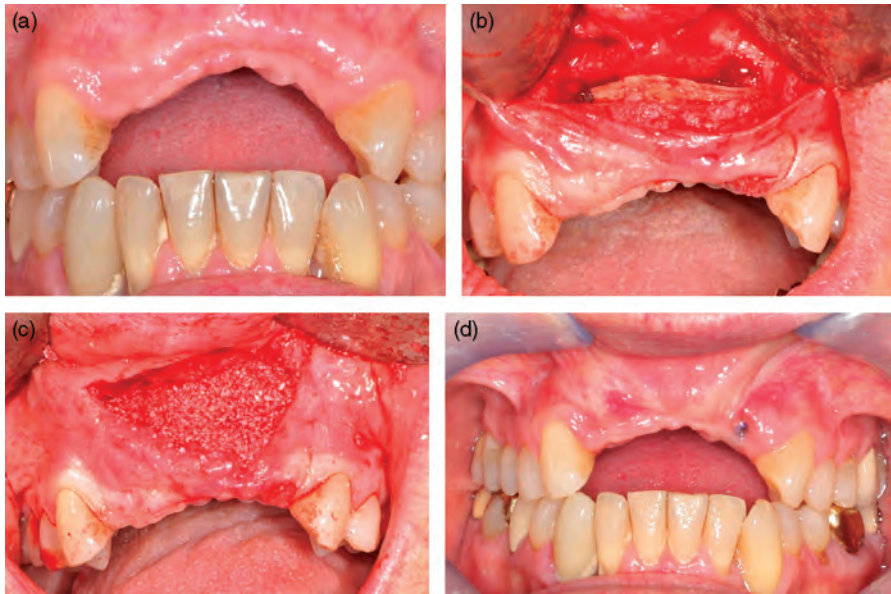


Figure 8.9 Anterior maxilla: immediate (static) distraction or “sandwich technique”: (a) maxillary anterior defect, (b) Ramus interpositional graft, (c) Bovine bone graft over osteotomy, (d) post-operative healing.

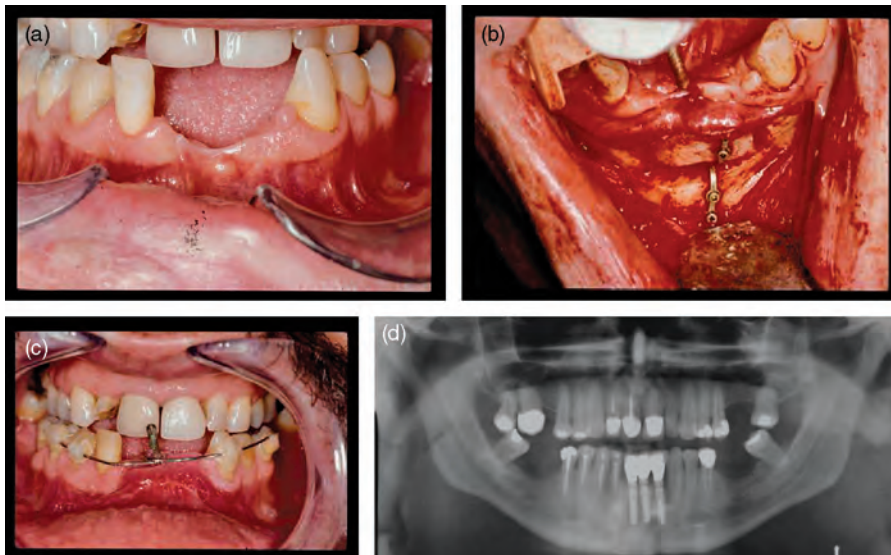


Figure 8.10 Anterior mandible: traditional (dynamic) distraction: (a) anterior mandibular defect, (b) distraction osteogenesis (DO), (c) after DO completion, (d) restored with dental implants.

Advantages

The major advantage of DO is that the gradual traction of the bone transport segment is followed by simultaneous bone osteogenesis and soft tissue regeneration. Distraction osteogenesis is comparable to other techniques for vertical augmentation of bone.

There may be less morbidity with this technique and it does not require a donor site.

Disadvantages

A second surgery to remove the distractor is required.

In a study by Swennen et al. [19] complications occurred in 22% of patients, mostly due to mechanical distractor-related problems and local infections. Infection was seen in 5.8% and device-related problems were present in 7.3% of all patients.

Complications that may resolve spontaneously within six months of the procedure are: temporary inferior alveolar nerve disturbances, pain, trismus, temporary facial nerve palsy, and minor

occlusal disturbances. There is also the possibility of localized infection, incorrect vector of distraction, device-related problems, and dehiscence. At times, there may be some technical complications with the device, which may cause device failure that will necessitate another surgery to either remove or replace the device. In cases of device failure, it may cause premature or deficient ossification and/or fracture of the supporting bone [20].

Alternative technique

Immediate (static) distraction or the “sandwich technique” is similar to traditional (dynamic) distraction osteogenesis but the application of the distractor is not necessary [21]. The osteotomy is the same as the traditional alveolar distraction. The transported segment is placed into the desired location and stabilized, usually with titanium mesh and mini screws. This creates a well-defined pocket in which to place a bone graft and can lead to predictable healing. By maintaining the soft tissue attached to the transported

segment of bone, the blood supply remains, which is different from placing an onlay block graft and requiring revascularization of the graft along the crest of the alveolus. This may lead to less resorption in this area [18].

4. Onlay block grafting

Bone can be harvested from various sites and used to reconstruct alveolar defects (Figures 8.11 to 8.16). Depending on how block grafts are shaped and used to restore the defect, they may be in the form of inlays, veneers, onlays, or saddle grafts. Ridge defects that have adequate vertical height but are too narrow may be restored with a veneer graft. Deficient alveolar ridges that require both horizontal and vertical augmentation may be restored with a saddle graft. The grafts must have a cortical portion that will allow screws to be placed to prevent the graft from moving during healing. These

grafts are revascularized and replaced with host bone. Block grafts take longer to integrate than cancellous bone grafts and a staged surgical approach is more predictable than placing implants in conjunction with the graft. Placing an implant simultaneously with the graft may be considered if there is sufficient basal bone to provide primary stability of the implant without relying on support from the grafted bone [22].

Advantages

Autogenous distant block bone grafts (iliac crest) are excellent to use for many types of augmentation procedures, especially for large vertical defects. These grafts create a source of viable cells and proteins and provide a scaffold for new bone formation, but without antigenicity [1]. Corticocancellous intraoral block bone harvested from the mandibular ramus are reliable grafts with a high rate of



Figure 8.11 Anterior maxillary ramus graft: (a) missing congenital lateral incisor, (b) placement of ramus veneer graft, (c) placement of titanium implant several months later.

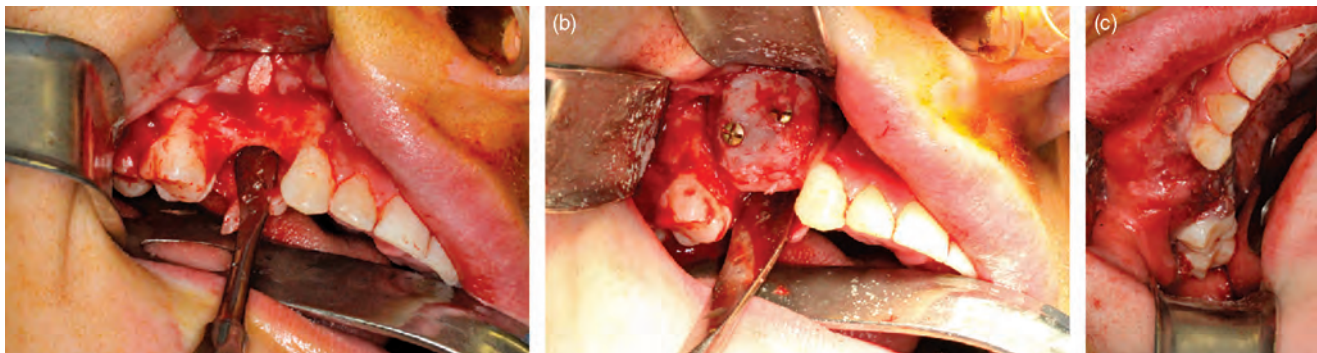


Figure 8.12 Anterior maxillary localized block graft: (a) maxillary defect, (b) placement of block graft, (c) tension-free closure.



Figure 8.13 Anterior and posterior distant (extraoral) maxillary block grafts: (a) iliac crest block grafts, (b) radiograph of dental implants, (c) dental prosthesis 5 years after grafting.



Figure 8.14 Posterior mandible: block graft: (a) mandibular posterior defect, (b) harvest of mandibular ramus graft, (c) graft secured into place.

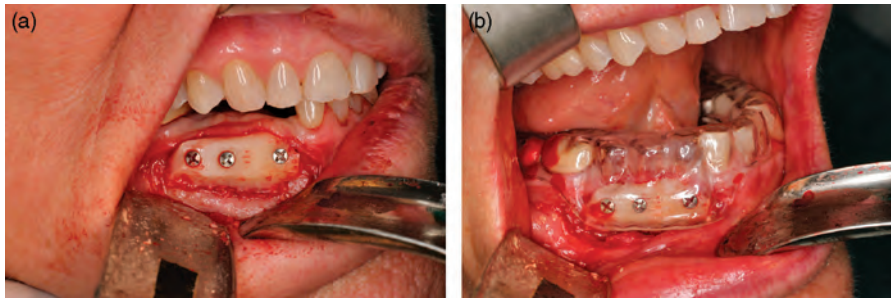


Figure 8.15 Posterior mandible: onlay graft: (a) mandibular posterior defect treated with ramus graft, (b) surgical guide used to aid in placement of block graft.



Figure 8.16 Mandibular continuity defect: (a) mandibular continuity defect, (b) iliac crest graft placed, (c) reconstructed mandible.

success for the alveolar reconstruction procedure for horizontal defects but have limited utility for vertical defects [23].

Disadvantages

A secondary donor site is required. There are possible complications associated with the harvest site. These complications are site-specific and may lead to damage to the inferior alveolar nerve or other complications such as gait disturbance, scarring, and infection.

Future possibilities

Autogenous bone remains the most predictable best option for complex alveolar defects. Advances in regeneration such as the incorporation of growth factors, stem cell treatments, virtual surgical planning, and 3D printing hold great promise for improving the way we can treat alveolar defects in the future. These advances may lead to improved outcomes but more studies are necessary to fully evaluate these technologies and their role in alveolar regeneration.

Summary

It is important to develop a treatment plan including the final prosthetic plan prior to performing a graft procedure. Various graft

materials including autogenous and non-autogenous grafts are available. There are also various techniques available for alveolar ridge augmentation. The least invasive and the most predictable procedure should be chosen, if possible. For more complex defects, techniques such as block grafts can give predictable results.

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SECTION II

Guided Tissue Regeneration (GTR) with Particulate Bone Grafting in Implant Dentistry

The Biology of Particulate Bone Grafting in Implant Dentistry: Regenerative Materials of Choice

Richard T. Kao,¹ Mark C. Fagan,² & Gregory J. Conte³

¹Private Practice, Cupertino, California, USA

²Private Practice, San Jose, California, USA

³Private Practice, San Francisco, California, USA

Bone grafting and bone graft substitute

There is a wide variety of bone grafts that can be considered for implant site preparation. These include autogenous graft, allograft, xenograft, alloplasts, and various growth and morphogenic factors. Successful correction of the implant site defect is dependent not only on graft selection but also on the regenerative approaches used in conjunction with graft materials.

Selection of bone graft and bone substitute materials

There is a large body of literature regarding the selection of graft materials for implant site preparation. The critical consideration in selecting either a single or a combination of graft materials is a function of whether the material is osteogenic, osteoinductive, or osteoconductive. Particulate graft materials can be categorized as: autograft particulate; allograft (freeze-dried bone allograft (FDBA) or demineralized freeze-dried bone allograft (DFDBA)); xenograft (demineralized bovine or equine bone mineral, algae-derived, or coral-derived); alloplast (hydroxyapatite (HA), β -tricalcium phosphate (β -TCP), bioglass, or calcium sulfate); and combinations of the above.

To date, autogenous bone graft is considered the “gold standard” for defect augmentation owing to its osteogenic, osteoinductive, and osteoconductive properties. It can be easily harvested with a bone scrapper, as trapped osseous coagulum, or with a trephined core that is subsequently milled into particulate form. The disadvantage is that at times, a secondary, or even an extra-oral site, may be required when a larger volume is needed, which increases the morbidity risk. This has resulted in clinicians evaluating three different materials as supplements or alternatives to autogenous bone. These include allografts (banked human bone), alloplastic (ceramic based), xenograft (of different animal origins), or a combination of the above.

Bone allograft is tissue banked based on strict criteria whereby the risk for infection, contamination, and immune response has reduced to less than 1 in 8 million [1]. Allografts are provided in various forms such as particulate, gels, and putties, but have two basic essential forms: freeze-dried bone allograft (FDBA) and demineralized freeze-dried bone allograft (DFDBA). It is purported that demineralization may expose bone morphogenetic protein

(BMP) with the DFDBA matrix [2–4]. Though the osteoinductive properties of BMP can be demonstrated experimentally, it is not clear if the level of osteoinductive properties is clinically significant. In fact, DFDBA does not yield reproducible clinical and histological results, and frequently shows inferior results when compared to autogenous bone or other substitutes. This may be reflective of batch and processing center variability. Both DFDBA and FDBA are utilized to stabilize the wound defect via their osteoconductive properties. Some clinicians favor mineralized FDBA, speculating that there is faster metabolic resorption, which permits faster bone replacement. In a series of studies evaluating ridge preservation with DFDBA or FDBA, Wood and Meally [5] evaluated histological cores of augmented sockets at 4–5 months post-graft. There were no differences in alveolar ridge dimensions between the two groups but DFDBA had a significantly greater percentage of vital bone (38.42% versus 24.63%) with less residual graft materials (8.8% versus 25.42%). However, utilizing a similar protocol, when evaluating the role of DFDBA particle size on grafting success, there was no statistically significant difference between groups for any clinical or histologic parameters [6].

Alloplastic grafts include dense and porous hydroxapatites, tricalcium phosphates, and a mixture of calcium phosphate materials. These osteoconductive materials can be resorbable or non-resorbable. When the material is resorbable, the resorption rate is dependent on the porosity of the materials, with increased microporosity leading to faster turnover. Though non-resorbable alloplast is used primarily in edentulous ridge maintenance, it is seldom singularly used for implant site preparation. In contrast, the resorbable properties of porous hydroxyapatite, calcium sulfate, β -tricalcium phosphate, and bioactive glass used singularly or in association with other materials has been effective when used as osteoconductive scaffolding agents to stabilize the wound repair site. These can also be used effectively to graft implant and sinus areas. In using these graft materials, one must understand the turnover time required to avoid premature implant placement. Sites too densely packed with these osteoconductive materials will not allow osseointegration to be achieved.

Xenograft use in ridge preservation is most commonly associated with deproteinized bovine bone mineral (DBBM). One of more

commonly known brand names is Bio-Oss® (Geistlich Pharma North America Inc., Princeton, NJ, USA). In a clinical study where DBBM was grafted versus non-augmented sites [7], the DBBM demonstrated less vital bone (25% versus 44%) suggesting a delay in bone formation in grafted sites supporting findings from other studies. In similar histologic analysis of sockets grafted by DBBM at 9–12 months, it was found that most DBBM particles were still present with no evidence of fibrous encapsulation [8,9]. These and other studies suggest the osteoconductive properties of DBBM which may be useful for ridge preservation. However, if an implant were to be placed 3–5 months post-extraction, this may not be an ideal material of choice due to the slow graft turnover and decreased volume of new vital bone needed for osseointegration.

Use of membrane barrier for guided bone regeneration (GBR)

Barrier membranes are regularly used in conjunction with bone graft materials for implant site preparation. Membranes are often used for space maintenance to inhibit cell ingression that results in fibrous repair, to provide occlusive properties so that regenerative cells may populate the occluded spaces where bone regeneration is desired, and to stabilize the blood clot in the regenerative space [10,11]. GBR membranes are available in absorbable or non-absorbable materials. Selection of the membrane type is based on the size of the defect and the number of supporting walls. Woven bone regenerates at approximately 60 µm per day, so augmentation of a defect of 5 mm or less may take up to 4–6 months, whereas larger defects may require 6 months to a year [12,13]. With small or multiwall support, the smaller volume of regenerative tissue can be supported with either type of membrane. Most would select absorbable membrane in order to avoid a secondary surgery to retrieve the membrane and also to minimize membrane exposure or perforation. As the defect size increases, one should consider a non-absorbable membrane. In larger defects, titanium-reinforced membranes are frequently considered. The tenting of the GBR membrane is often stabilized with the use of pins, screws, and a supporting post. Though these supplemental stabilization pins and screws help ensure patency of the created space, there is little literature that indicates advantage with their use. Hwang and Sonick [14] provide an excellent detailed resource for clinicians on the topic of GBR.

Supplementation of bone graft with biologics (biomimetics)

To improve the effectiveness of particulate graft materials, there have been various strategies to osteoinduction properties.

Platelet-rich plasma (PRP) is a fraction that can be processed from autologous blood [15]. To do so, a small volume of blood is collected and fractionated in a centrifuge into platelet-poor plasma (PPP), platelet-rich plasma (PRP), and the dense red blood cell layer. After fractionation, PRP is dispensed and mixed with bovine thrombin. This mixture can be used in conjunction with a bone graft or over wounds. PRP has been shown to be a source of transforming growth factor β -1 (TGF β -1), vascular endothelial growth factor (VEGF), platelet derived growth factor (PDGF), and a coagulation of matrix glycoprotein and thrombospondin-1 [16–18]. When PRP is added to particulate bone graft, the fibrin formation coalescence serves as a bioactive scaffold to coalesce the

loose graft material, forming a putty graft material that can be sculpted. The use of PRP in conjunction with bone graft is to amplify and accelerate the early wound-healing process.

Interest in this growth factor came out of the PRP studies where activation of the platelets in PRP released PDGFs. Platelet-derived growth factor (PDGF) is a protein that has the ability to stimulate cell growth, chemotaxis, proliferation, and differentiation [19,20]. Growth factors regulate expression of mineral associated genes that are primarily stored in platelet alpha granules. Secondary producers of these growth factors include osteoblasts, macrophages, and monocytes. For implant site preparation, recombinant human PDGF- $\beta\beta$ (rhPDGF- $\beta\beta$) has been used successfully in guided bone regeneration (GBR), block graft augmentation, and sinus lift. For ridge augmentation, rhPDGF- $\beta\beta$ has been used with autogenous bone, DFDBA, FDBA, xenograft, or mineral collagen bone substitute with and without membranes for successful ridge augmentation [20–22]. A small case series of sinus lifts where rhPDGF- $\beta\beta$ was used in conjunction with bovine xenograft indicates that significant vital bone is formed as early as 3.5 months post-surgery [23]. These studies suggest that rhPDGF added to bone graft may accelerate bone formation, allowing for earlier implant placement; however, more research is needed to confirm this.

Bone morphogenetic proteins (BMPs) are a group of differentiation factors that act as morphogenetic signals to orchestrate bone development throughout the body [24]. Though recombinant human BMPs (rhBMPs) are used in orthopedic applications such as spinal fusions and non-unions, rhBMP-2 has been FDA approved for sinus augmentation and localized alveolar ridge augmentations. This product is reconstituted and used in conjunction with an absorbable collagen sponge (ACS). The use of rhBMP-2 and ACS in ridge augmentation and preservation is shown to be safe [25–27]. However, there is some concern that ACS has poor scaffolding properties and there is a small case series where rhBMP-2 and ACS have been used with GBR approaches, such as titanium mesh and inclusion of graft materials, to provide additional three-dimensional support for the graft [28,29]. Of recent issue is the concern that overactivation of BMP signaling may result in cancerous diseases, such as the potential development of esophageal adenocarcinoma when used in the proximal portion of the gastrointestinal tract [30,31]. A recent meta-analysis has shown rhBMP to be safe [32]. However, the use of rhBMP is not common due to the high cost of the material and the comparable end results that can be achieved utilizing other techniques have resulted in a minimal incorporation of this graft approach in implant site development.

Stem cell technology has recently been used in implant site development. Mesenchymal stem cells (MSCs) may be processed whereby immunogenic cells are selectively depleted and osteoprogenitor cells are enriched [33]. This product is commercially available as a cryopreservation of MSC with DFDBA (Osteocel, ACE Surgical Supply, Brockton, MA, USA). This material has been shown to be effective in enhancing bone formation in the sinus [34,35] and for deficient alveolar ridges [36,37]. This commercial product has a minimum of 50 000 osteoprogenitor cells/cm³, which is significantly higher than what can be found in iliac crest graft (~13 000 cells/cm³) or adult marrow (~1000–1500 MSC/cm³) [33]. This enriched MSC source displays the fact that success of the graft procedure is dependent on recruitment and proliferation of osteoprogenitor cells and that MSC may provide an important clinical alternative to acellular bone grafts; however, the potential use of MSC-DFDBA needs further evaluation.

Table 9.1 Graft and GBR membrane selection considerations for implant site preparation.

Defect morphology	Regenerative approach		Healing time
	Graft materials	GBR membranes	
• Extraction socket with thick buccal/lingual walls	None	None	2–3 months
• Extraction socket with thin (≥ 1 mm) buccal/lingual walls	Autograft/DFDBA/FDBA	None	2–3 months
• Ridge splitting, grafting with delay placement	Autograft/DFDBA/FDBA	Absorbable GBR membrane	2–3 months
• Extraction socket with fenestration/narrow dehiscence defect/history of fistula tract	Autograft/DFDBA/FDBA	Absorbable GBR membrane	3–4 months
• Crestal sinus/osteotome sinus lift approach	None (≤ 2 mm) Autograft/DFDBA/FDBA	None	5–6 months
• Extraction socket with loss of buccal/lingual walls • Horizontal defects ≤ 2 mm	Autograft/DFDBA/FDBA ± Biologics	GBR membrane ± titanium support (esp. when ≥ 2 mm positive architecture required)	5–6 months
• Horizontal defects > 2 mm • Vertical augmentation	Autograft/DFDBA/FDBA ± Biologics	GBR membrane with titanium support	6+ months
• Sinus lift (lateral wall approach)	Autograft/DFDBA/FDBA/Xenograft/ alloplastic graft/combination of above ± Biologics	Absorbable GBR membrane	9–12 months

Regenerative strategies/approaches utilizing particulate bone grafts

There is a large and heterogeneous body of literature available regarding augmentation localized bone defects for implant site preparation. A recent systematic review evaluated the level of evidence for the use of particulate bone graft [38].

In dehiscence-type and fenestration-type defects, the best-documented augmentation protocols involve the use of particulate graft with GBR, particulate autograft with or without GBR, and a non-resorbable GBR approach.

In horizontal and vertical ridge augmentation, autogenous or allograft bone block alone, or combined with particulate graft materials with or without GBR membrane, is the most effective regenerative approach. In this type of defect, the particulate bone graft is used primarily as “mortar” to achieve filling of gaps and sharp block graft irregularities. It should also be noted that there are advanced techniques whereby particulate grafts have been effectively used for horizontal and vertical ridge augmentation [39–41], but these are technically sensitive surgical procedures that require focal training. In the absence of this type of training, practitioners are advised that the results may not be consistent.

In maxillary sinus floor elevations, the use of particulate bone graft is the primary graft of choice for the osteotome or crestal sinus approach. It should be noted that when minimal sinus lift is needed (≤ 2 mm), the sinus can be lifted, not grafted, and the Schneiderian membrane can be supported by the implant. The space under the membrane will fill with a blood clot, which will become bone with healing. With the lateral window technique, osseous coagulum, allograft, xenograft, alloplast, or a combination of the above have been shown to be effective.

Determinants for implant site augmentation

Given the wide variety of graft materials, biologics, and regenerative membranes, materials selection can be confusing. Table 9.1 provides some guidance for a novice operator. With clinical

experiences, each clinician will develop their personal decision algorithm for implant site preparation. It should be noted here that not all bone defects need to be augmented. Small and narrow defects with adequate buccal and lingual walls will normally regenerate without manipulation. As the defect becomes larger and the bony walls become more compromised, a variety of graft materials as well as biologics should be considered. When a “regenerative wall” is needed, one should consider the addition of a GBR membrane. The absorbable membranes are convenient to use but as the defect becomes larger, the need for a non-absorbable GBR membrane becomes more prevalent. Should a positive architecture be required, titanium-reinforced non-absorbable GBR membrane should be considered. It is important for each clinician to understand the defect requirements, material cost, and necessary healing time and convey this information to the patient.

Conclusion

Particulate bone graft is an essential part of the implant site preparation armamentarium, and it is important to understand that it is the primary graft source for ridge preservation, correction of dehiscence- and fenestration-type of defect, and sinus grafting. It is also used secondarily as a “filler” to improve space maintenance in autogenous or allograft block graft when used in horizontal and vertical defects. There is a high level of evidence to support the fact that implant survival rates in augmented bone are comparable to implants placed in native bone [37].

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Implant Site Development with Particulate Bone Grafts

Gregory J. Conte,¹ Mark C. Fagan,² and Richard T. Kao³

¹Private Practice, San Francisco, California, USA

²Private Practice, San Jose, California, USA

³Private Practice, Cupertino, California, USA

Introduction

The healing events following tooth extraction have been well documented in the literature [1–3]. In order to understand alveolar ridge remodeling, it is important to understand the structure of alveolar bone and to appreciate the changes that occur following tooth extraction.

The structure of alveolar bone includes the supporting alveolar (basal) bone and the alveolar bone proper (bony ridge). The supporting alveolar bone consists of the *compact* bone of the cortical plates and the *spongy* trabecular bone between the cortical bone of the maxilla or mandible. Compact bone is designed for load bearing, while trabecular bone is less mineralized and made up primarily of cancellous bone. The alveolar bone proper surrounds the roots of teeth and gives attachment to the periodontal ligament fibers. The alveolar bone consists of the lamellated bone and the bundle bone. Sharpey's fibers of the fibrous periosteum attach to the circumferential lamellae, while the concentric lamellae form osteons, or haversian systems. These systems make up the fundamental functional unit of compact bone. The bundle bone, where the periodontal ligament fibers insert, lines the alveolar socket and is the part of the alveolar bone proper. Sharpey's fibers extend from the cementum and run perpendicularly to attach to the bundle bone. After tooth extraction, the bundle bone is the first bone resorbed, whereas alveolar bone is gradually resorbed throughout life [4,5].

The role of the bundle bone in the dimensional change of the alveolar ridge was investigated in several dog studies by Araujo et al. [6–8]. This research group describes bone resorption in two phases following tooth extraction. During the first phase, bundle bone is rapidly resorbed and replaced with woven bone, leading to a reduction in bone height. This is most notable on the buccal aspect of the socket, as its crestal portion is comprised primarily of bundle bone. The function of bundle bone is to anchor the tooth to the alveolar bone through the periodontal ligament. As the tooth is extracted, the bundle bone loses its function and subsequently resorbs, leading to a reduction in bone height and width. This becomes even more pronounced in the anterior dentition, where the buccal plate is generally thinner, averaging 0.8 mm compared to 1.1 mm in premolar sites [9]. This thin labial bone may be comprised solely of bundle bone, especially at the crest, and loss of this bone results in significant horizontal and vertical deficiency. During

the second phase of bone resorption, the outer surface of the alveolar bone is remodeled, causing further horizontal and vertical tissue reduction. The reason for this remodeling process is not well understood. Disuse atrophy, decreased blood supply, and increased inflammation might all play important roles in this process [10].

The resorption rate of the alveolar ridges is pronounced during the first 6 months following extraction, and proceeds at an average of 0.5–1.0% per year for the entire life [11,12]. A recent study evaluating dimensional changes following tooth extraction in human molar and pre-molar sites estimated that 50% of crestal width can be lost within a 12 month period, with two-thirds of the hard and soft tissue changes occurring within the first 3 months following extraction [13]. Additionally, a systematic review found significant horizontal and vertical alveolar ridge reduction over a 12 month period following tooth extraction [14]. In this review, 20 studies were included that reported on post-extraction dimensional changes relative to a fixed reference point. The authors reported horizontal bone loss of 29–63% and vertical bone loss of 11–22% 6 months after tooth extraction.

The vertical and horizontal dimensional changes of the alveolar ridge following tooth extraction may complicate restorative procedures, especially if dental implants are planned (Figure 10.1a and b). This is especially true in the esthetic zone, where hard and soft tissue loss can have devastating effects. Hammerle et al. [15] reported in a meta analysis review that the alveolar ridge undergoes a mean horizontal reduction in width of 3.80 mm and a mean vertical reduction in height of 1.24 mm within 6 months after tooth extraction without ridge preservation therapies. In the past decade, the use of materials and techniques for alveolar ridge preservation has been extensively studied and reviewed. Darby et al. define alveolar ridge preservation as “any procedure undertaken at the time of or following an extraction that is designed to minimize external resorption of the ridge and maximize bone formation within the socket” [16]. *Socket preservation* is a procedure using bone graft substitutes or guided bone regeneration in an effort to help prevent buccal-lingual ridge collapse of a preserved tooth socket following extraction [17]. This procedure requires careful tooth removal and complete preservation of the labial/buccal plate of bone. This process becomes a *socket augmentation* procedure if the labial/buccal plate has been damaged upon tooth removal or if pathology that further compromises the alveolar bone exists. It is

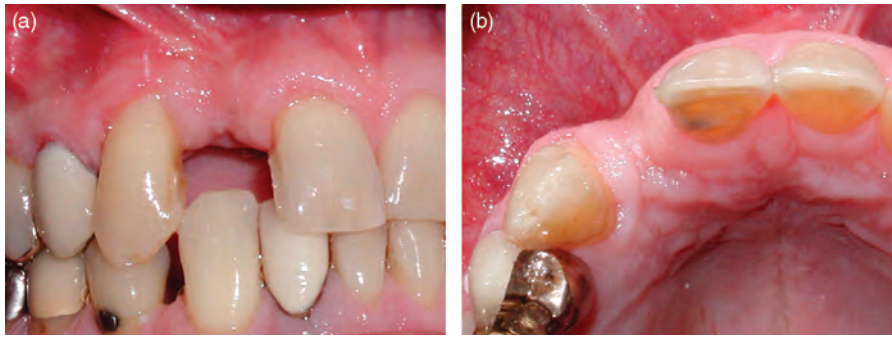


Figure 10.1 Healed edentulous site several years post-extraction. No socket bone grafting procedure was performed at the time of extraction. Note the horizontal and vertical soft tissue deficiency present.

important to distinguish between *socket preservation* and *socket augmentation* because the augmentation procedure can be a larger, more difficult procedure that may require flap elevation and the use of advanced surgical techniques.

Description

Several preservation and augmentation techniques, and the use of various graft materials with and without the use of barrier membranes, have been studied and described in the literature. The use of graft materials in a socket following extraction is not without controversy. Several studies have reported that the use of slowly or non-resorbing bone graft materials interfere with osseointegration due to the failure of the graft to be resorbed and replaced by vital bone [18,19]. Questions exist as to whether or not there is a benefit in adding a graft material to an intact extraction socket. If there is a benefit, what is the best material to use? Should barrier membranes be utilized? What about the use of soft tissue grafts? The selection of possible graft materials is covered in Chapter 9.

The concept of guided bone regeneration (GBR) utilizes barrier membranes to keep gingival and epithelial cells from penetrating into the defect, allowing bone cells to repopulate and regenerate the site. Space maintenance and the formation of a stable clot are essential for successful guided bone regeneration. Studies in humans and animals have demonstrated that sockets that are protected by a stable blood clot heal by regeneration of bone and that the epithelium does not penetrate the clot, but, rather, migrates over the granulation tissue to close the healing socket. This leads to questions as to whether or not barrier membranes have an effect in maintaining alveolar ridge morphology. Several studies have demon-

strated improved hard and soft tissue dimensions with the use of barrier membranes [20–22]. A technique for socket preservation utilizing a collagen barrier membrane is presented in Figures 10.2 to 10.8. With the socket preservation procedure, it is imperative to extract the tooth with minimal trauma and every effort should be made to preserve the interproximal soft tissue. In the case described in the figures, a collagen barrier is adapted along the inner aspect of the facial socket wall and bone graft material is loosely placed into the socket. The membrane is flipped to cover the graft material and is sutured to the palatal tissue with chromic gut suture. The exposed membrane will be trimmed down as the epithelium migrates to close the wound. A temporary removable partial denture with a ridge lap pontic is used and the pontic area is relieved so that there is no contact with the membrane covering the socket (Figure 10.5a). It is very important to keep the pontic at least 1–2 mm away from the membrane during the healing phase because pressure on the healing tissue will not allow the soft tissue to migrate over the membrane. The exposed membrane will break down as the epithelium migrates to close the wound. Additionally, healing within the socket will cause expansion and extrusion of some of the graft material. Pressure from an interim prosthesis at this stage can lead to incomplete bone formation. It generally takes 2–4 weeks for the soft tissue to cover the socket. The transition to an ovate pontic for soft tissue development can begin at three months following the extraction and preservation procedure, with implant placement typically at four-six months post extraction and graft (Figures 10.6 to 10.8).

Socket augmentation and alveolar ridge regeneration procedures can be much more difficult than socket preservation procedures. Socket augmentation requires regeneration of damaged or missing labial/buccal alveolar bone upon tooth extraction (Figure 10.9a to c),

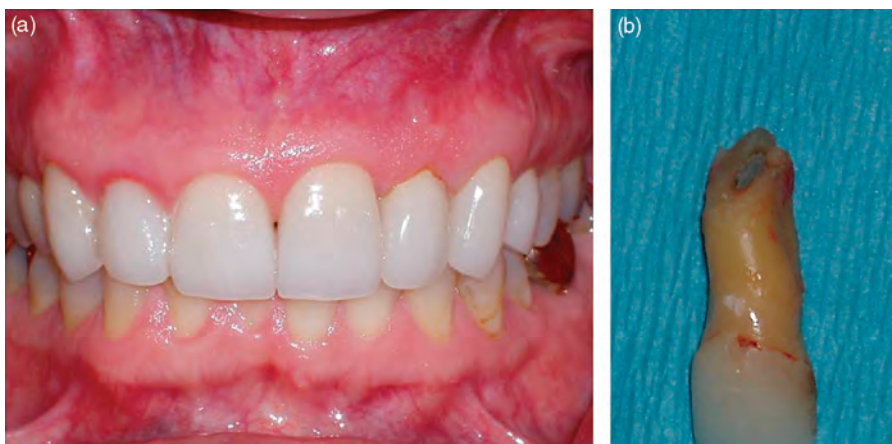


Figure 10.2 (a) Preoperative view. Upper left lateral incisor planned for extraction due to severe root resorption. (b) Extracted upper left lateral incisor. Note the severe root resorption at apex.

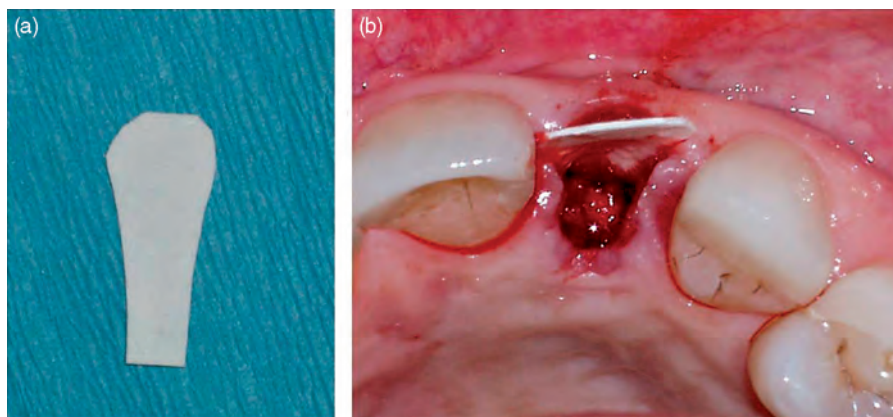


Figure 10.3 (a) A collagen barrier membrane cut to a shape that can fit into the extraction socket and cover the defect. (b) The membrane is positioned into the socket with the long, narrow portion up against the buccal wall of the socket. Particulate bone graft material is packed into the socket up against the membrane.

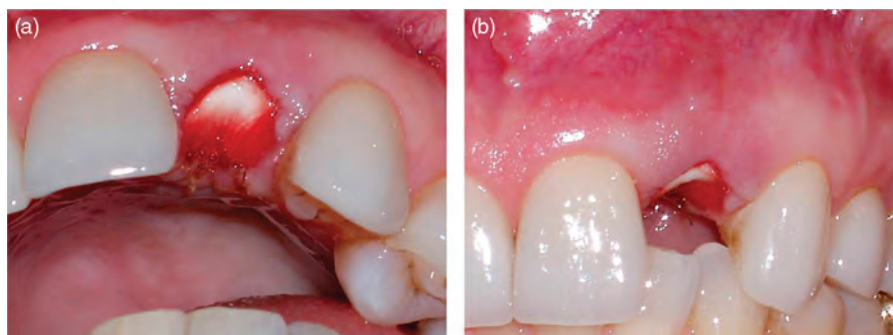


Figure 10.4 (a) The membrane is flipped to cover the socket and tucked into the undermined palatal tissue. It is sutured on the palatal aspect with a 6-0 resorbable suture. (b) Buccal view shows completed socket preservation with minimal trauma.

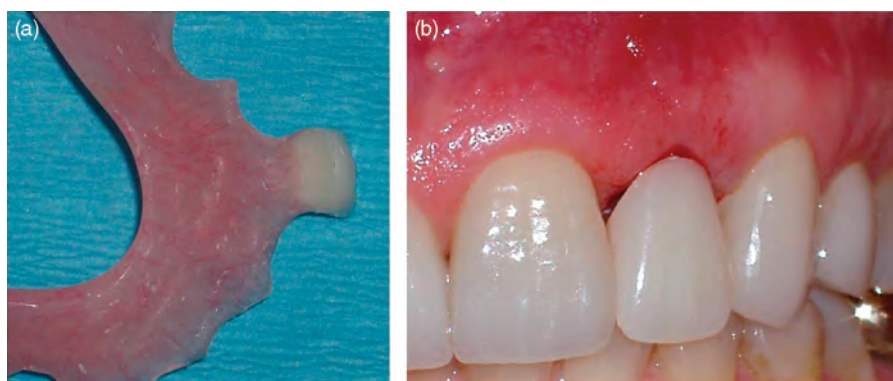


Figure 10.5 (a) The acrylic removable partial denture has been adjusted to create a ridge lap pontic. (b) The pontic on the partial denture is reduced slightly to allow for a minimum of 1 mm clearance over the membrane covering the socket.

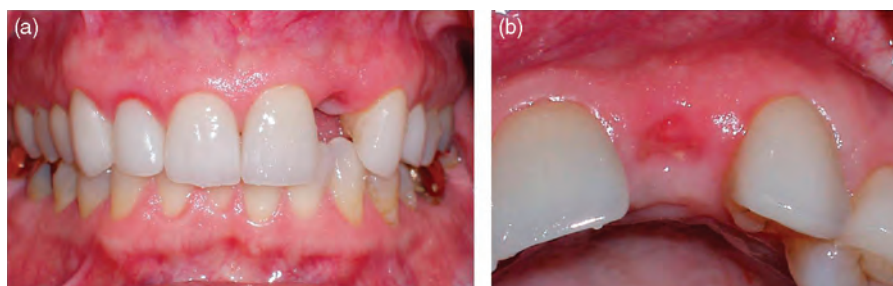


Figure 10.6 (a) Three month post-extraction and socket preservation procedure. (b) Conversion to the ovate pontic in temporary partial denture for gingival shaping.

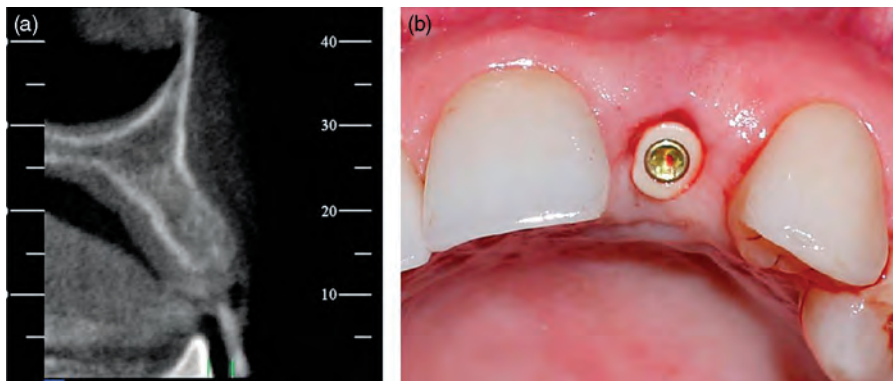


Figure 10.7 (a) Three-dimensional CBCT of socket preservation shows excellent ridge width for proper implant placement. (b) Implant placement with a flapless approach.

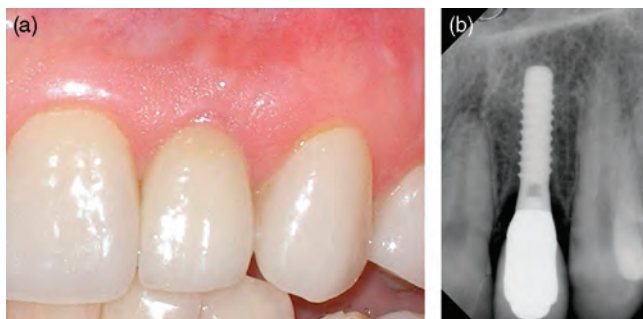


Figure 10.8 (a) Note the excellent tissue health and contour around the implant supported crown. (b) Completed clinical and radiographic views.

while ridge augmentation is used to regenerate and restore atrophic alveolar ridges. Advanced surgical principles and guided-bone regeneration techniques are needed to completely restore lost hard and soft tissue. This often consists of full thickness mucoperiosteal flaps with vertical and periosteal releasing incisions needed to secure primary wound closure. Space maintenance is imperative for guided bone regeneration to be successful, and tenting screws are often used to protect the blood clot and keep the barrier membrane and soft tissue from collapsing into the space. An example of a socket augmentation procedure utilizing guided bone regeneration principles is presented in Figures 10.10 to

10.16. In this example, the maxillary incisors were extracted due to advanced periodontal disease and significant loss of horizontal and vertical bone was evident upon extraction. Following extensive socket degranulation, two small bone screws were placed in the interseptal area and positioned vertically so that approximately 3–4 mm of the screws were present above the existing alveolar bone (Figure 10.11a and b). The area was grafted with demineralized bone allograft and covered with two layers of a resorbable collagen barrier. The area was closed primarily and allowed to heal for 5 months prior to implant placement.

The alveolar housing itself can be utilized as the tenting mechanism for horizontal augmentation during ridge-splitting techniques. When there is adequate vertical height present but lacking width the desired three-dimensional implant site can be obtained by partial sectioning of the alveolar housing and spreading the coronal aspect of the ridge. Once the ridge is spread, FDBA and a GBR membrane can be used to fill in the gap. Figure 10.17a to f depicts a possible sequence for ridge-splitting techniques. Whether implant placement is completed at the same time as the split or in a delayed manner is determined on available stabilizing bone.

The placement of a free soft tissue graft to cover the augmented socket was introduced to minimize tissue shrinkage and allow for rapid soft tissue closure [23]. Soft tissue grafts in the form of free autogenous connective tissue, or rotated pediculated grafts, can also be used in combination with bone graft substitutes to augment large hard and soft tissue deficiencies. There are several advantages to being able to combine therapies such as hard and soft tissue grafting

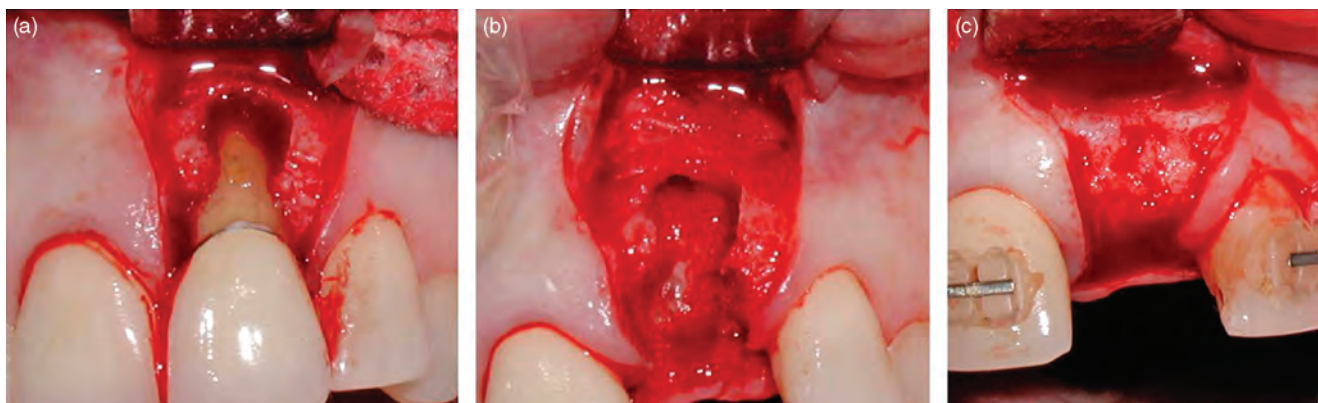


Figure 10.9 (a) Vertical root fracture of the upper left central incisor leads to extensive bone loss. (b) The tooth is removed and a socket augmentation procedure is performed. Note the flap design with mesial and distal vertical incisions for access to the defect. (c) Re-entry at six months demonstrates complete osseous regeneration.



Figure 10.10 (a) Clinical and radiographic appearance of a case demonstrating localized aggressive periodontitis. (b) The maxillary anterior teeth have severe attachment loss and poor prognosis.

with possible implant placement. These include decreasing the number of appointments, decreasing the overall discomfort of the patient, and possibly decreasing the treatment time prior to implant restoration. A mentioned article presents the results of advanced facial bone loss cases, illustrating the interpositional vascularized augmentation neogenesis (IVAN) technique using bone grafts, membrane barriers, and closure with a pediculated connective tissue graft (PCTG) to regenerate bone and soft tissue at the time of extraction [24]. Whether an implant is placed immediately in each individual case is largely based on the ability to achieve primary implant stability.

In an example of delayed implant placement, clinical examination revealed gingival inflammation extending apically along the facial aspect of the maxillary left central incisor (Figure 10.18a to k). Radiographic evidence indicated radiolucency along the root and surrounding the apex. The tooth was extracted and the socket was degranulated. The defect was filled with freeze-dried bone allograft (FDBA) and covered with a titanium-reinforced barrier membrane for space maintenance. A PCTG was raised from the left palate and rotated over the membrane. The graft was fixed to the facial flap for stability with little attempt to coronally position it to cover the

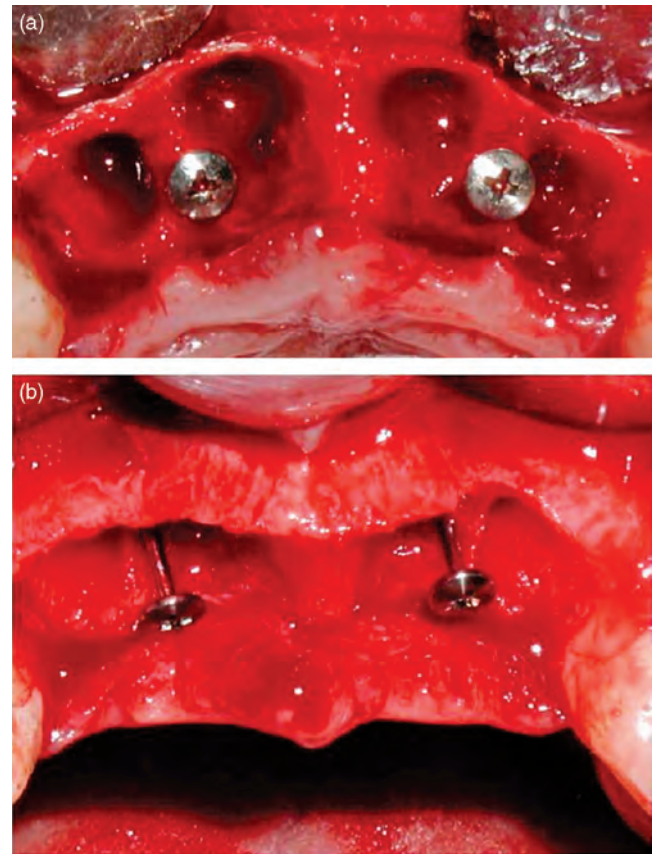


Figure 10.11 (a) The maxillary anterior teeth are removed and two 12 mm bone screws are placed in the interseptal areas. (b) The bone screws are used for tenting the membrane to prevent collapse into the defects. Note the amount of vertical augmentation needed for proper alveolar reconstruction.

connective tissue graft (Figure 10.18e). During the six-month healing phase, no exposure of the membrane was noted. At implant placement, the membrane was uncovered and removed, thus exposing the rebuilt ridge. The implant was placed using a surgical stent and allowed to heal for 4 months. The implant was uncovered and the definitive restoration was placed (Figure 10.18j and k).

In the second example, an immediate implant placement was completed using the IVAN technique for a maxillary left central incisor crown fractured below the gingival margin (Figure 10.19a). The tooth was extracted and the defect was degranulated (Figure 10.19b). It was also radiographically determined that there was adequate anchoring bone available apical to the defect and an

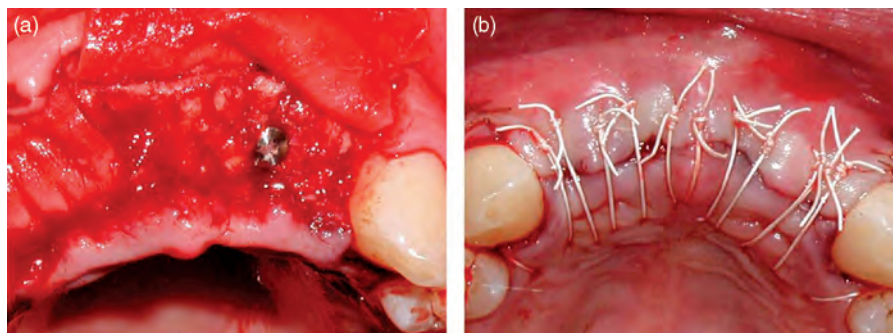


Figure 10.12 (a) The socket defects are filled and bone graft material is added to the level of the bone screws. The graft material is covered by a collagen barrier membrane. (b) Passive primary closure with an interrupted and mattress suture.



Figure 10.13 An Essix appliance is placed immediately following the surgical procedure.

immediate implant was placed (Figure 10.19c). The facial aspect of the implant was grafted with FDBA and overlaid with calcium sulfate to aid in space maintenance. In addition, a resorbable collagen barrier membrane was placed (Figure 10.19d). After 4.5 months of integration, the implant was uncovered (Figure 10.19e) and a healing abutment was placed. The implant was restored with a cement-retained crown (Figure 10.19f and g).

In dehiscence-type and fenestration-type defects, the best-documented augmentation protocols include the use of a particulate graft with GBR, particulate autograft with or without GBR, and a non-resorbable GBR approach [25]. In the first case (Figure 10.20a to e), the upper right central incisor needed extraction due to root resorption and failing endodontic treatment (Figure 10.20a). Immediate implant placement was planned, but there was a fenestration-type defect (Figure 10.20b), which was managed with FDBA with a titanium-reinforced GBR membrane. The IVAN technique was also used to gain soft tissue volume (Figure 10.20c). An exposure after 6 months of healing revealed good bone fill of the fenestration defect (Figure 10.20d and e).

In managing the dehiscence-type defect, GBR with particulate grafting can be effective if the defect is ≥ 2 mm. In the first phase of anterior rehabilitation, a failing anterior bridge required extraction of the upper right cuspid. The resulting defect was managed with grafting and use of the IVAN technique as described above. This resulted in adequate volume for implant placement (Figure 10.21a). To restore the anterior segment, two implants were planned for the two lateral incisor positions. However, these sites had inadequate horizontal bone volume (Figure 10.21b). By utilizing FDBA with a titanium-reinforced GBR membrane, adequate horizontal width was obtained after 6 months of healing (Figure 10.21c). Two implants were placed (Figure 10.21d) and the final restoration was a single implant-supported crown on the upper right canine and a 4-unit implant-supported bridge (Figure 10.21e).

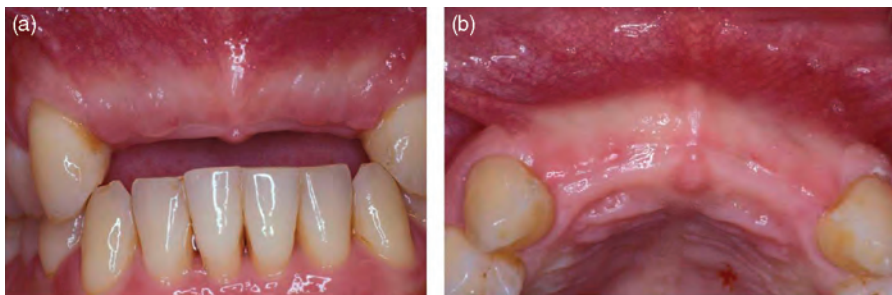


Figure 10.14 (a) Clinical presentation at five months following an extraction and socket augmentation procedure. (b) Note the thickness of the soft tissue and convexity of the alveolar ridge.

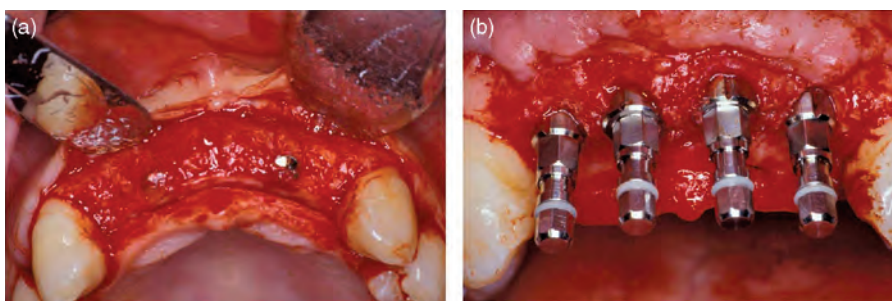


Figure 10.15 (a) Surgical re-entry at five months. Note the extensive vertical augmentation to the top of the bone screws. (b) Proper three-dimensional implant placement.

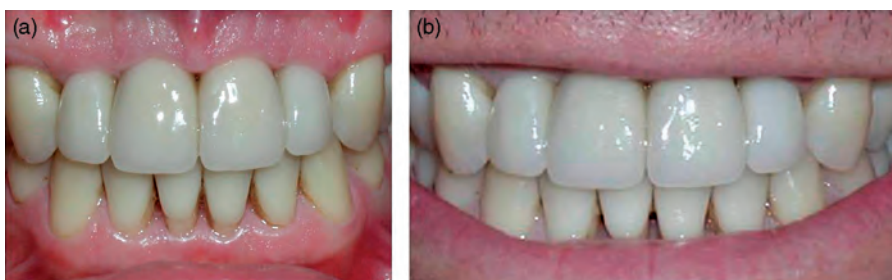


Figure 10.16 (a) Completed restoration with individual implant-supported crowns. (b) Smile reveals natural looking esthetic result.

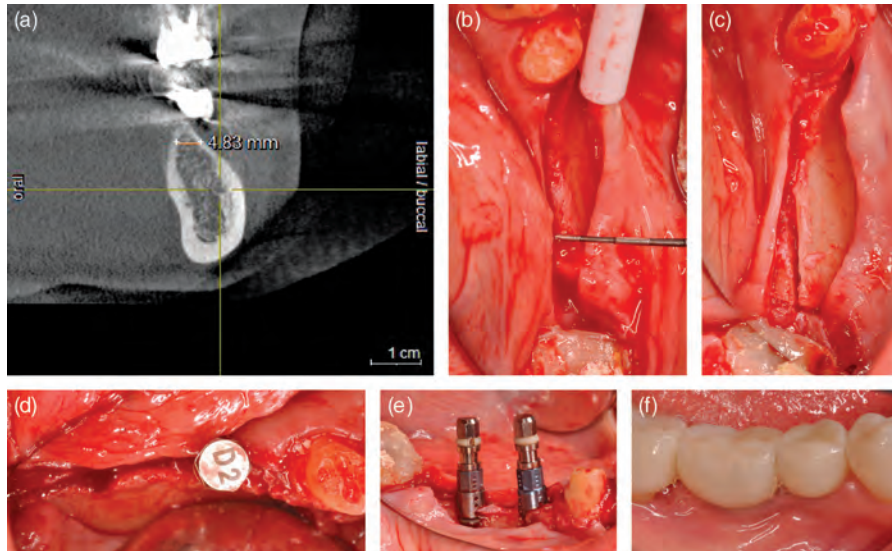


Figure 10.17 (a) Cone beam Cat Scan cross-sectional image of the mandibular right molar region, indicating a lack of ridge width for proper implant placement. (b) An apically directed photo indicating approximately a 3 mm bone width at the coronal aspect of the ridge. (c) Photo of initial ridge osteotomy cuts across the coronal aspect of the ridge and mesial, distal vertical releasing cuts. (d) Sequential ridge expanders are used to spread the sectioned bony segment to an adequate width. (e) With adequate ridge width attained, an implant placement with adequate stabilization was achieved. FDBA was used to fill the gap between bony plates and the GBR membrane covered the site prior to primary closure. (f) Photos of definitive restorations placed following 4 months of healing following a ridge split and implant placement.

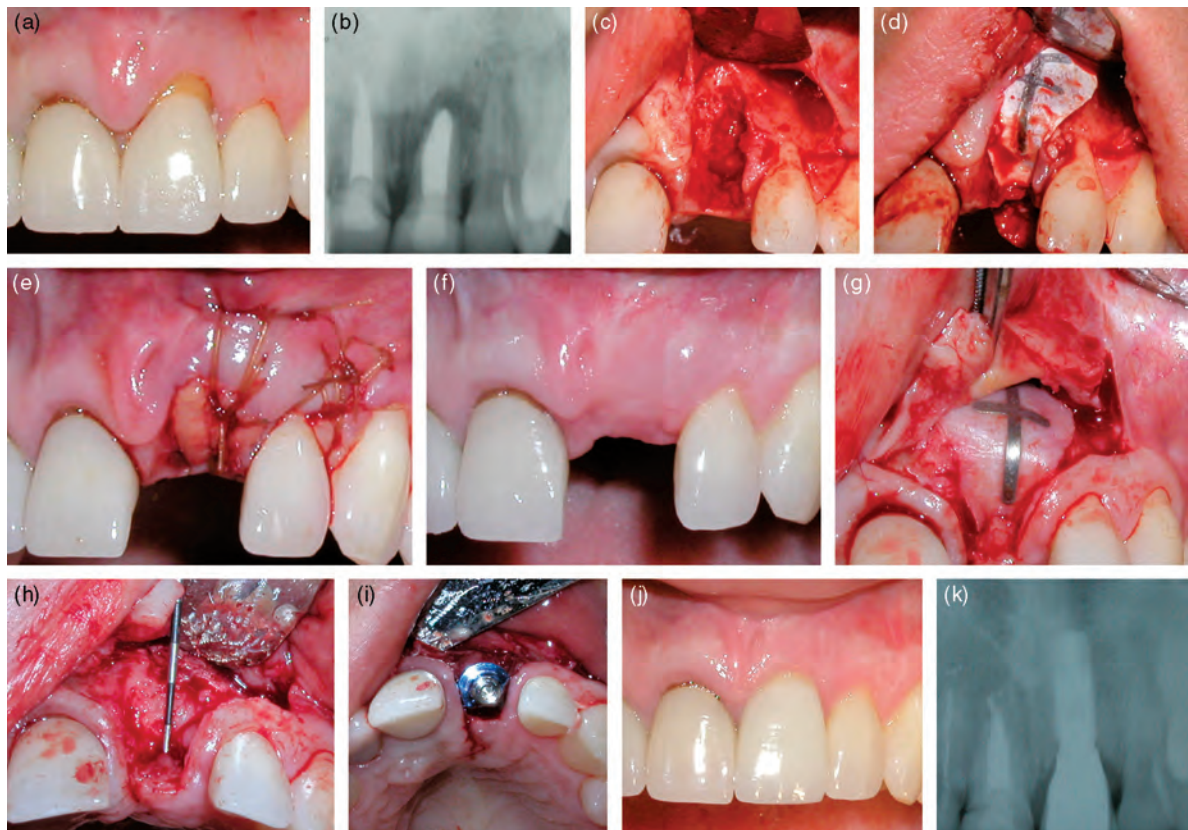


Figure 10.18 (a) Initial presentation of a maxillary left central incisor. Note the adjacent gingival margin height discrepancy; 2 mm and the generalized gingival recession. (b) Initial radiograph indicating osseous loss beyond the root apex. (c) Initial defect presenting with complete loss of facial bone. (d) The defect was filled with FDBA and covered with a titanium-reinforced ePTFE membrane placed over the defect and under palatal tissues. (e) The PCTG was rotated over the defect and sutured in place. Note the extent of exposed PCTG tissue over the non-absorbable membrane. Little attempt to coronally reposition the facial tissues was made. (f) Tissue healing at 6 months. No exposure of the ePTFE membrane was noted. (g) Exposure of the ePTFE membrane. (h) Measurement of the regained width of alveolar housing, now adequate for implant placement. (i) Implant placement. (j) Definitive restoration in place. Note the gain in marginal gingival height and little loss in interproximal papillae. (k) Radiograph after definitive restoration placement.

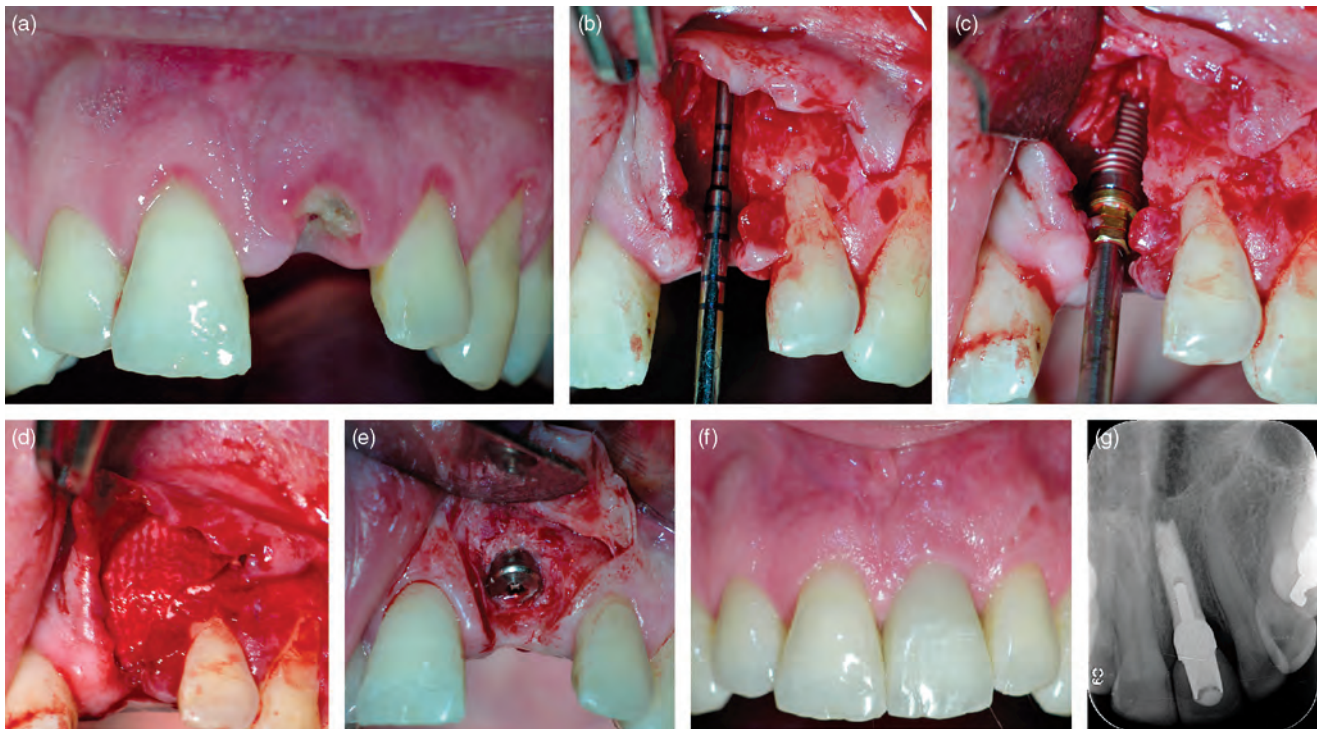


Figure 10.19 (a) Initial presentation of a fractured maxillary central incisor. Note the high scalloping and papillae heights. (b) Initial defect with loss; 13 mm of facial bone. (c) Immediate implant placement to the final depth. Note the number of threads exposed on the facial aspect and above any marginal bone. (d) The implant was covered with FDBA, calcium sulfate barrier, and a bioabsorbable membrane. (e) When the implant was uncovered, bone covered all threads and to just below the polished collar. Some residual allograft particles were evident. (f) Definitive restoration in place. Note the minor loss of papillae heights. (g) Radiograph after definitive restoration placement.

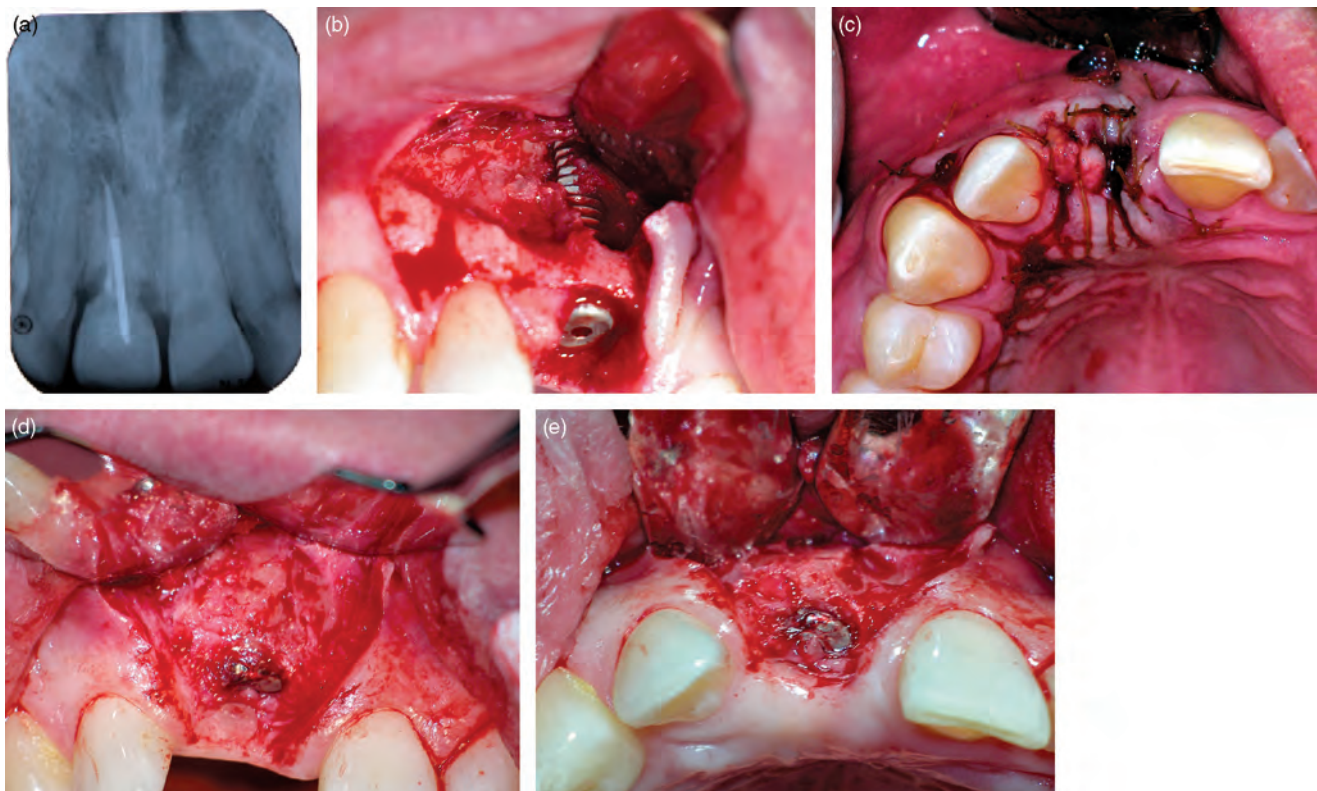


Figure 10.20 (a) Initial radiograph indicating resorption and periapical radiolucency. (b) Photo after extraction and immediate implant placement. Note the facial fenestration due to apical infection. (c) Following the IVAN protocol utilizing FDBA and ePTFE membrane, the site was augmented and closed. (d, e) Exposure of implant 6 months after placement showing approximately a 2–3 mm horizontal augmentation.

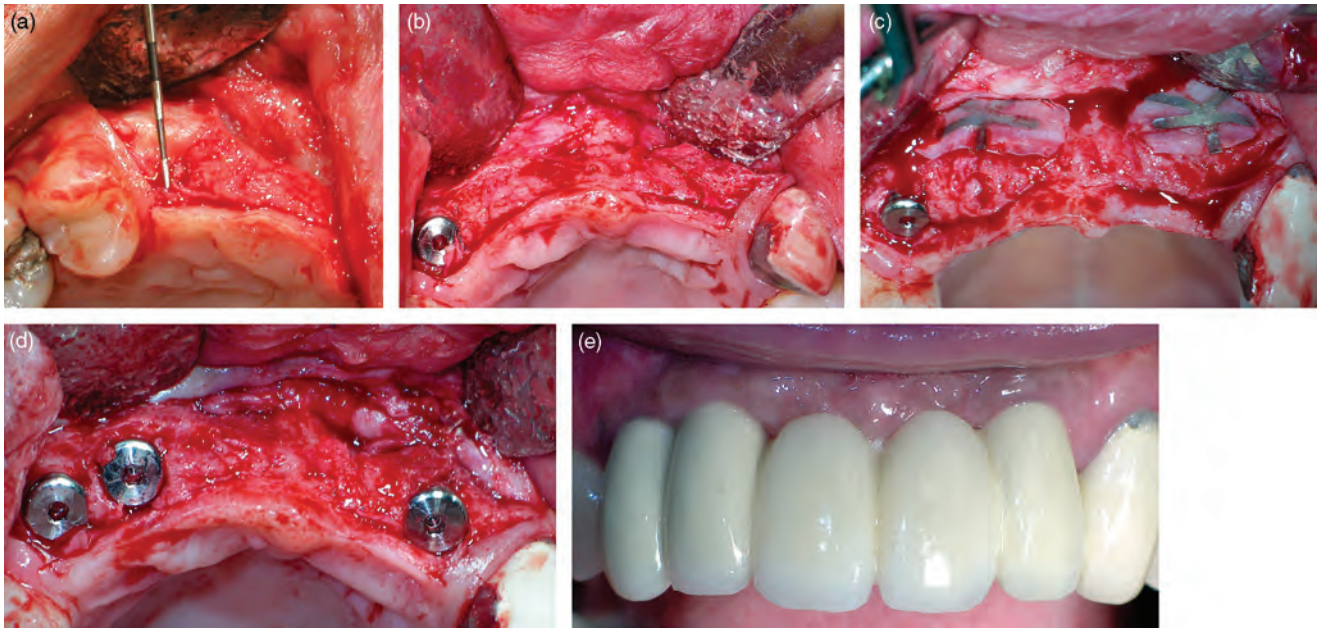


Figure 10.21 (a) Photo showing bone augmentation of the maxillary right canine following the IVAN delayed implant protocol using FDBA and ePTFE membrane. Note approximate 6 mm horizontal augmentation from the palatal socket wall. (b) Photo at exposure of the implant placed 4 months prior into the augmented maxillary right canine site. Note the lack of bony housing width at apical portions of maxillary right and left lateral sites. FDBA and ePTFE augmentation was completed. (c) Following a 6 month healing, the maxillary lateral sites were exposed and membranes removed. (d) Increased apical ridge width allowed for proper implant placement into the maxillary lateral augmented sites. (e) Photo of definitive restoration placed by a restorative dentist allowing for 4 months of osseointegration healing of implants in maxillary lateral sites.

Discussion

The use of a graft material for the fresh extraction socket has been proposed to preserve the natural tissue contours at the time of extraction and is well supported by the literature [26–28]. Various materials have been studied, and it is important to understand that different grafting substitutes will have different effects on two critical outcomes at the time of implant placement. The first is the percentage of vital bone and residual graft material remaining at the time of implant placement and the second is the clinical horizontal and vertical hard and soft tissue ridge alteration. A recent human randomized controlled clinical trial evaluating ridge preservation with a rapidly resorbing bone filler (calcium sulfate, or CS) versus a more slowly resorbing bone substitute (freeze dried bone allograft, or FDBA) found that while there was more vital bone and less residual graft material for the CS at 3 months (32% and 2.54% versus 17% and 21.37%), there was significant horizontal bone loss in the CS group, resulting in 15–20% horizontal soft tissue reduction [29]. Graft materials with high resorption rates allow for the formation of bone with little residual graft particles at the time of implant placement; however, their ability to sustain the alveolar ridge volume in the long term might be inferior to that of mineralized grafts.

In dehiscence-type and fenestration-type defects, the best-documented augmentation protocols are the use of particulate graft with GBR, particulate autograft with or without GBR, and a non-resorbable GBR approach. The volume that can be achieved varies. Our clinical experience indicates that defects ≥ 2 mm can be achieved easily with particulate graft and GBR membrane used in conjunction. As more bone volume is required, one needs to consider the use of a titanium-reinforced GBR membrane or the alternative of bone blocks.

The scientific evidence from the literature suggests that none of the grafting materials has a clear benefit over the other, although certain trends can be interpreted. Multiple studies utilizing *mineralized* graft material taken from core biopsy samples demonstrated approximately 17–27% vital bone following 3–6 month healing periods, compared with the *non-mineralized* products, which demonstrated vital bone findings of approximately 28–53%. It is unknown whether or not mineralized versus non-mineralized graft materials have any effect on dental implant osseointegration. Histological evidence has demonstrated that bone formation occurs over the surface of implanted osteoconductive graft particles and that bone-to-implant contact following bone regeneration performed with different bone fillers is similar to that of implants placed in pristine bone (40–65%) [30–33]. It is important to understand that the use of osteoconductive bone graft fillers do not enhance or accelerate bone healing but allow for better preservation of the ridge volume, which is critical for both the esthetics and function of future implant restoration.

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CHAPTER 11

Horizontal Alveolar Ridge Augmentation Using Titanium Mesh and Particulate Bone Graft for the Treatment of Alveolar Ridge Defects

John F. “Eric” Hamrick

Department of Periodontics, Medical University of South Carolina School of Dentistry, Greenville, South Carolina, USA

Introduction

Guided bone regeneration to aid in the development of an adequate alveolar ridge form and volume for proper implant placement has been successfully accomplished with various techniques and materials over the past 30 years in implant dentistry. Prior research in periodontal regeneration around teeth by Nyman, Karing, and others [1] with the use of membranes to exclude unfavorable tissues to assist the development of a fully functional periodontal ligament or PDL and periodontal attachment led to the development of guided bone regeneration, or GBR, as described by Buser [2]. Instead of regenerating the periodontal attachment, in GBR the goal is to isolate and develop bone as the selected tissue for regeneration.

With the development of GBR, which accelerated in the 1990s and continues today, clinicians have been able to successfully treat alveolar dehiscences, fenestrations, ridge concavities, extraction sockets, and other alveolar ridge deficiencies.

This chapter will review the techniques required to accomplish GBR with the use of particulate bone graft and titanium mesh combined with the use of rhBMP-2 in the treatment of horizontal alveolar ridge defects [3]. Although we will briefly discuss and demonstrate the use of titanium-reinforced dense polytetrafluoroethylene (d-PTFE) barrier membranes (Cytoplast, Osteogenics, Lubbock, TX, USA) and the use of resorbable membranes in GBR, this will be done primarily for comparison purposes only, as the focus of this chapter will be on titanium mesh as a barrier in GBR therapy.

Basic surgical principles of GBR

The basic principles involved in GBR are the same despite the type of exclusive membrane being used. As described by Sonick and Hwang, these principles include [4]: (1) primary wound closure, (2) angiogenesis, (3) space maintenance, and (4) wound stability.

Primary wound closure

The importance of tension-free closure of any type of alveolar bone graft procedure cannot be overstated. Meticulous periosteal releasing incisions of the buccal flaps and the use of vertical releasing incisions where necessary are of great value in allowing for flap closure without tension [5]. In the mandibular posterior region, a blunt dissection of

the mylohyoid muscle can be very helpful in achieving primary wound closure, and can help prevent the advancement of the mucogingival junction from being positioned crestally (Figure 11.1). Great care must be applied with blunt dissection of this muscle to avoid complications with vital lingual anatomic structures. Because flap opening during post-operative healing is one of the primary reasons for graft resorption and/or failure, this step is of primary importance when completing GBR procedures.

Angiogenesis

The initiation of the vascular supply to the newly grafted site is accomplished through careful decorticating of the cortical plate to open into existing vascular channels. This important step is essential to graft healing and is especially important in locations where the native cortical bone is thicker (i.e. the mandible). The decortication step initiates the regional acceleratory phenomenon (RAP) [6], resulting in the rapid development of the formation of vascular supply to the graft [7].

Space maintenance

In sites where there are alveolar ridge defects with natural concavities or other morphologic shapes that allow for natural space-maintaining on either end of the alveolar defect, the actual bone graft itself will often provide the space required to allow for the regeneration of needed bone, regardless of the occlusive membrane or mesh being utilized. Where there are flat ridge deformities not conducive to space maintenance, the creation of a space in which bone needs to regenerate is more clinically challenging. The use of tenting devices such as screws and pins can be helpful in preventing a membrane or titanium mesh from collapsing into the space, thus preventing adequate bone regeneration. The use of more rigid, non-resorbable membranes or titanium mesh can be helpful in the long-term maintenance of that type of space, especially in larger defects [8].

Wound stability

Any factors that cause trauma and/or excessive mobility to a healing GBR site can disrupt the initial fibrin clot and thus wound healing, including disruption of clot formation, an early formation of granulation tissue, and an early lamellar bone formation. These factors

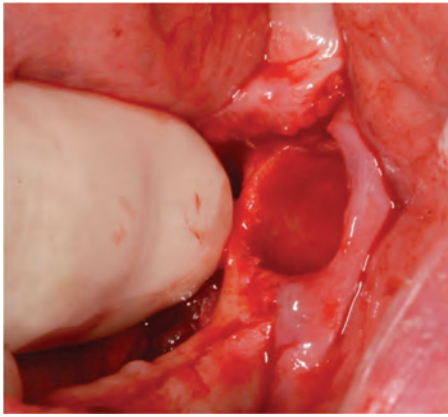


Figure 11.1 Blunt dissection of the mylohyoid muscle to provide for lingual flap release to aid in primary closure of bone grafting in the posterior mandible.

include trauma from removable prosthetic devices, patient habits, or lack of patient compliance with dietary restrictions. The effect of trauma can disrupt not only the normal cellular cascade, leading to early bone formation, but may also lead to early flap opening.

Surgical technique of GBR with non-resorbable devices

Incisions and flap design

A mid-crestal incision is made across the length of the defect, and vertical releasing incisions are generally made at least one tooth away from the site being treated. Bisection of the crestal keratinized gingiva is accomplished with this incision. In some cases, an envelope-style flap without the need for vertical incisions may be appropriate, but this flap design often requires extending a sulcular incision at least two teeth beyond the defect being treated, involving the reflection of additional papillae. In the esthetic zone, these vertical incisions are often modified to spare adjacent papilla in order to minimize the risk of esthetic complications during wound healing. In this scenario, care must be given to meticulous flap management and closure, as the mesh will be in close approximation to the vertical incisions (Figure 11.2).

Flap elevation and site preparation

Full thickness mucoperiosteal buccal and lingual (palatal) flap elevation is completed beyond the mucogingival junction and at least 5 mm beyond the defect being treated. Careful manipulation of

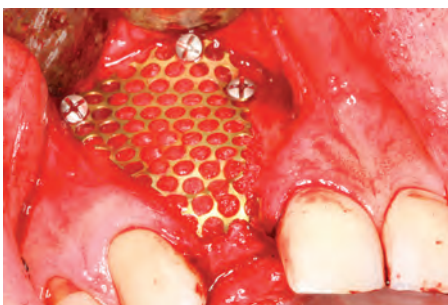


Figure 11.2 Note the close proximity of the titanium mesh to the vertical papilla sparing incisions.

the flaps around important anatomic structures, i.e. mental and infraorbital foramina and their respective nerves and blood vessels, must be observed [9]. Once the flaps have been elevated, careful removal of any residual soft tissue on the grafted site being treated is then completed. This step is accomplished with the use of back-action chisels, as well as diamond or carbide-fluted burs. Removal of all soft tissue to thoroughly clean the bone is critical, as residual soft tissue may impede the regeneration process.

Decortication through the existing cortical bone into the bone marrow is then accomplished, initiating the RAP phenomenon, as previously described. This step is accomplished using a small round bur or a small-diameter carbide end-cutting bur [10].

Harvesting of bone

When treating smaller horizontal alveolar ridge defects, the use of bone allograft material is often sufficient to avoid the need for and harvest of the autogenous bone. When larger defects are being treated, the use of autogenous bone combined with bone allograft is the technique employed by the author. In treating larger defects, a 50–50 mix of autogenous and allograft bone is ideal. The mandibular ramus buccal shelf is the primary donor site for most cases. However, the treatment of even larger defects requires the use of the mandibular symphysis as the donor site for graft harvesting. Bone scrapers are often used when only a limited amount of bone is required. In the treatment of larger defects, trephines are used to harvest bone cores. Once harvested, these cores are particulated by the use of a bone mill.

Buccal flap release

Before initiating the grafting process, releasing of the flap(s) is then completed. Flap release generally results in increased bleeding and such bleeding should be controlled prior to proceeding with graft and mesh or membrane placement. Holding the coronal edge of the flap with Adson tissue forceps to provide slight tension and stability to the flap, the incision is completed with a new 15 or 15c blade and is made near the base of the flap, in a distal-to-mesial direction. The working edge of the blade is oriented perpendicular to the underside of the flap. This incision should be through the periosteum and only slightly into the underlying connective tissue. Metzenbaum scissors are then inserted 1 to 2 mm into the wound, opening the beaks of the scissors in a direction parallel to the releasing incision [11].

With larger cases requiring a longer initial crestal incision, more than one application of spreading with the Metzenbaum scissors may be required to adequately release the flap for tension-free closure. This technique for proper buccal flap release is fundamental to any type of alveolar bone graft procedure where maintaining primary closure is paramount. This is particularly true of GBR grafts where non-resorbable membranes or titanium mesh is to be used. Early exposure and infection of non-resorbable membranes often requires removal of the barrier. This generally results in significantly less bone regeneration [12].

If titanium mesh is to be used as the barrier, it is helpful to have the mesh pre-trimmed prior to the surgery on a stone model. Care must be taken not to allow the mesh, or any other non-resorbable membrane, to touch adjacent root surfaces. In the case of titanium mesh, the initial pre-trimming should allow for the mesh to be several mm longer than needed in a buccal-lingual dimension, as adding particulate bone and a collagen sponge will occupy considerable space and can result in the mesh not extending sufficiently beyond the defect. This may cause the mesh to be too short for the defect being treated. The mesh and/or non-resorbable membrane should be stabilized with screws or tacks such that the periphery should be at least 3 mm beyond the alveolar defect.

Stabilization and immobility of titanium mesh or a non-resorbable membrane is vital to GBR success. Lack of stability and resulting movement at the GBR site impair bone healing and regeneration [13].

It is usually necessary to stabilize the mesh or non-resorbable membrane on either the lingual or buccal aspect of the site being treated with at least one screw or tack when beginning the grafting procedure after the final trimming has been completed. This technique allows the surgeon to place the grafted materials and then position the remaining mesh efficiently over to the buccal or lingual aspect of the surgical site for final membrane or mesh fixation.

Flap closure technique

The vertical releasing incisions on either end of the surgical site are closed with single interrupted sutures. The mid-crestal incision over the grafted site is closed in two layers. The first layer closure involves the use of horizontal mattress sutures, which leads to some degree of eversion (Figure 11.3) of the flaps with a connective tissue layer from both sides of the flaps in intimate contact. Interrupted sutures are then placed in between the horizontal mattress sutures to complete the final layer of wound closure. 5.0 Gortex polytetrafluoroethylene (PTFE) suture is used to close the mid-crestal incision and either 5.0 Gortex suture or 5.0 gut suture is used to close the vertical incisions.

The majority of cases being presented by the author with titanium mesh involve the use of product Infuse®, which is a recombinant bone morphogenetic protein-2 (rhBMP-2) in a collagen sponge (INFUSE®, Medtronic, Minneapolis, MN, USA) and particulate allograft and autogenous bone. BMP-2 is a genetically engineered version of a natural protein designed to regulate bone growth and healing. It is used on a natural carrier, a sponge

manufactured from bovine Type 1 collagen. INFUSE® is approved by the US Food and Drug Administration (FDA) for use in certain maxillofacial bone grafting procedures, such as sinus augmentation and localized alveolar ridge augmentation. The description of the BMP-2 product INFUSE® in this chapter is for off-label use.

Figures 11.4 to 11.9 illustrate the surgical technique in the treatment of a horizontal alveolar ridge defect (GBR) with titanium mesh, particulate bone, and rhBMP-2.

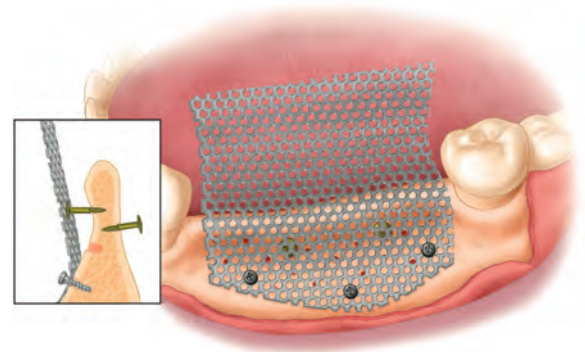


Figure 11.5 The titanium mesh has been trimmed and initially fixated on the buccal in preparation for bone grafting.

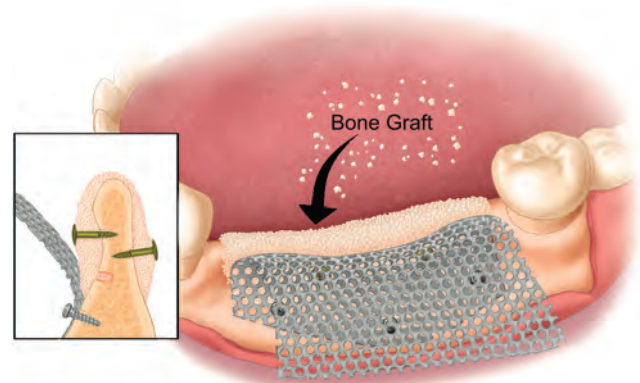


Figure 11.6 Particulate graft is placed under the mesh.

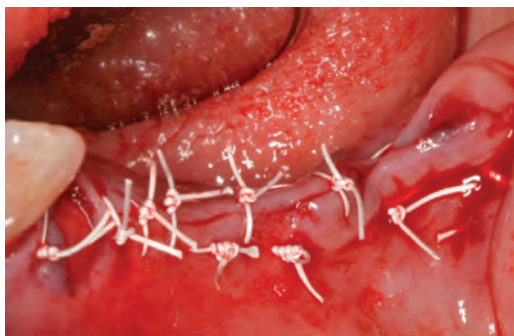


Figure 11.3 Primary closure with horizontal mattress sutures, as well as interrupted sutures in between, illustrating two-layer closure.

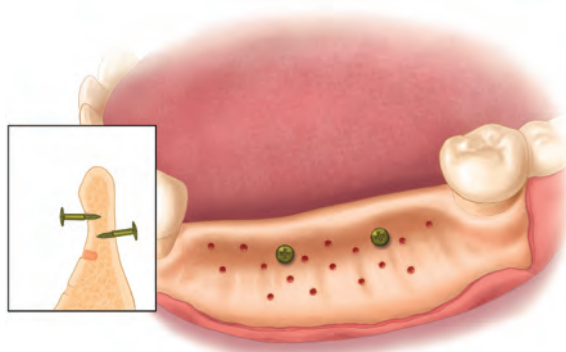


Figure 11.4 Following flap elevation, the ridge defect has been decorticated and tenting screws placed on the buccal and lingual.

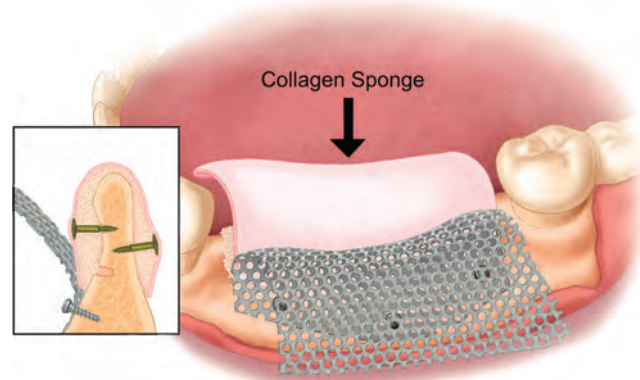


Figure 11.7 Collagen sponge infused with rhBMP-2 is placed over the graft prior to final mesh fixation.

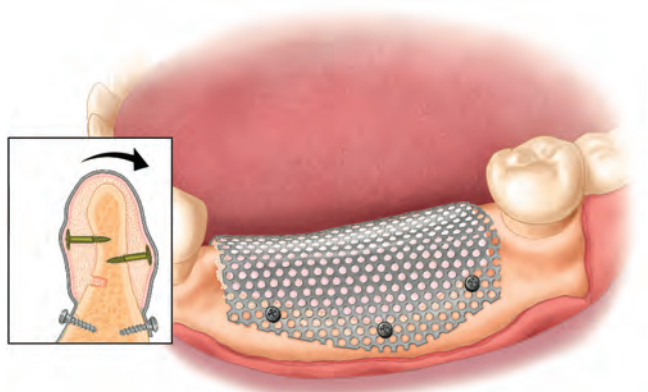


Figure 11.8 Final mesh fixation on the lingual with fixation screws.

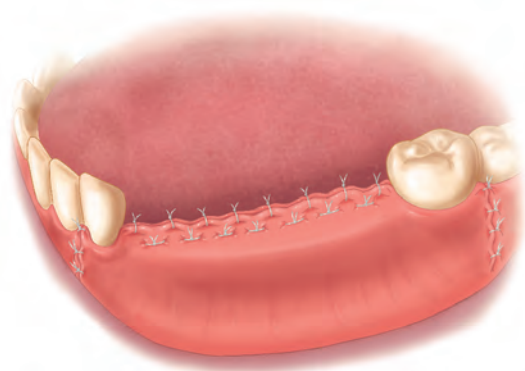


Figure 11.9 Flap release has been accomplished and primary closure achieved with both horizontal mattress sutures and interrupted sutures.

Case reports

Case 1

Case 1 involves the treatment of missing tooth 30. The resulting horizontal defects on the buccal and lingual aspects of the alveolar ridge both exhibited natural concavities (Figures 11.10 and 11.11). These defects were treated with a composite graft material consisting of a 50/50 mix of autogenous and freeze-dried bone allograft (Puros, Zimmer, Inc., Warsaw, IN) (Figure 11.12). The autogenous bone was harvested in particulate form from the mandibular right ramus, utilizing an Ebner autogenous bone scraper (Figure 11.13). A resorbable membrane Ossix® Plus membrane (Datum Dental Ltd., Lod, Israel) was used as a barrier and no tenting apparatus was required as a result of the natural space maintaining morphology of the defect (Figure 11.14). This particular resorbable, porcine membrane is highly cross-linked, and is often noted to be found at least partially intact during re-entry of the graft site up to six months later. Following four months of healing, the site was re-entered and a 5.0 diameter titanium implant was placed (Figure 11.15). The horizontal augmentation resulted in approximately 6–7 mm of buccal-lingual bone growth, resulting in adequate width to support the large diameter implant and restoration (Figure 11.16).

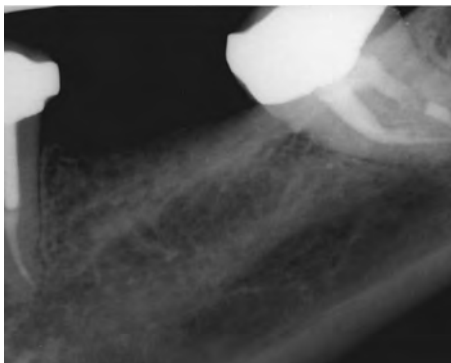


Figure 11.10 Radiograph of missing mandibular right 1st molar tooth. Note that both abutment teeth have been endodontically treated.

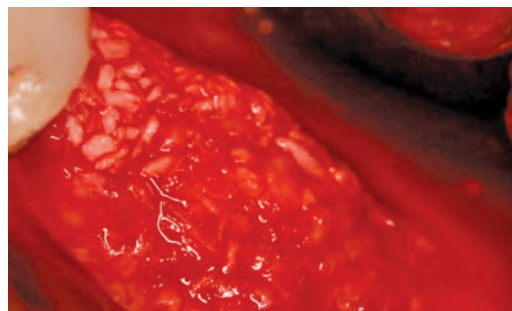


Figure 11.12 Particulated composite graft hydrated with autogenous platelet rich plasma. Note good consolidation of the graft.

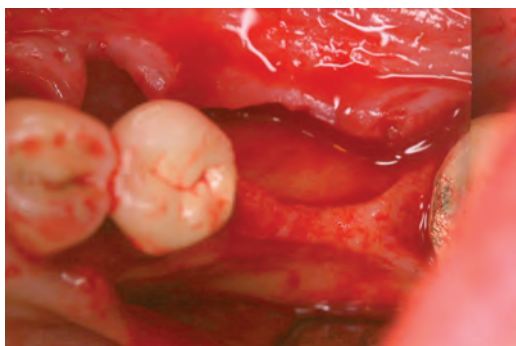


Figure 11.11 Representative case with natural buccal and lingual space maintaining concavities.

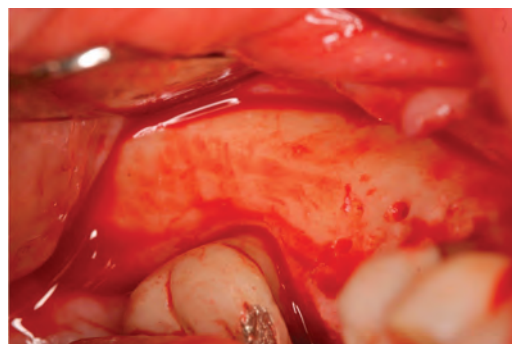


Figure 11.13 Ramus buccal shelf harvest site for procuring autogenous chips of bone for the composite graft.

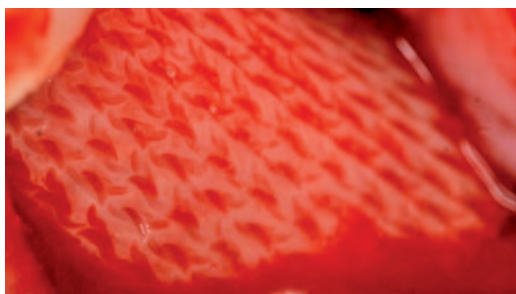


Figure 11.14 Representative case of a well-adapted porcine collagen membrane over the bone graft (Ossix® Plus membrane).

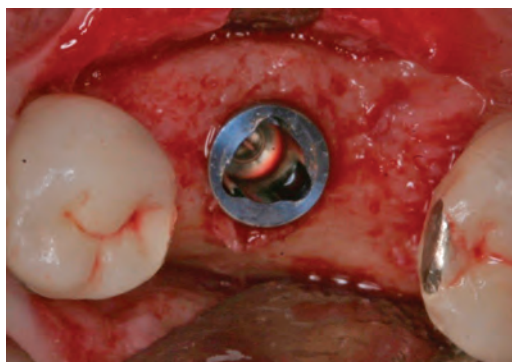


Figure 11.15 A 5.0 mm Nobel Replace Select diameter implant placed in an ideal prosthetic position.



Figure 11.16 Final radiograph of the restored implant in 1 month post-loading.

Case 2

Case 2 involved the use of titanium-reinforced dPTFE barrier membrane in the treatment of advanced horizontal alveolar bone defect in the anterior maxilla, as described by Jovanovic et al. [14]. The defect resulted from a prior automobile accident. Due to a lack of keratinized tissue, the initial procedure involved a free gingival graft with a vestibuloplasty procedure to widen the zone of keratinized gingiva. When closing the flaps over a larger GBR site, it is advantageous to have keratinized tissue to work with in achieving primary flap closure [15]. Following three months of healing, guided bone regeneration in the area of both missing maxillary central incisors and left lateral incisor positions was accomplished with the use of tenting screws, autogenous bone, and bone allograft with titanium-reinforced dPTFE membrane as the barrier (Figure 11.17). Platelet-rich plasma (GEM-21S, Lutipold Pharmaceuticals Inc., Shirley, NY) was used to hydrate the bone graft. The previously described GBR technique was used with a variation in the placement of the tenting screws. This variation involved drilling completely through the ridge defect and then threading the tenting screws from buccal to lingual such that both ends of the screw could be used to create space (Figure 11.18). The sharp ends of the screws were blunted with a tapered diamond drill. The titanium-reinforced dPTFE barrier membrane was carefully trimmed and shaped to cover the grafted site, and then was fixated with bone screws (Figures 11.19 and 11.20). The author has used this technique in numerous clinical cases with predictable success in treating horizontal alveolar ridge defects. The normal suturing protocol for a two-stage layered primary closure was completed. Figure 11.21 illustrates the healed ridge after five months of healing at the time of implant placement surgery.

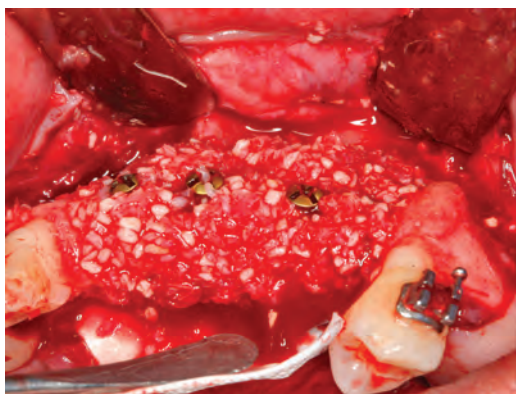


Figure 11.17 A composite graft hydrated with platelet rich plasma – GEM-21S. Note the titanium-reinforced dPTFE barrier membrane fixated to the palatal side of the defect prior to graft placement.

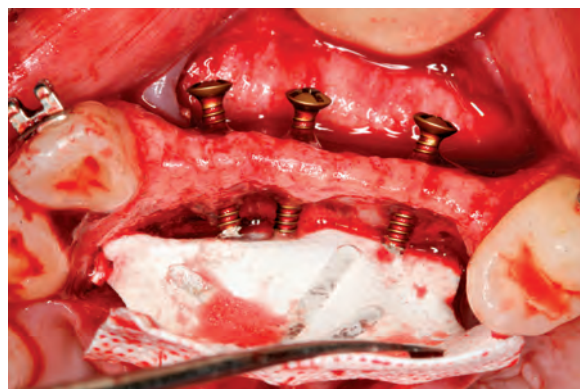


Figure 11.18 Tenting screws placed through the alveolar ridge, with both the screw heads and the blunted tips utilized for space maintenance.

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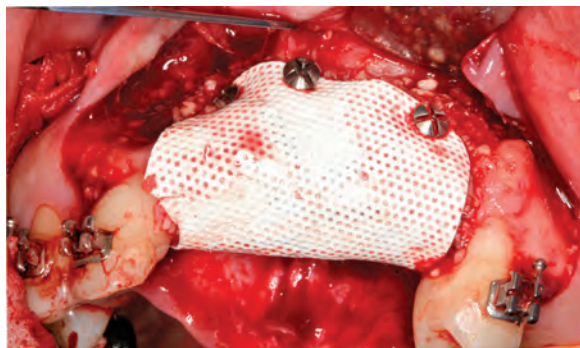


Figure 11.19 Final fixation of the membrane with three 4 mm bone screws.

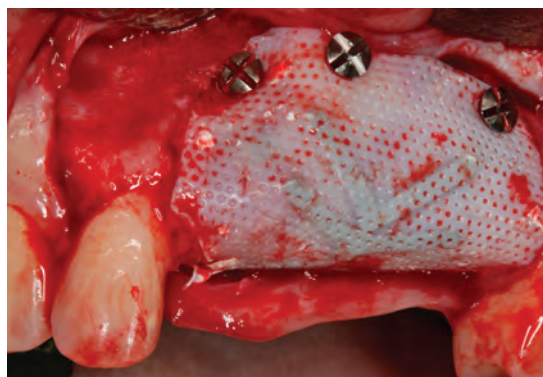


Figure 11.20 Representative image of three bone screws fixating the buccal aspect of the membrane. Note how the membrane was trimmed approximately 1 mm away from the adjacent teeth.

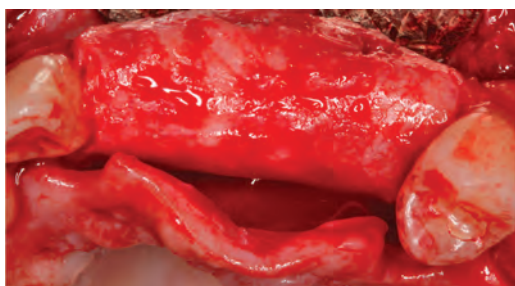


Figure 11.21 Photo of the healed GBR site after 5 months of healing. Approximately 7 mm in gain of alveolar bone width was achieved, in preparation for ideal implant placement.

Case 3

Case 3 involved replacement of lower right first and second molars due to the loss of the abutment tooth, a second molar, which served to support a fixed restoration that extended from the second premolar to the second molar (Figure 11.22). The resulting alveolar defect was noted to have a flat alveolar outline with a minimal bony concavity (Figure 11.23). This site was treated with an allograft only (Puros) combined with a collagen sponge saturated with recombinant bone morphogenetic protein-2 (rBMP2) (Medtronic) (Figure 11.24). Titanium mesh (Synthes, Inc., West Chester, PA, USA) was used as the barrier to contain the graft (Figure 11.25). Then 4 mm titanium screws (Synthes, Inc., West Chester, PA, USA) were used to fixate the mesh both buccally and lingually. In this case, no tenting device was used, as the graft itself was deemed sufficient for this purpose. Primary closure over the surgical site was accomplished as previously described (Figure 11.26). After three months of wound healing, a periapical radiograph and a cone beam CT (CBCT) scan were taken to evaluate bone healing (Figure 11.27). After six months of post-operative healing, two titanium implants were placed to replace both missing molar teeth (Figure 11.28). The resulting bone augmentation allowed for placement of two 4.5 diameter implants to support the final non-splinted restorations (Figure 11.29).

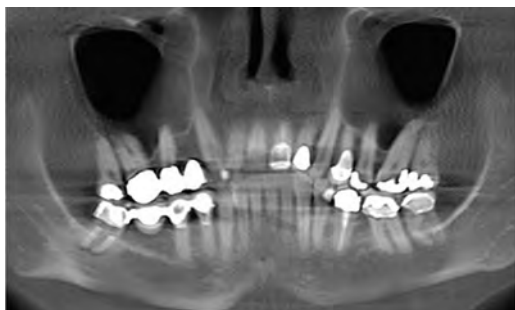


Figure 11.22 Panoramic radiograph of the failed bridge abutment mandibular right second molar tooth due to recurrent caries.

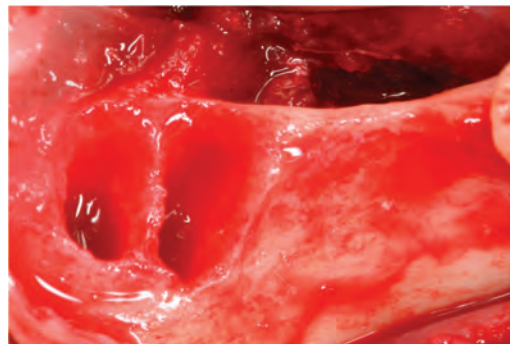


Figure 11.23 Photo of the extraction site as well as the buccal-lingual ridge defect in the mandibular right first molar area.

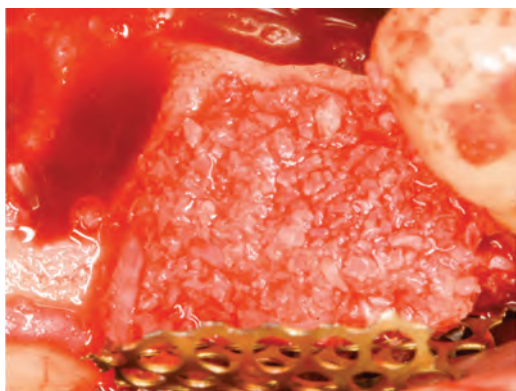


Figure 11.24 Representative image of the composite bone graft and rhBMP-2 sponge over the graft. Titanium mesh has been fixated on the buccal side with bone screws in advance of graft placement.

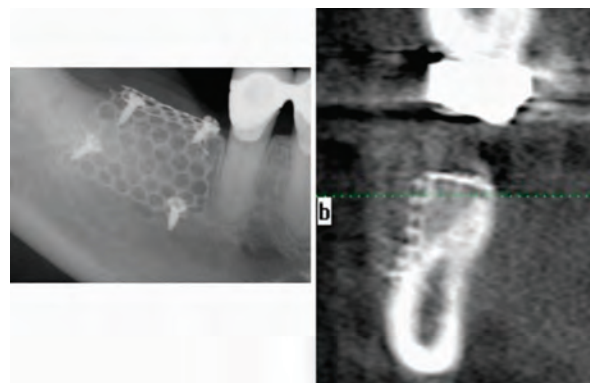


Figure 11.27 A three-month post-healing periapical radiograph and cross-sectional CBCT image of the graft. Note the delineation between the original defect and the newly regenerating bone.



Figure 11.25 Final fixation of titanium mesh over the bone graft and collagen sponge.

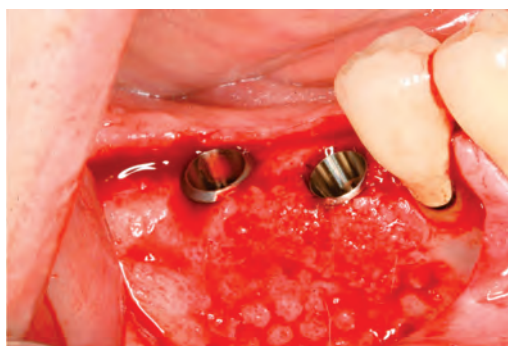


Figure 11.28 The resulting GBR procedure allowed for sufficient augmentation of bone width for ideal implant positioning.

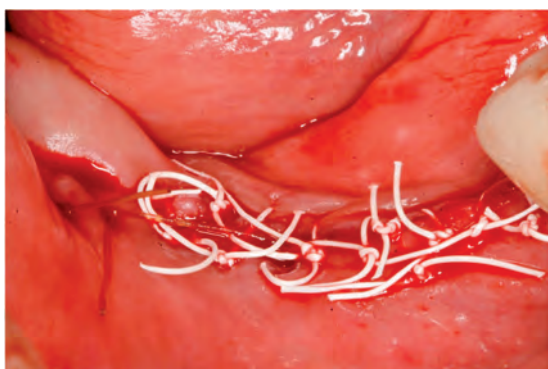


Figure 11.26 Note the primary closure of the GBR site with 5.0 Gortex suture and 4.0 Chromic Gut suture.



Figure 11.29 Two final non-splinted ceramic restorations in place.

Case 4

Case 4 involves treatment of an atrophic posterior left mandibular site where first and second molar and second premolar teeth were lost 20 years previously (Figure 11.30). In treating this defect, the ridge width in some areas was less than 1 mm in thickness (Figure 11.31). The resulting alveolar defect was primarily horizontal in nature with minimal vertical loss. This site was treated with GBR using a composite graft, combined with rhBMP-2 and titanium mesh. Due to the extent of buccal-lingual bone loss, three tenting screws (Synthes, Inc., West Chester, PA, USA) were utilized to provide for adequate space for bone regeneration (Figure 11.32). The apical extent of the mesh was fixated buccally with bone screws and the grafting procedure was followed as previously described. Following placement of the graft and a BMP-2 sponge, the mesh was fixated to the lingual side with two bone screws as described by Wikesjö et al. [16]. In this case, a collagen membrane Bio-Gide® (Geistlich Pharma North America Inc., Princeton, NJ, USA) (Figure 11.33) was used as an additional protective barrier over the titanium mesh, directly under the incision line closure. The membrane itself can aid in the preventing contamination of the mesh during early wound healing if slight flap retraction were to occur.

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Figure 11.30 A representative cross-sectional image of the atrophic ridge in the mandibular left posterior quadrant.



Figure 11.31 A clinical photo of the alveolar ridge defect demonstrating severe buccal-lingual loss of bone.

After six months of healing, the site was re-entered and three endosseous implants were placed (Figure 11.34). The resulting horizontal bone augmentation was adequately sufficient in a buccal-lingual dimension for ideal prosthetic placement of the implants and support of the final ceramic restorations (Figure 11.35).



Figure 11.34 After four months of healing, the three implants in the mandibular left second and first molars and second premolar sites were uncovered. Note the significant gain in ridge width as a result of the GBR procedure.



Figure 11.32 This image illustrates decortication and stabilization of the trimmed titanium mesh in preparation for bone augmentation.



Figure 11.33 After graft and rhBMP-2 sponge placement, the mesh was fixated lingually with two bone screws. An additional bovine collagen membrane was placed over the mesh at the crest beneath the incision closure site.



Figure 11.35 The final implant supported ceramic restorations.

Case 5

Case 5 involves reconstruction of the alveolar ridge of the anterior maxillary bone in preparation for implant placement in the area of missing anterior maxillary teeth from the right lateral incisor to the left canine with a screw-retained hybrid restoration (Figure 11.36). During the course of treatment, the maxillary left first premolar tooth was also extracted and replaced for both periodontal and restorative reasons.

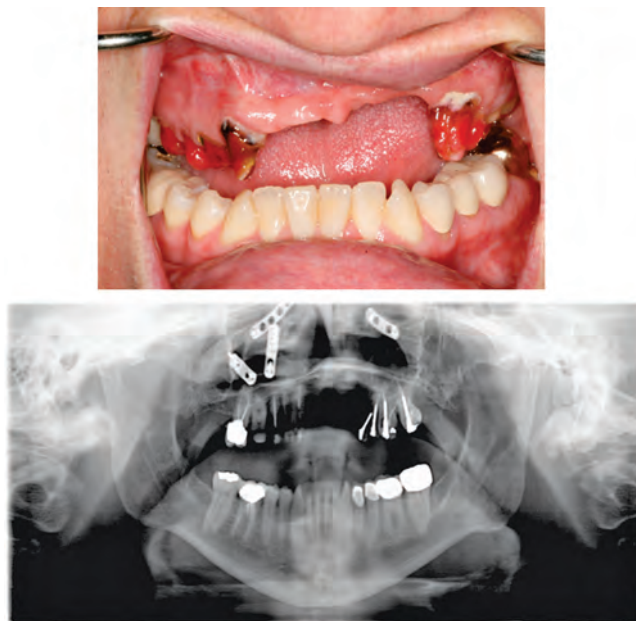


Figure 11.36 An initial pre-treatment photo and panoramic radiograph of the severe alveolar ridge defect in the maxillary anterior area.

The patient lost both teeth and alveolar bone from an automobile accident approximately 15 years prior to the treatment. Severe buccal-lingual bone loss was noted in a horizontal dimension on the right lateral and central incisor sites. On left lateral and central incisor and canine sites, the remaining maxillary ridge was noted to be severely atrophic, both vertically and horizontally, on the CBCT scan (Figure 11.37). Thin keratinized gingiva and alveolar mucosa was also observed on the buccal aspect of the ridge.

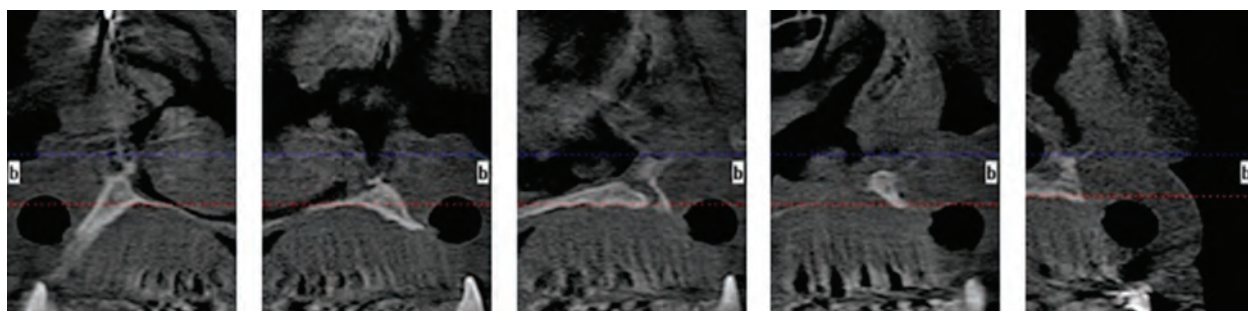


Figure 11.37 Pre-treatment cross-sectional CBCT images of the atrophic anterior maxilla. Note the severe vertical bone loss on the patient's anterior maxillary left side, in the lateral incisor and canine area.

Prior to bone augmentation, a free gingival graft and vestibuloplasty procedure was completed to thicken and widen the zone of keratinized gingiva and allowed to heal for three months prior to bone augmentation (Figure 11.38). Guided bone regeneration therapy was performed using titanium mesh, supported vertically and horizontally by tenting screws. The composite graft used included a 50–50 mix of autogenous bone harvested from the mandibular symphysis and a cortico-cancellous allograft (Puros). The autogenous bone cores were particulated with a bone mill.

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Figure 11.38 Vestibuloplasty and a free gingival graft were completed to augment soft tissue thickness and dimension prior to bone grafting.

Due to the large defect size, a BMP-2 graft and ACS sponge were placed over the graft to stimulate additional bone induction. Periosteal-releasing incisions were made to assist in primary flap closure, as previously described (Figures 11.39 to 11.43).

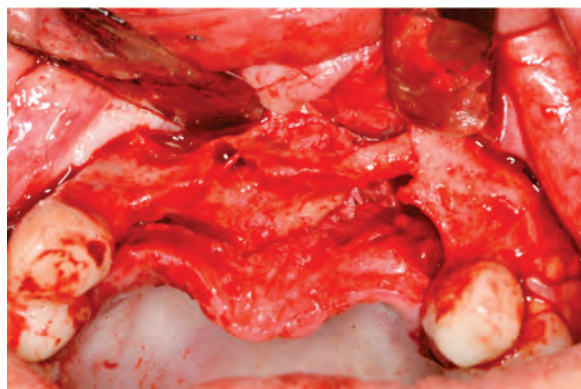


Figure 11.39 A preliminary image of the compromised alveolar ridge following initial flap reflection.



Figure 11.40 Harvesting of autogenous bone with trephine drills from the mandibular symphysis.



Figure 11.41 Placement of tenting screws for augmentation of width and height of bone. Due to the lack of bone above the nasal floor in the lateral incisor and canine sites, fixation of a vertical tenting screw here was not possible.



Figure 11.42 After securing the mesh palatally, the composite graft was placed. The rhBMP-2 infused collagen sponge was then placed over the bone graft.

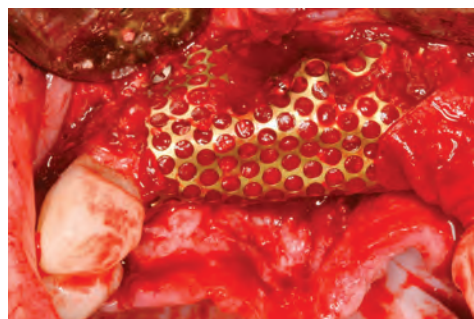


Figure 11.43 The last step prior to flap closure involved securing the mesh buccally and apically with additional bone screws. It should be noted that the diameter of tenting screws is wider than the mesh openings, preventing collapse of the tented mesh.

A 7-month healing period was allowed prior to reentry of the graft and placement of dental implants. A pre-operative CBCT scan was taken again at that time (Figure 11.44). Significant bone regeneration was noted in both vertical and horizontal dimensions, which allowed for favorable prosthetic positioning of implants with the aid of a surgical guide fabricated by prosthodontist (Figures 11.45 and 11.46). Healing screws were placed in the implants and primary flap closure was completed with a 5.0 Gortex suture. The implants were allowed a 4-month healing period and then surgically uncovered, and healing abutments placed. A screw-retained acrylic hybrid temporary restoration was placed approximately 4 weeks later. At the time of this writing, the patient was in the provisional phase of the prosthetic treatment (Figure 11.47).

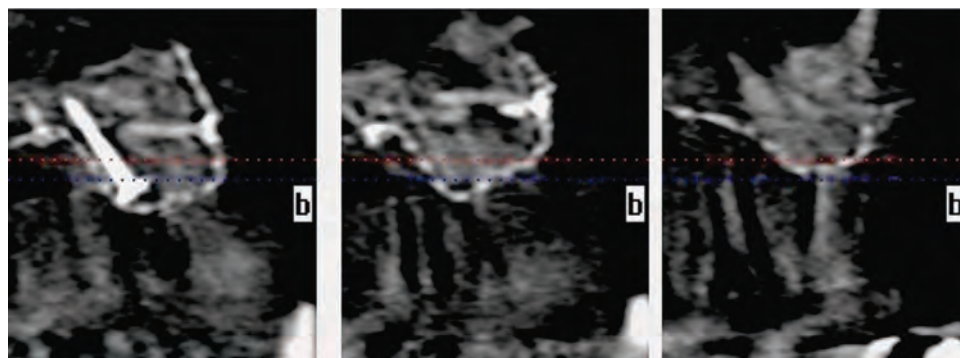


Figure 11.44 Three-month post-operative cross-sectional CBCT images of the healing bone graft. Note the extensive bone regeneration both vertically and horizontally.



Figure 11.45 Representative photo of implant placement after six months of graft healing.

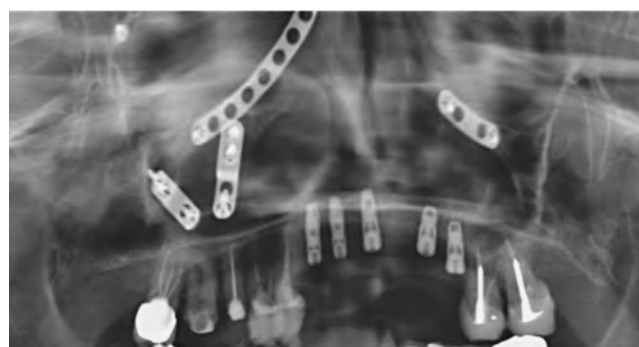


Figure 11.46 A panoramic image of implants following placement.



Figure 11.47 Following surgical uncovering of the implants and four additional weeks of healing, a temporary screw-retained implant-supported hybrid restoration was placed.

Post-operative care

The use of titanium mesh or non-resorbable membranes (i.e. titanium-reinforced dPTFE) requires more frequent post-operative visits during the first 4 weeks, as an exposure of these barriers often leads to bacterial invasion and infection, and ultimately loss of the graft. The patient begins the antibiotic regimen two days prior to the surgery and continues to completion for 8 days. A 0.12% chlorhexidine rinse twice per day is administered until soft tissue closure is confirmed. At the first post-operative visit at approximately 7 days, if slight incision line separation is noted, the use of GEM 21S® growth-factor enhanced matrix (Osteohealth, Shirley, NJ, USA) over the area may encourage more rapid revascularization and soft tissue bridging. The author has used this adjunctive biologic in numerous cases involving titanium mesh and titanium-reinforced dPTFE barrier membrane with good success. The key is early recognition and supportive use of the biologic in the early stage of wound healing. The patient is routinely seen every two weeks for the first three appointments and once a documented wound healing over the incision line is noted, monthly post-operative visits are maintained until the appointment for fixture placement several months later.

Complications

The most common post-operative complication with the use of titanium non-resorbable barriers involves the incision line opening and exposure of the mesh or membrane, which may lead to bacterial contamination, infection, and loss of the graft. In the scenario of early non-resorbable membrane or mesh exposure, the patient should be followed on a weekly basis and the membrane or mesh removed at the earliest signs of infection [17]. If this occurs, early intervention is critical to prevent graft failure. Generally speaking, titanium mesh requires removal within 2 to 6 weeks following exposure. Various studies report a range in non-resorbable membrane or titanium mesh exposure of 9–18% [18,19]. This often requires removal of the contaminated membrane or titanium mesh and replacement with a cross-linked resorbable membrane that will be less prone to infection if exposed, and still perform as an effective barrier membrane with documented resistance to degradation out to five or six months. Ossix® Plus membrane (Datum Dental Ltd., Lod, Israel) is a good example of such a membrane. The author has used this GBR rescue technique successfully in a number of such cases (Figures 11.48 to 11.50).

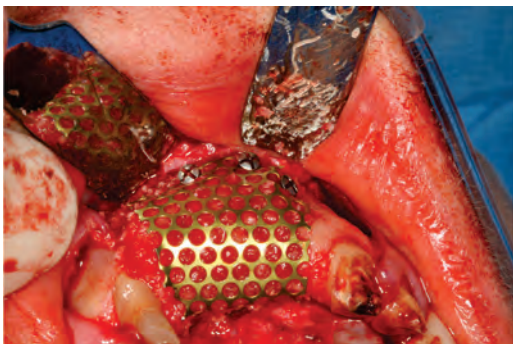


Figure 11.48 Three weeks following GBR procedure using titanium mesh as the barrier, the mesh became exposed with evidence of infection. The mesh was removed between the third and fourth week of healing.

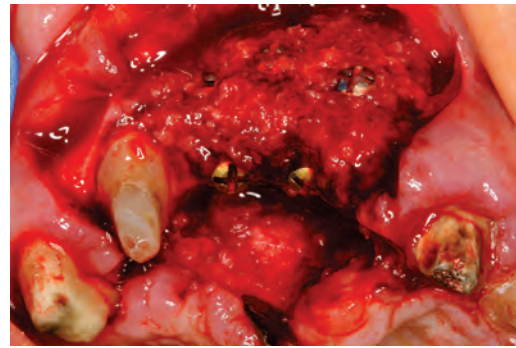


Figure 11.49 After mesh removal, the top surface of the graft was removed in an effort to reduce contamination. The remaining graft was rinsed with 0.12% chlorhexidine rinse for 1 minute and then rinsed with sterile saline.

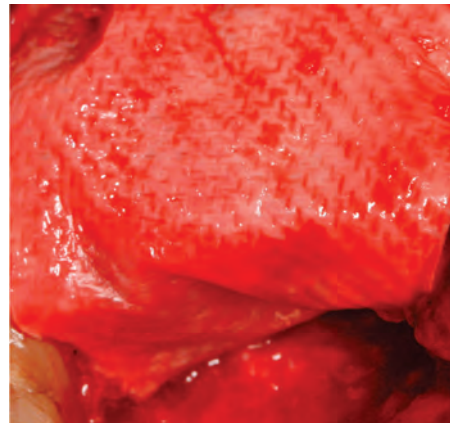


Figure 11.50 A resorbable collagen membrane (Ossix® Plus) was placed as a new barrier membrane and the flap closure was accomplished. The GBR site remained closed for two additional weeks of wound healing without evidence of further infection.

In cases involving titanium mesh over GBR sites when BMP-2 is used, the other significant side effect involves post-surgical swelling. During the initial two weeks of healing, this biologic stimulates a cellular cascade response that often contributes to additional post-surgical inflammation and swelling that is unresponsive to steroid therapy (Figure 11.51).



Figure 11.51 Significant post-surgical swelling noted 10 days following titanium mesh composite grafting with the use of rhBMP-2 (Infuse®).

Discussion

Non-resorbable rigid membranes, including titanium mesh, are often used in the treatment of larger alveolar ridge defects where a longer healing time as well as continued space maintenance is required for regeneration. Although this chapter primarily focuses on the treatment of horizontal bone defects, in cases where both vertical and horizontal defects are treated simultaneously, using a more rigid barrier to maintain a three-dimensional space is more predictably accomplished with these types of space maintaining devices [20]. Titanium-reinforced dPTFE barrier membrane (Cytoplast, Osteogenics, Lubbock, TX, USA) and titanium mesh (Synthes, Inc., West Chester, PA, USA) are two excellent barriers for the treatment of these types of alveolar ridge defects.

In larger, more demanding GBR cases, the use of resorbable membranes is less predictable in obtaining the desired outcome of complete regeneration or clinically successful regeneration. This is particularly true in treating larger defects where natural concavities are absent and tenting is required. In the author's experience, the Ossix® Plus membrane (Datum Dental Ltd., Lod, Israel) may rival non-resorbable barriers when augmenting large buccal-lingual ridge defects. As mentioned previously, this membrane remains intact as a barrier out to 25 weeks, is well tolerated, and has been used in numerous horizontal GBR cases by the author with predictable results.

Bio-resorbable membranes have fewer complications, are generally easier to adapt, and in morphological defects that are conducive to space maintenance require no fixation. In comparison to non-resorbable devices, however, the duration of membrane integrity is highly variable across the spectrum of available membranes. In cases where vertical augmentation in excess of 2–3 mm is necessary, non-resorbable membranes and titanium mesh prove to be superior [21,22].

Conclusion

Horizontal augmentation with GBR has become an extremely predictable technique in providing state of the art alveolar bone augmentation in dental implant therapy for patients. The advent of tissue engineering technology combined with GBR in the treatment of larger alveolar ridge defects will likely continue to improve clinical outcomes and allow clinicians to treat larger ridge defects with intraoral grafting techniques. Despite new advances in tissue engineering, the basic principles and surgical steps in guided bone regeneration must still be meticulously followed for predictable results.

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Management of Complications of Guided Bone Regeneration

Mark C. Fagan,¹ Gregory J. Conte,² and Richard T. Kao³

¹Private Practice, San Jose, California, USA

²Private Practice, San Francisco, California, USA

³Private Practice, Cupertino, California, USA

Introduction

Guided bone regenerative (GBR) techniques are very successful and regularly used modalities for alveolar ridge augmentation in implant dentistry. Despite high rates of positive treatment outcomes, complications of GBR sites are still a relatively common occurrence of GBR techniques. Some etiologic components for post-surgical complications are inadequate blood supply at the recipient site, perforation of GBR materials through the overlying soft tissue, infection of the underlying GBR materials, or any combination of the above. Furthermore, one of the etiologic components can lead to another, such as membrane exposure leading to infection of the site. Understanding the causes of complications is important to help decrease their occurrence.

Pre-treatment assessment

Any complex surgical treatment should be pre-planned using detailed case evaluation, including a work-up of the patient's medical and dental histories. The pre-treatment assessment should also contain adequate clinical diagnostic information and appropriate communication between all treating dental and medical practitioners. Some pre-treatment risk factors, which can potentially jeopardize the success of GBR techniques, include: (1) diabetes, (2) bisphosphonate therapy, (3) radiotherapy, and (4) smoking.

Diabetic hyperglycemia inhibits host defenses against infection [1,2], including many leukocyte functions [2,3]. Hyperglycemia also impairs wound-healing because of its deleterious effects on collagen formation, resulting in diminished wound tensile strength [4,5]. Since uncontrolled diabetes is capable of seriously affecting wound-healing, elective reconstructive surgery should be delayed until the disease is well controlled. Glycated hemoglobin (hemoglobin A1C) tends to be the most common modern test of plasma glucose concentration over a relatively long period of time (3–4 months) and therefore a good indicator of pre-operative diabetes control with a "healthy" A1C number below 6.0%.

Intravenously administered bisphosphonates used in cancer or osteoporotic patients may predispose these patients to bisphosphonate-related osteonecrosis of the jaw (BRONJ). This can occur spontaneously or with bone exposure due to tooth extraction and oral surgery [6].

Oral bisphosphonate use for osteoporosis has a lower incidence of BRONJ, but should still be considered a potential risk based on dosage and length of use [7,8]. Surgical exposure of bone is generally not recommended in these patients without a thorough knowledge of the patient's risks.

Radiation is commonly used in therapy for head and neck tumors. Based on site and dosage, osteoradionecrosis (ORN) can occur. Early presentation, within 2 years, is thought to be related to high doses of radiotherapy (>70 gray), whereas late presentation is usually secondary to trauma and delayed wound healing within compromised tissue [9]. Studies have reported osteoradionecrosis and soft tissue dehiscence in previously irradiated patients undergoing oral surgery. However, there remains ambiguity due to some authors reporting increased complication rates, whereas other authors having found no statistical relationship for irradiated patients [10]. Due to potential risks, consultation with the treating radiologist is recommended so that oral surgical treatment takes into account the individual's needs versus the risks.

Smoking is known to reduce wound healing capacity. Lindfors et al. [11] describe treatment of 27 augmentations resulting in an overall success rate of 85%. Augmentations performed in non-smokers were successful in 95% of cases, while the success rate in smokers was 63%. Signs of soft tissue inflammation were present in 37% of augmentation sites, happening more often in smokers – 75% – than in nonsmokers – 21%. Smoking has a significant negative influence on success of GBR, suggesting it is ideal for patients to cease smoking prior to treatment.

Guided tissue regeneration membrane choice

Although both non-resorbable and resorbable membranes are used, recent GBR procedures depend primarily on resorbable porcine- or bovine-derived collagen membranes that may or may not be cross-linked. Fundamentally, membranes must maintain their integrity for durations long enough to allow a clinically sufficient amount of new bone to form [12–15]. Premature exposure of GBR materials (Figure 12.1), either membrane or grafting, can cause significant complications. Dehiscence complications include exposure of the



Figure 12.1 Photo showing early exposure of a non-resorbable membrane. Note the relatively minimal inflammation when using chlorhexidine as a topical antibacterial agent.

GBR materials through the soft tissue caused by flap necrosis, punctiform trauma, or an underlying infection. Even though the majority of soft tissue dehiscence cases without infection improve, premature membrane exposure may compromise new bone formation during GBR procedures [16,17]. In a comprehensive meta-analysis, Machtei [18] demonstrated significant differences in quantities of bone regeneration between intact and prematurely exposed collagen membranes during GBR procedures around implants. Sites with no membrane exposure yielded approximately six times more new bone regeneration during GBR procedures than

sites that became exposed. Regardless of the reason for dehiscence, the result can seriously affect treatment outcomes. Figure 12.2a to d depicts a case where premature exposure of the guided tissue regeneration (GTR) membrane and graft left minimal, if any, bony regeneration.

A systematic review by Jensen and Terheyden [19] revealed a mean complication rate of 12.2% for staged procedures of horizontal augmentation. The use of non-resorbable versus resorbable membranes was associated with mean complication rates of 23.6% versus 18.9%, respectively. When no membrane was used, the mean complication rate was 9.4%. Vertical augmentation procedures were found to have premature exposure of grafting materials in 18.8% of cases. Autologous block grafts versus particulate materials for staged vertical augmentation had complication rates of 29.8% versus 21.0%, respectively.

In their systematic review of augmentation techniques for major defects in completely edentulous ridges, Chiapasco et al. [20] indicated a complication rate of 4.7% for onlay grafts. These studies indicate an advantage for using resorbable membranes.

However, when using resorbable membranes, the surgeon will need to utilize some type of “tenting” mechanism to maintain space versus reinforced non-resorbable membranes. Another factor that may have an effect on premature exposure is the chemical composition of the resorbable membrane used. Cross-linking between collagen fibrils has become an important method of slowing collagen membrane resorption times in order to maintain membrane-protected spaces critical to successful bone regeneration [12,13]. Although successful in slowing resorption times, a number of studies suggest that cross-linked membranes may be more prone to premature membrane exposure than non-cross-linked

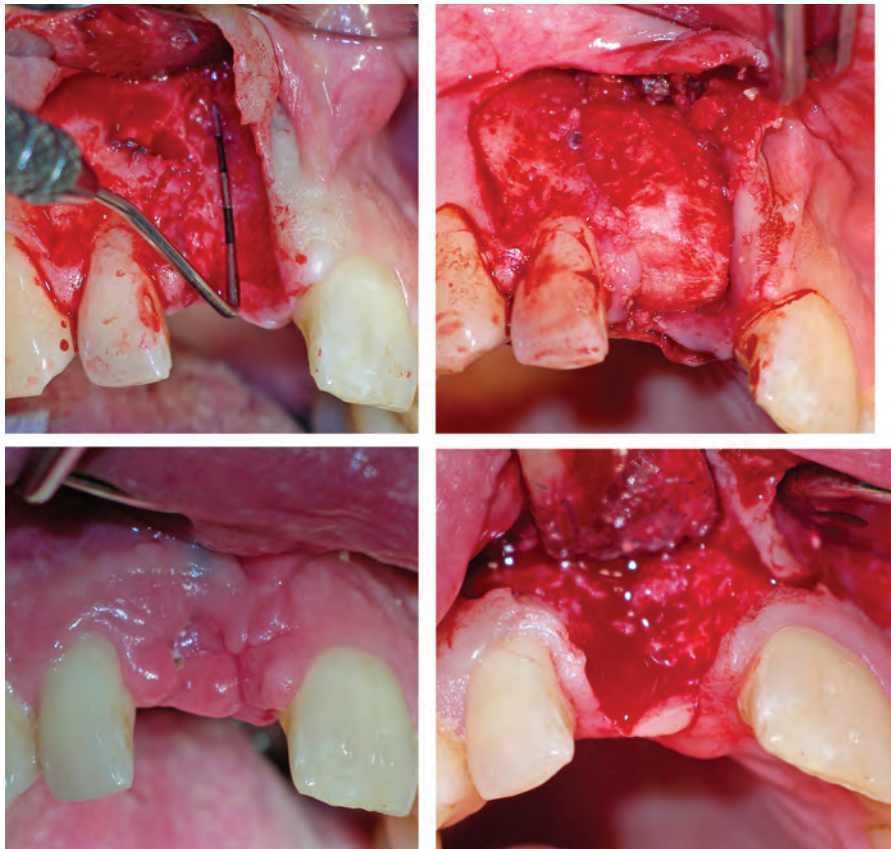


Figure 12.2 (a) Photo of the extraction socket after tooth removal. There is complete loss of facial alveolar bony plate. (b) After placing tenting screws for space maintenance and FDBA graft, a resorbable collagen membrane was positioned over the site. (c) Early post-surgical exposure of the GBR materials left a significant soft tissue defect along with loss of graft material. (d) Re-entry into the site approximately two months after initial wound dehiscence shows complete loss of grafting material and no bony regeneration.

membranes [16,17,21]. Research continues on defining membranes that maintain their integrity for a sufficient length of time and biocompatibility to reduce soft tissue exposure.

Infections

Infections of surgical sites can be of odontogenic or non-odontogenic etiologies. Once initiated, the appearance and progression of infection from either odontogenic or non-odontogenic sources may be similar. Odontogenic infections of a surgical site can occur if there is an infection of *endodontic* origin in a tooth near the surgical site. Appropriate pre-treatment assessment, including radiographic analysis of adjacent teeth, can help in reducing this risk. Another potential origin of an odontogenic infection can be from bacteria associated with the *periodontium* near the surgical site. Appropriate assessment and prior treatment of periodontal infection should be completed prior to GBR surgical therapy. Infections from odontogenic origin may contribute to complications at a surgical site whether or not there is a dehiscence of the soft tissue over the surgical site or not.

Non-odontogenic infections can occur from extraoral or intraoral sources. These types of surgical site infections can occur from iatrogenic reasons or soft tissue dehiscences. Iatrogenic bacterial inoculation can be caused by poor aseptic technique of a surgeon or assistant during the actual surgery. Contamination with extraoral bacteria caused by inappropriate handling of the graft or membrane materials would significantly increase the risk of surgical site infection. Due to high numbers of naturally present bacteria, it is difficult to completely keep an intraoral surgical site sterile. However, maintaining the site as aseptically as possible, reducing contamination of GBR materials with intraoral bacteria, will reduce post-surgical infection risk. Non-odontogenic infections of intraoral bacterial origin can also be facilitated through premature exposure of membrane or graft materials.

Surgical considerations

With any surgical procedure, appropriate systemic antibiotic coverage during the healing phase should be considered. Dehiscence of a surgical site not associated with an infection from the underlying grafted space or materials may begin by lack of adequate blood supply or punctiform type due to sharp edges of GBR materials. Lack of adequate blood supply to the overlying soft tissue at the grafted site may be at the incision site or other soft tissue areas over the GBR materials. The dehiscence at the incision line may be instigated by location of the incision, suturing too tightly, lack of passive flaps, or inadequate closure of the raised soft tissue flaps.

An attempt should be made to make the incision of the flaps over healthy bone, avoiding having the incision being placed over the grafted site. One study concluded that the location of a crestal incision might be a significant factor in reducing the incidence of membrane exposure by minimizing flap necrosis for buccal bony dehiscences [22]. The mean keratinized gingival width of adjacent teeth may be used as a guide to determine the initial incision location. However, this effect may be less significant when palatal/lingual gingiva is greater than 3.0 mm [22].

If the proposed grafted site is lacking keratinized gingiva or has a “thin” gingival biotype, soft tissue grafting can significantly improve the tissue characteristics. The width of keratinized tissues present can be augmented with a free gingival graft. Thickening of the soft tissue along with added keratinized tissues can be accomplished



Figure 12.3 Photo showing the inversion of the buccal and lingual flaps and mattress type of suturing to allow connective tissue–connective tissue positioning for better wound closure and healing.

with connective tissue grafting. Both of these approaches may help minimize tissue movement over GBR materials and resist the punctiform type of perforations.

Lack of blood supply due to suturing the flaps at closure too tightly will compromise blood flow and not allow the incision site to heal properly, leading to dehiscence. Similarly, lack of passive flaps will cause pull at the incision line and not allow proper adaptation for connective tissue adhesion, also leading to dehiscence. One of the ways to improve closure over a GBR site is adapting passive flaps to allow for connective tissue-to-connective tissue contact. This can be accomplished through adequate flap release, inverting the flap edges, and suturing with mattress, horizontal or vertical, type suturing (Figure 12.3).

Mixing antibiotics with the graft materials is another possible technique that can help inhibit infection in GBR procedures. This is supported by reports in both dental and orthopedic literature, which discuss the efficacy of adding antibiotics to create a highly concentrated amount of antibacterial agents in a localized manner. A study by Kaur and Sikri [23] reports improvement in bone fill in intrabony defects around teeth. A systematic review article by Anagnostakos and Schroder [24] discusses the literature regarding this topic, with reference to the choice of bone, antibiotics, manufacturing details, and clinical experience. However, exactly how this relates to oral GBR techniques is not well defined.

In order to reduce the punctiform type of dehiscence, appropriate trimming or fixation of the edges of either non-resorbable or resorbable membranes should be completed. Stabilizing the edges with screws or tacks will aid in inhibiting “curling” of the edges in addition to immobilizing the membrane, and may improve GBR outcomes [25].

Treatment

Once a premature exposure or infection occurs, the practitioner needs to decide on a treatment strategy: maintenance of the membrane exposure to prevent infection of the GBR materials or removal of the membrane and attempted closure over the graft material. Management of soft tissue dehiscence without infections can be accomplished with topical rinsing of the site with antiseptic rinses such as polyvidone iodine or chlorhexidine.

If an infection is detected, appropriate systemic antibiotic therapy can be considered. Beta-lactam antibiotic, like amoxicillin, is the drug of choice in these cases. Clindamycin is an alternative in patients allergic to penicillin [26]. The duration of antibiotic therapy regiment continued after detecting an infection has not been defined and should be determined by the surgeon based on individual patient risk presentation. However, if antibiotic therapy is not effective, the membrane might need to be removed and the site evaluated and possibly debrided. Appropriateness of closure after membrane removal should be determined on a case-by-case basis. Re-grafting of the area may be attempted once healing has occurred.

Conclusion

Even though guided bone regenerative therapies are highly effective, there are significant risks for complications. In order to reduce the risk for GBR complications, careful evaluation of each step of the process is important. Assessment of a patient's medical and dental history is a primary concern. Secondly, a detailed knowledge of the types of GBR materials available is important to choose the most appropriate materials for each case. Thirdly, surgical planning with emphasis on incision site, flap relaxation, and proper flap closure is of paramount importance. If a post-surgical complication does arise, early intervention based on the type of complication is necessary to assist in obtaining as much bony regeneration as possible.

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SECTION III

Autogenous Block Bone Grafting for Horizontal Alveolar Ridge Deficiency

Autologous Intraoral Block Bone Grafting for Augmentation of Severe Atrophic Maxilla: Advantages of Combined Therapy

Devorah Schwartz-Arad

Schwartz-Arad Day-Care Surgical Center, Oral and Maxillofacial Surgery, Advanced Implantology, Periodontology and Endodontology, Ramat Hasharon, Israel

Introduction

The reconstruction of atrophic alveolar ridges using autologous bone grafting was originally reported in 1975 [1]. It is still considered as the “gold standard” bone-grafting material, as it combines all properties required in a bone graft material: osteoinduction (bone morphogenetic proteins (BMPs) and other growth factors), osteogenesis (osteoprogenitor cells) and osteoconduction (scaffold) [2–5].

Possible donor sites for autologous bone grafts include extraoral (distant) sources such as the calvaria, tibia, and the iliac crest [6]. However, the use of intraoral sources, such as the mandibular symphysis [7,8] and ramus [9,10] is more readily available, offers no cutaneous scarring, minimal discomfort, and less morbidity compared with the extraoral sources. The mandible, as a preferable donor site, has advantages that also comprise good bone quality, convenient surgical access, minimal volume loss, good incorporation with a short healing time, high biocompatibility, and embryological proximity [11].

The anatomic configuration in the maxillary recipient atrophic site influences the surgical therapies approach and preferences. The author suggests dividing the maxilla according to bone shape and quality, neighboring anatomical structures, and resorption pattern to five different areas: anterior (centrals and laterals), two middle (canines and first premolars), and two posterior (second premolar and molar area) [12].

In the anterior and posterior maxilla the presence of the nasal cavity and maxillary sinus limited the vertical available bone for dental implantation compared to the canine fossa area, which is normally characterized by better shape and higher residual bone quality. Moreover, in the anterior region, the direction of resorption differs from the middle and posterior; while in the anterior maxilla the resorption occurs mainly horizontally (twice the vertical resorption), the posterior area resorption is mostly vertical (also due to the maxillary sinus pneumatization). As a whole, the posterior and middle maxillary regions lose considerably less bone during atrophy than the anterior area. The faster rate of bone resorption in the anterior maxilla may also be a result of forces generated by residual natural mandibular incisors [13–15]. Furthermore, the intermaxillary relationship is better in the edentulous posterior region

compared to the Class III relation at the anterior edentulous maxillary area, due to the different resorption patterns of the anterior edentulous mandible and anterior maxilla.

As recommended by Branemark et al., when surgical reconstruction is performed in the severe posterior atrophic maxilla, the reference standard of care would be to perform the maxillary sinus augmentation procedure for vertical augmentation. In the case of severe anterior maxillary atrophy the treatment protocol would be subnasal vertical augmentation [16].

Both surgical procedures, sinus and subnasal floor elevation, do not compensate for the anterior defect nor the intermaxillary relationship. Therefore, combination of surgical therapies is needed. Horizontal and additional vertical augmentation is achieved by autologous onlay bone graft (AOBG) augmentation whenever necessary [17–20]. The use of vertical augmentation through a combination of sinus elevation procedures and AOBG with bone blocks harvested from the mandibular symphysis or ramus has been described previously [16,17]. The author reported that this procedure had good predictability for reconstruction of extensive atrophic ridges with low complication and failure rates [17]. Recent studies describe extensive bone deficiency reconstruction using solely intraoral block bone grafts by means of the multitier technique, possibly by reharvesting bone from the same donor site [21,22].

Growth factors (GFs) are expressed during different phases of tissue healing and are therefore a key element in promoting tissue regeneration [23]. The use of platelet-rich plasma (PRP) as a source of GFs has been presented by Marx and colleagues [24,25]. PRP is an inexpensive way to obtain many GFs in physiological proportion and therefore has gained wide interest as a therapy for both soft and hard tissue injuries [25–27]. However, there is controversy in the literature regarding the effectiveness of PRP in the bone regeneration process, which might be due to different protocols and equipment for obtaining PRP (centrifugation) and the low numbers of systematic studies carried out to date [28].

Platelet-poor plasma (PPP) is the upper layer of plasma, which is formed after centrifugation of whole blood and is composed of acellular plasma containing fibrinogen and growth factors [29]. The author uses the PPP as a “biological membrane” to cover the entire

augmented area and donor sites that were filled with bone substitutes as scaffold, saturated in PRP, to facilitate the healing and angiogenesis process. The benefits of PPP are probably due to elevated levels of fibrinogen, which has the ability to form a fibrin-rich clot once activated [30]. The clot within the injured space provides a provisional matrix for cell migration [31,32]. However, there is need for controlled clinical studies for further understanding and proving the beneficial effect of the PPP as a biological membrane in combination with PRP and filling scaffold for better healing processes.

Bone-marrow aspirate is a rich source of progenitor cells, cytokines, and growth factors needed for bone formation [33,34]. The bone marrow stroma contains mesenchymal stem cells (MSCs), also known as marrow stromal cells [33]. MSCs can be differentiated into diverse tissues, such as bones, cartilages, muscles, fat, and tendons, and small amounts of MSCs extracted from the bone marrow can be cultivated to provide large amounts that continue to function normally [34]. The stem cells are typically harvested directly from the red marrow in the iliac crest, often under general anesthesia. The procedure is minimally invasive, performed as an outpatient procedure. It has been suggested that transplantation of autologous stem cells from aspirated bone marrow can enhance bone healing [35–37]. The application of uncultured bone marrow-derived cells to improve tissue regeneration may avoid the risks associated with *in vitro* expansion of stem cells. Previous studies in bone and cartilage tissue engineering have shown significant therapeutic benefits associated with the use of uncultured marrow-derived cells [38–40].

The rational, protocol and surgical technique for simultaneous AOBG, sinus, subnasal augmentation and implantation, for fixed implant supported restoration of severely resorbed edentulous maxilla

Objectives

This surgical technique demonstrates the treatment rational for edentulous maxillary severe atrophy for an implant-supported fix prosthesis. The emphasis of this treatment is combining several state-of-the-art surgical augmentation therapies to optimize dimensional increases in the deficient ridges in the edentulous maxilla in preparation for implant therapy. The bone is reconstructed by using the anatomy (subnasal and sinus floor augmentation), several surgical techniques (bone augmentation, soft tissue manipulation, and implant placement) in a systematic team-oriented protocol (surgeon, restorative dentist and the dental technician) to get the best predicted esthetic results.

Surgical steps

A description of the simultaneous use of a few surgical techniques for fixed prosthetic reconstruction of severe edentulous maxillary ridge is as follows:

- Autologous onlay bone grafting for both vertical and horizontal bone augmentation
- PRP/PPP or BMAC (bone marrow aspiration concentrated) covered by PPP
- Subnasal elevation procedure
- Sinus floor augmentation

- Buccal fat pad flap
- Connective tissue grafting
- Simultaneous or late implantation.

Autologous onlay bone grafting

Recipient site

A mid-crest incision was made along the recipient area with vertical releasing incisions in the posterior tuberosity areas, preventing any incisions in the anterior esthetic zone. A mucoperiosteal flap was reflected (Figure 13.1A). The recipient site was decorticated and recontoured using a round bone bur (for better adaptation of the graft and improving graft-to-recipient bone contact.

Donor sites

Bone blocks were harvested solely from intraoral donor sites (i.e. the mandibular ramus or/and symphysis) (Figure 13.1B to D). The ramus area was accessed using an extension of the commonly used envelope flap for third molar extraction. The incision was made in the buccal vestibule, medial to the external oblique ridge, and extended anteriorly and laterally to the retromolar pad, continuing anteriorly into the buccal sulcus of the second molar. A mucoperiosteal flap was reflected, exposing the lateral aspect of the ramus and third molar area. A reciprocating or oscillating saw or piezoelectric surgery device was used to cut through the cortex along the anterior border of the ramus. An anterior vertical cut was made in the mandibular body (the length depended upon the size of the graft needed) and a posterior vertical cut was made on the lateral aspect of the ramus. No inferior osteotomy was performed. The border cuts were made only to the depth where bleeding occurred from the underlying cancellous bone to prevent injury to the underlying neurovascular bundle. A thin chisel was gently tapped along the entire length of the osteotomy, taking care to avoid injury to the inferior alveolar nerve by preventing the cancellous bone to penetrate beneath the cortical layer. Graft splitting from the ramus was then completed.

For the symphysis, an intrasulcular incision and two vertical releasing incisions were made posterior to the second premolar regions, reflecting the mucoperiosteal flap at the facial side.

After exposing the symphysis and locating the mental foramina, a reciprocating saw or piezoelectric surgery device was used to outline a rectangle, the size of the exposed defect. The superior aspect of the rectangle was at least 3–5 mm below the tooth apices, and medially to the mental foramina the integrity of the lower border of the mandible was maintained. Osteotomes were used to free the blocks graft and harvest cancellous bone. In selected cases, a vestibular incision was performed, no vertical incisions were needed, and the free-gingival line of the lower teeth was unharmed. The bone blocks were restored in a sterile cold sodium chloride 0.9% solution for a minimal time before fixating in the recipient site (Figure 13.1B to D).

Fixation of blocks

The block grafts were positioned over the recipient site in a vertical dimension (i.e. “saddle” augmentation) and/or horizontal dimension (i.e. “veneer” augmentation) with the endosteal side of the graft facing the cortical bone. To ensure immobilization, the grafts were fixed to the recipient site using titanium self-tap screws, 1.6 mm in diameter, to be removed during implant placement or uncovering when simultaneously performed (Figure 13.1E and F). Any sharp angles in the block segment that could perforate the overlying flap were eliminated, leaving a smooth outline.

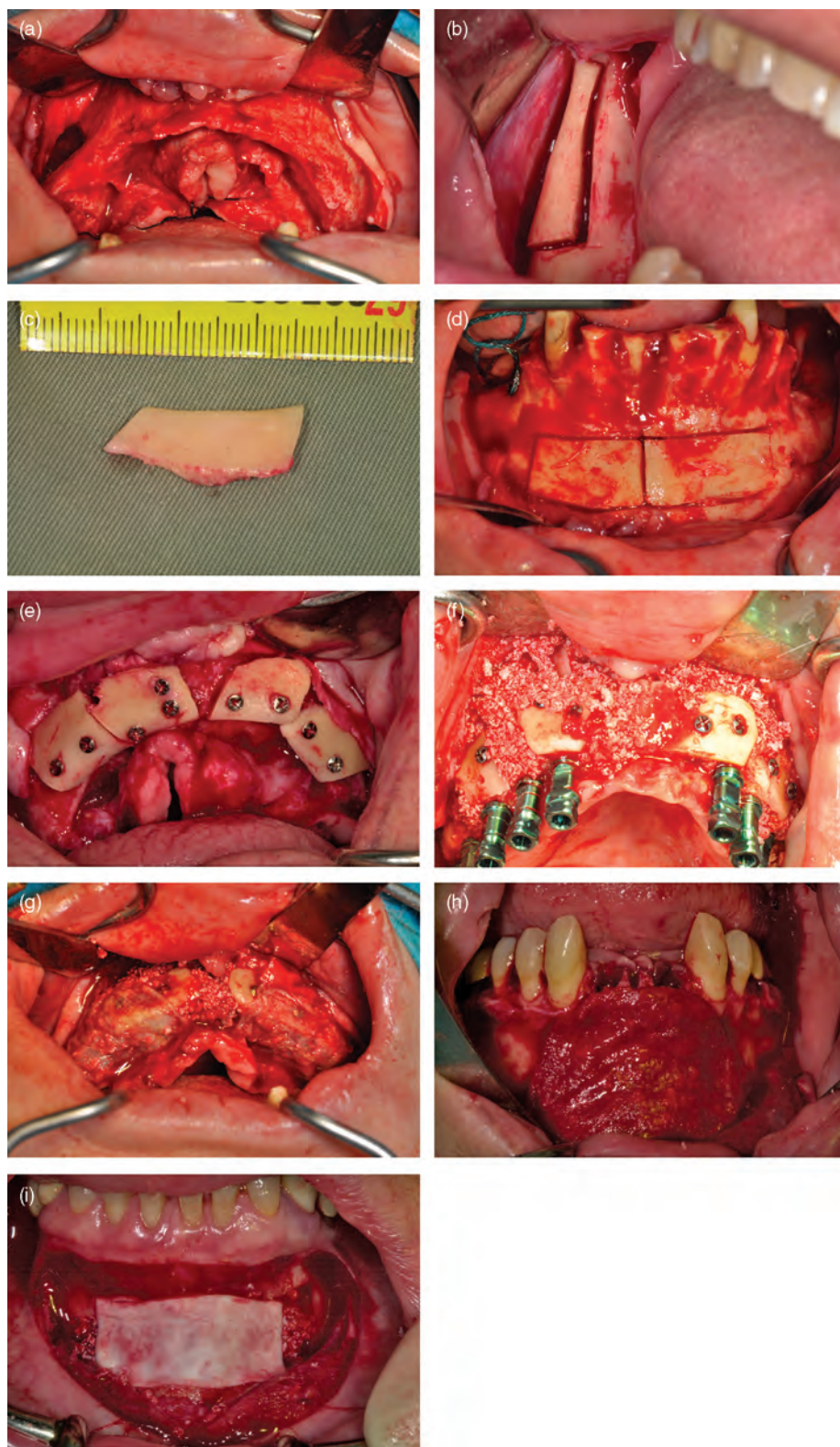


Figure 13.1 (A) Recipient side: mid-crest incision was made along the recipient edentulous area with vertical releasing incisions in the posterior tuberosity areas, preventing any vertical incisions in the anterior esthetic zone. A mucoperiosteal flap was reflected. Donor sites: (B to D) bone blocks were harvested solely from intraoral donor sites (i.e. the mandibular ramus (B, C) or/and symphysis (D)). (E, F) To ensure immobilization, the grafts were fixed to the recipient site using titanium self-tap screws, 1.6 mm in diameter, to be removed during implant placement or uncovering when simultaneously performed. (F) Cortico-cancellous particles and Bio-Oss saturated with platelet-rich plasma (PRP) or bone marrow aspiration concentrated (BMAC) were used to fill the gap between the graft and recipient bed site. (G) Platelet-poor plasma (PPP) was used to cover the entire augmented area. (H, I) The donor defect was filled with Bio-Oss saturated with PRP or BMA, covered with PPP and in some cases with resorbable membrane.

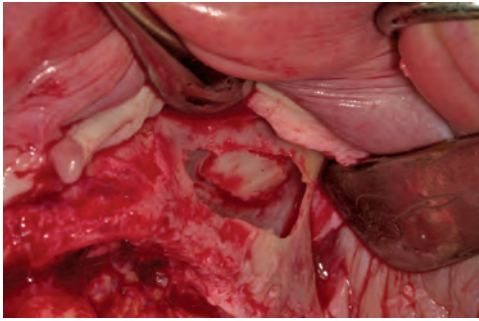


Figure 13.2 In cases of severe posterior maxillary atrophy, the sinus augmentation procedure was performed via the lateral wall approach, for vertical augmentation.

Corticocancellous particles and bone substitutes ((Bio-Oss), Geistlich Sons, Wolhusen, Switzerland) saturated with PRP or BMAC (Harvest Technology, Plymouth, MA) were used to fill the gap between the graft and recipient bed site (Figure 13.1F). PPP was used to cover the entire augmented area (Figure 13.1G). The periosteum at the base of the facial flap in the recipient site was carefully incised to allow stretching of the mucosa and tension-free adaptation of the wound margins. The flap was layered sutured first with 5-0 rapid Vicryl followed by continuous horizontal mattress suture Nylon 05 suture, which were removed 2 weeks later. Treatment of the donor site was completed only at the end of the procedure, after the fixation of the bone graft and

the suturing of the recipient site. The donor defect was filled with bone substitutes (Bio-Oss) saturated with PRP or BMAC, covered with PPP and in some cases with resorbable membrane (Bio-Gide, Geistlich Sons, Wolhusen, Switzerland), and sutured with the same technique and sutures (Figure 13.1H and I).

In cases of severe posterior maxillary atrophy, the sinus augmentation procedure was performed via the lateral wall approach, for vertical augmentation (Figure 13.2). If additional augmentation was needed, horizontal and/or vertical augmentation with AOBG was then performed (Figure 13.3A). The compartment was then filled with bone substitutes (Bio-Oss) saturated with PRP/BMAC (Figure 13.3B and C). The fenestrated lateral wall of the maxillary sinus was covered with PPP followed by suturing with a 4/0 Vicryl or Nylon suture (Figure 13.3D and E). In cases of Schneiderian membrane perforation, an overlapping PPP or collagen resorbable membrane was used to repair the perforation (Figure 13.3F and G).

In severe three-dimensional atrophy of the anterior maxilla, subnasal floor augmentation was performed for vertical augmentation, AOBG used for horizontal augmentation.

The surgical technique for subnasal elevation included: under general anesthesia, a mucoperiosteal flap was elevated to expose the residual maxillary ridge and the piriform apertures, the nasal mucosa was carefully dissected from the nasal floor and the medial and later bony margins (Figure 13.4A). The internal nasal floor was filled with bone substitutes (Bio-Oss) saturated with PRP or BMAC (Figure 13.4B). If it was necessary, the horizontal augmentation was performed using AOBG, (Figure 13.4C).

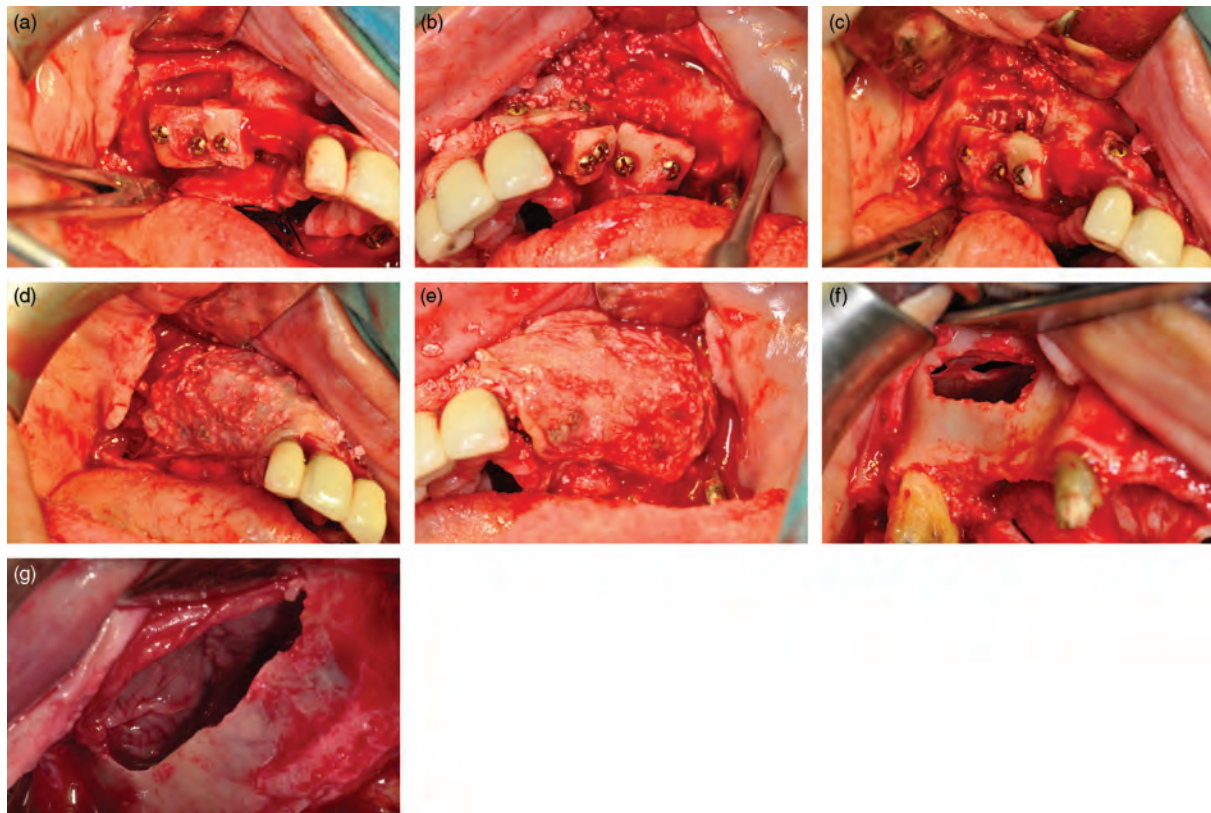


Figure 13.3 (A to C) The vertical and two-dimensional vertical and horizontal augmentations were done mainly in the posterior maxilla. (D, E) The fenestrated lateral wall of the maxillary sinus was covered with PPP after filling with Bio-Oss saturated in PRP or BMAC. (F, G) In cases of Schneiderian membrane perforation, an overlapping PPP or collagen resorbable membrane was used to repair the perforation.



Figure 13.4 (A) Subnasal elevation procedure: the nasal membrane is reflected superiorly. (B) The subnasal area was filled with bone substitutes (Bio-Oss) saturated with PRP or BMAC. Four implants were placed simultaneously. (C) Vertical and horizontal augmentation was performed using AOBG.

PRP/BMAC and PPP preparation

The preparation of PRP or BMAC and PPP was performed using the Harvest SmartPrep® Multicellular Processing System (Harvest Technology). To create the PRP/BMAC plus scaffold, the (Bio-Oss) was saturated with PRP or BMAC. The CaCl and thrombin mixture was added to form a gel with internalized (Bio-Oss) particles that were used as a filling material in both the recipient (filling any gaps between the recipient bed and block grafts) and the donor sites. The upper layer of plasma (PPP) was gently transferred into a sterile cup using a sterile syringe with a blunt needle (Figure 13.5A). To create a membrane-like gel, the PPP was activated by adding a mix of humane thrombin and CaCl (Figure 13.5B).

Implant phase, simultaneous or separate phase implantation

Simultaneously or 6 months later (following panoramic radiograph and computed tomography (CT) examination), dental implant placement was performed. The length and diameter of the implants were chosen according to the area to be rehabilitated, to the prosthetic indications, and to the bone shape and volume available in each implant site.

The implants were submerged as part of the augmentation and implantation protocol, as a two-stage procedure. The healing period was 5–7 months (mean 6.5 ± 2.58), panoramic radiography was performed and the implants were uncovered later restored by fixed prosthesis. The implants were followed by clinical examination and panoramic radiography annually for 5 years, followed then every two years.

Buccal fat pad flap

The buccal fat pad flap is an axial flap (Figure 13.6). The use of a pedicle buccal fat pad as a flap for closure of post-surgical maxillary defects becomes a recognized option for the reconstruction of small- to medium-sized soft tissue and bony defects in the oral cavity. When precisely dissected and mobilized, the buccal fat pad provides a 7 cm × 4 cm × 3 cm pedicle graft (Figure 13.6A). There are several reported indications to use the fat pad flap: reconstruction of small to medium acquired or congenital soft-tissue and bone defects in the oral cavity, secondary palatal cleft coverage, coverage of maxillary bone grafts (Figure 13.6B), alternative or backup for failed buccal advancement flaps, palatal rotation and transposition flaps, and tongue and nasolabial flaps [41,42].

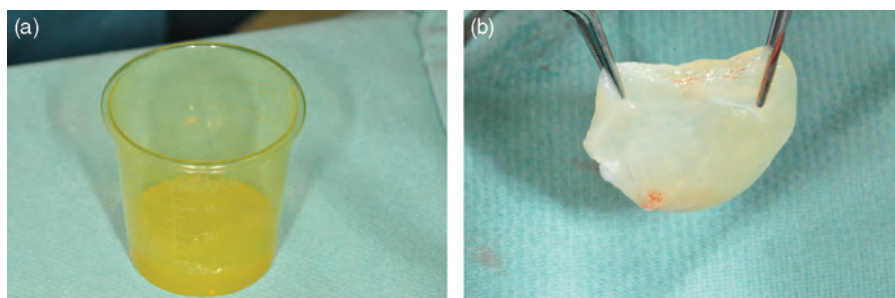


Figure 13.5 Platelet-poor plasma (PPP) used as a biological membrane.

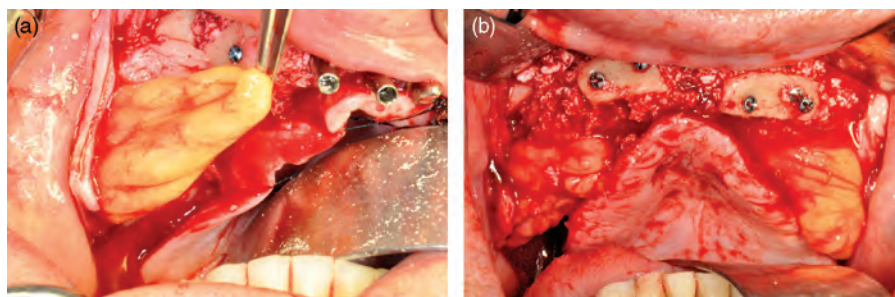


Figure 13.6 (A) The buccal fat pad flap is an axial flap. When precisely dissected and mobilized, the buccal fat pad provides a 7 cm × 4 cm × 3 cm pedicle graft. (B) It can be used for covering the surface of bone grafts in order to improve the vascularization of the bone graft and to support the volume of facial tissue.

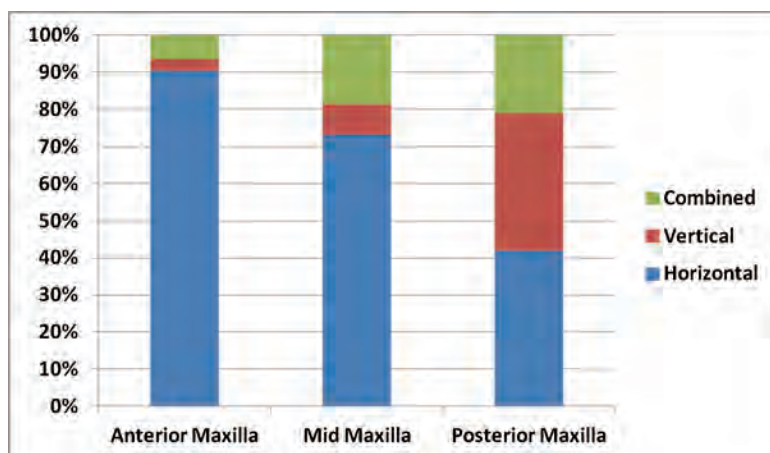


Figure 13.7 Block graft position according to the augmented area and bone graft direction (Pearson Chi-Square 0.0001).

Connective tissue grafting

A partial thickness palatal flap was performed as part of the uncovering of implants after implant placement simultaneously or in a delayed fashion.

Results of Onlay Bone Graft augmentation for the Treatment of Maxillary Atrophy: a 10 years study

During the ten years (2000–2010) a total of 109 AOBG were performed using this surgical technique, out of which 108 were diagnosed as successful (99.1%). Up to nine blocks were grafted per augmentation site, when in the majority of the cases one to three blocks were used for each atrophic maxilla. In 45 cases AOBG was combined with subnasal and/or sinus augmentation. The majority of the AOBG were horizontal, when the vertical and two-dimensional augmentations were done mainly in the posterior maxilla (Figure 13.7). Most of the AOBG healing processes were uneventful (95.4%). Only one bone graft (0.9%) was defined as failure due to graft exposure. Sinus augmentation procedures were performed in 29 of the cases, via the lateral wall approach, and 16 subnasal augmentations.

In 108 patients a total of 272 dental implants were performed; the majority were defined as survived (94.5%). Mean follow-up time was 43.6 ± 32.5 months. Out of the 15 failed implants, 5 failed during the surgical phase and 10 (66.6%) along the prosthetic phase following rehabilitation. Out of 15 failed implants only 5 occurred in smokers; this was statistically not significant.

Discussion

The rehabilitation of the severe atrophic edentulous maxilla presents a challenge because of the resorption patterns that occur after teeth loss. The retruded position of the severely resorbed residual maxilla in relation to the mandible create a non-esthetic Angle Class III like profile with reduced support of the upper lip (Figure 13.8A and B). Therefore, for many dental practitioners, the edentulous maxilla is considered to be a clinical challenge during dental implant treatment. This is because of its insufficient bone quality, deficient alveolar ridge, undercuts, and nasal and sinus pneumatization often encountered after tooth loss (Figure 13.8C to G). Various hard tissue augmentation procedures have been described to enhance the

height and width of the alveolar ridge, including sinus, subnasal, and bone augmentations. The use of autologous transplants from varying donor sites is a preferred method, due to their osteoinductive and osteogenic properties [41,42]. For many years the only option for reconstruction of the edentulous severe atrophic maxilla was an autologous bone graft from extraoral sources such as the iliac crest [16]. The advantages of extraoral bone are the amount of available bone that could be harvested. However, the procedure associates with a long healing time and high morbidity compared with the intraoral bone sources. The uniqueness of the combined surgical treatment described in this chapter is the fact that only intraoral bone was used for the severe atrophic maxilla reconstruction, obtaining a high bone graft and implant success and survival rates (Figure 13.8H to M).

After extensive reconstruction of the atrophic maxilla with bone grafts and dental implants, long-term stability and a good esthetic outcome are desirable. In the literature the survival rate of implants placed in the augmented sites varied between 76.8% and 100%, with the majority of studies indicating more than 90% survival after at least 1 year of function [3,4]. The reported mean survival rate of implants placed in reconstructed maxillae with a staged approach varied between 80% and 100% as a result of different types of defects and surgical approaches [43–45].

The healing process, after autologous bone transplantation, is well researched and described [46,47]. First, resorptive processes dominate in the context of inflammation followed by the healing process includes graft vascularization and penetration of the proliferative cells to the transplanted bone. Finally, the transplanted bone will be resorbed and replaced successively with new bone [48,49]. In the described cases all augmentations, both at donor and augmented sites, in addition to bone graft or bone supplement, were saturated with PRP or BMAC as a source of essential growth factors, following PPP covering to facilitate the healing and angiogenesis. It has been shown that PRP in combination with bovine bone substitutes manifest a positive effect on bone formation [50,51]. Several studies have reported autologous bone use in combination with PRP to improve bone implant integration [25,51–53]. We suggest that PRP stimulates the healing process of the grafted bone by local delivery of growth factors that could promote the healing process and eventually prevent the resorption course. In fact, in this study we have demonstrated a low rate of the marginal bone loss (2.6%) following implant placement.

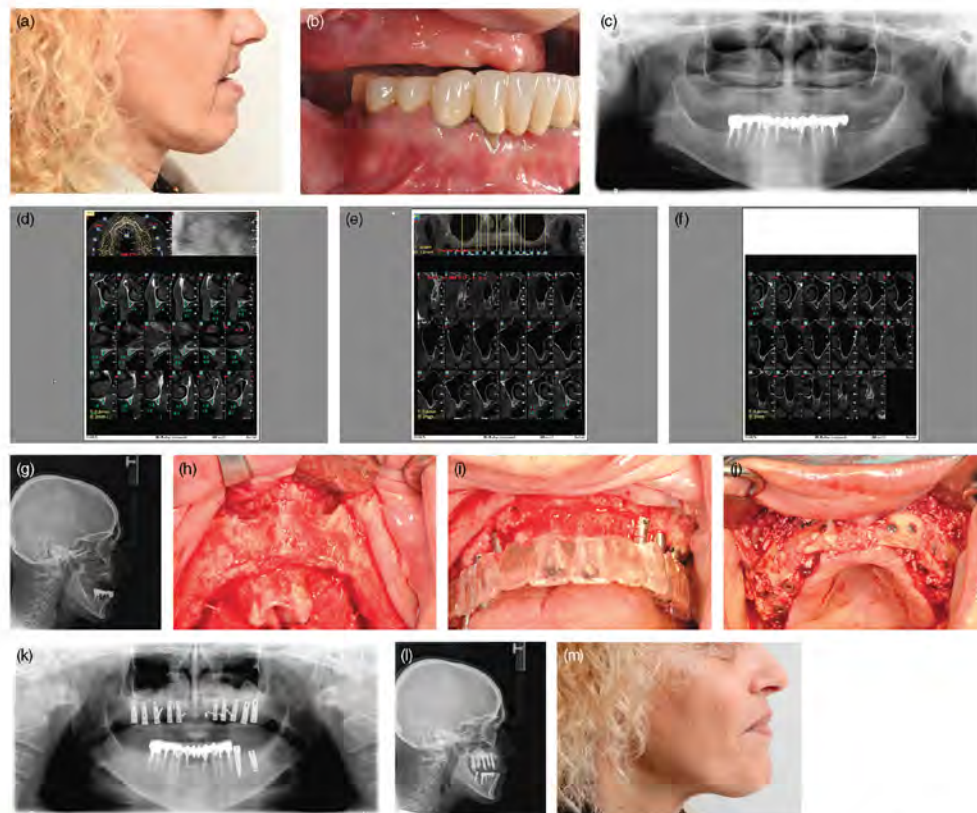


Figure 13.8 (A, B) Preoperative profile and intraoral views. Notice the class III relationships due to loss of maxillary bone support and loss of upper lip support. (C-F) Pre-operative panoramic and CT views: maxillary edentulous ridge with extensive bone atrophy. (G) Pre-operative Cephalometric view: maxillary edentulous ridge with extensive bone atrophy. Note the acquired Class III relationship due to maxillary bone atrophy compare to the mandible. The soft tissues contour follows the class III, characteristic to such severe atrophy cases. (H) Sub-nasal elevation procedure, one can see the anterior nasal spine, nasal floor and nasal membrane which is reflected superiorly. (I) Intraoral labial view of the maxillary atrophied ridge after mucoperiosteal flap retraction and positioning of surgical template with parallel pins in the desired implant locations. (J) Labial view of horizontal AOBG on the day of the augmentation. Corticocancellous particles and Bio-Oss saturated with BMAC were used to fill the gap between the graft and recipient bed site, partially covered by PPP. (K) Postoperative panoramic view demonstrating ten maxillary dental implants placed simultaneously with the vertical augmentation using Bio-Oss saturated in BMAC for sub-nasal and sinus augmentation procedures, combined with horizontal bone augmentation, using intraoral autologous bone blocks, for fix prosthesis. (L, M) Post-operative Cephalometric and profile views: maxillary ridge after combined horizontal, vertical augmentation and implantation 6 month post-operative immediately after implant uncover, and immediate temporary fixed rehabilitation performed at time of second stage surgery. Note the correction to Class I relationship compare to the pre-operative situation (8G).

Most of the augmentations were horizontally located in the anterior maxilla, which was done for two purposes: to support the dental implants and to support the soft facial tissue. Vertical and two-dimensional augmentations were done mainly in the posterior maxilla due to severe atrophy and an enlarged intermaxillary distance and pattern of maxillary resorption.

Although smoking has been shown to be a risk factor in onlay bone graft (OBG) complications [54–56], in these cases it did not appear to be significant in promoting implant failure.

The definition of “success” at present is not only long-term survival of the implants but good aesthetic results that depend on the state of soft tissues as well. Severe bone atrophy is always accompanied by abnormality in the gingival gum morphology. The purpose of soft tissue augmentation is to improve the gingival biotype in the buccal aspect of the dental implants [57]. It is often performed as a secondary surgical procedure. In this study 26 subepithelial connective tissue grafts were performed.

An additional procedure that could be performed in combination with onlay bone graft is the buccal fat pad (BFP). The BFP has been used for reconstruction of oral defects and had shown great success in all of the previous studies owing to its physical and biological properties. The advantages of BFP include an anatomically favorable location, the ease and minimal dissection with which it can be harvested and mobilized, excellent blood supply, simplicity, versatility, low rate of complications, and minimal to no donor site morbidity [58]. The BFP has been used successfully for covering the surface of bone grafts in order to improve the vascularization of the bone graft and to support the volume of facial tissue [59].

In summary, augmentation of atrophied maxilla through the positioning of horizontal and vertical autologous onlay bone grafts, following a technique that was described in this study, should be considered reliable, safe, and very effective in obtaining a high bone graft success rate following a high long-term implant survival rate (Figure 13.8A to M).

Conclusion

The advantages of combined surgical solutions with intraoral autogenous bone graft in the treatment of the deficient ridge were presented.

This surgical chapter demonstrated the treatment of advanced cases of maxillary deficiency. The emphasis was on combining several state-of-the-art surgical augmentation therapies to optimize dimensional increases of the deficient ridges in the edentulous maxilla in preparation of implant therapy. The bone was reconstructed by using the anatomy (subnasal and sinus floor elevation) and several surgical techniques (bone augmentation, soft tissue manipulation and implant placement) in a systematic team-oriented protocol (surgeon, restorative dentist, and lab) to get the best esthetic results.

Disclosure

Dr. Devorah Schwartz-Arad declares that the research data in the chapter was not funded by any commercial entity and that there was no income from a commercial entity related to this research.

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Autogenous Block Bone Grafting from Extraoral (Distant) Sites for Alveolar Ridge Augmentation: Techniques and Surgical Considerations

Erica L. Shook and A. Thomas Indresano

Department of Oral and Maxillofacial Surgery, University of the Pacific Arthur A. Dugoni School of Dentistry and Highland Hospital, San Francisco, California, USA

Calvarial bone graft

Introduction

The calvarium is an excellent source of cortical block grafts for use in the craniofacial region. The parietal bone is typically the preferred harvest site as it has the maximal bone thickness and is located in the hair-bearing region, thus allowing better concealment of the scar. A study analyzing skull thickness on 281 skulls from the Cleveland Museum of Natural History found the average skull thickness to be 6.33 mm (range of 5.3–7.5 mm) with the greatest thickness being located in the posterior parietal bone [1]. Anatomy of the skull includes an outer cortex, the medullary space or diploe, and the inner cortex. Graft harvest options include: split outer-table grafts (partial thickness of the outer cortex), outer-table grafts (full thickness of the outer cortex), split bicortical grafts (full thickness of the outer cortex and partial thickness of the inner cortex), and full-thickness bicortical grafts (full thickness of the inner cortex and the outer cortex) [2]. Outer table grafts are the most commonly used [3] and will be the technique described here.

Procedure

Pre-operative assessment should include radiographic evaluation to include at a minimum PA (posterior–anterior) and lateral skull views or, more preferably, a craniofacial CT or CBCT scan. CT/CBCT imaging is preferred as it allows for more accurate and reliable measurement of cranial bone thickness [4]. The patient's hairline should then be assessed and incision placement should be confined to the hair-bearing area for better concealment of the scar. Although a coronal incision would provide access to the calvarium, such a large approach is usually not necessary for calvarium graft procurement unless a large amount of bone graft is needed. Some surgeons advocate use of a hemicoronal approach [3] or a 20 cm parasagittal incision coursing anterior–posteriorly [5], whereas others report adequate exposure can be achieved using smaller (4–6 cm) horizontal or vertical incisions with generous subperiosteal dissection directly over the parietal prominence of the skull (see Figure 14.1) [6,7]. Determination of incision location and length should be made according to surgeon preference and amount of bone graft needed.

Calvarial graft harvesting is typically done in the operating room under general anesthesia. Once the surgeon determines the location of graft harvest (usually the patient's non-dominant hemisphere) and amount of bone graft needed, the surgeon selects the incision location and length and the hair is clipped immediately over this region. Surrounding hair is then held away from the surgical site with either rubber bands or an ointment (see Figure 14.2). The patient is then prepped and draped in sterile fashion. The incision line is marked with a marking pen and local anesthesia is administered along the length of the incision. The incision can be made using either a 15 or 10 blade, or with monopolar electrocautery (Bovie) using a Colorado tip on a low-energy setting. Incisions should be made parallel to the hair follicles in order to minimize alopecia and down to the level of bone. Bipolar electrocautery may be used for hemostasis. Use of electrocautery near hair follicles does increase the risk of alopecia, so judicious use is advised. Some surgeons prefer to use Rainey clips along the flap margin for hemostasis, but these too may cause alopecia. Subperiosteal dissection is performed using a no. 9 periosteal elevator in order to expose the desired donor region [6].

A marking pen and ruler are used to map out the desired graft. When large amounts of bone are needed, it is advised to harvest multiple smaller rectangles (~1.5 cm × 4 cm) to minimize the risk of fracture. The donor site should be posterior to the coronal suture and approximately 3 cm lateral to the sagittal suture/mid-line of the skull (see Figure 14.3) in order to avoid the region of the sagittal sinus, which, if encountered, could lead to significant hemorrhage. A fissure bur is used with copious irrigation to outline the donor site down to the depth of the medullary space where bleeding bone will be evident. The bur angulation may be perpendicular to the surface (see Figure 14.4) or it can be angled/beveled (see Figure 14.5) to aid correct trajectory of the osteotomes. The latter will produce a graft that is wider along its outer portion. If the bur is held perpendicular, a trough/gutter will need to be placed along the lateral aspect of the proposed donor site to allow proper osteotome angulation (see Figure 14.4). Once the outline of the donor site is completed down to the medullary space, a straight or curved osteotome is then used along the long edge of the donor site (see Figure 14.6), being mindful of the trajectory – too steep and the cranial vault may be entered; too shallow and the graft may fracture. The osteotome should follow the medullary space and should be used along the full length of the donor site to gradually lift the outer table off the

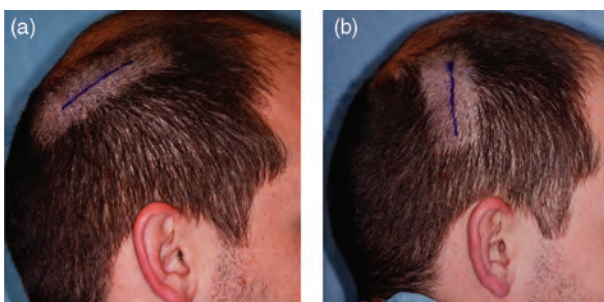


Figure 14.1 Skin markings of vertical and horizontal incisions over parietal prominence.



Figure 14.2 Example case showing hair clipped over site of planned incision and surrounding hair held in rubber bands.



Figure 14.4 Example of graft outlined using a bur angulation that is perpendicular to the surface with a trough placed along the lateral aspect.

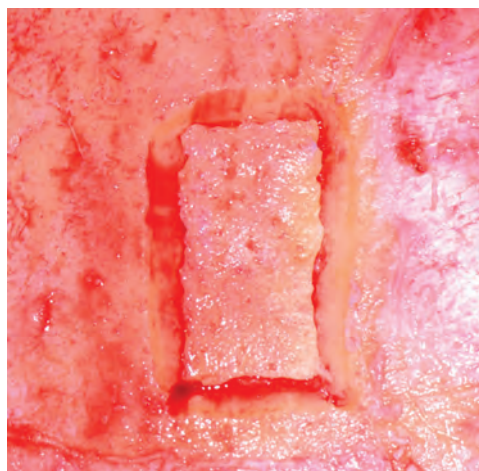


Figure 14.5 Example of graft outlined using a bur angulation that is angled/beveled from the surface.

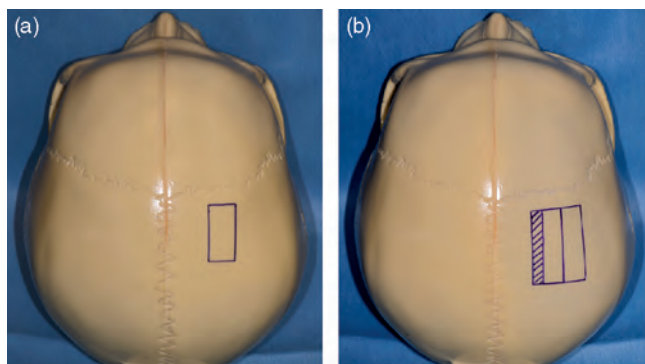


Figure 14.3 Outline of planned calvarial bone graft harvests. (a) Single rectangular graft is planned for removal using an angulated bur cut (no trough). (b) Multiple rectangular grafts are planned for removal to allow for a greater amount of total bone graft. The shaded portion represents the planned trough to be placed in order to allow proper osteotome angulation when a perpendicular bur cut is utilized.

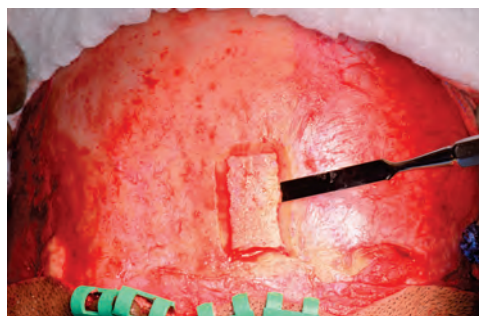


Figure 14.6 Osteotome being used along the full length of the graft following the medullary space to gradually remove the graft.

underlying medullary space. If desired, cancellous diploic bone may be harvested using a curette to remove it from the surface of the inner table. The graft should then be stored in cool, sterile saline until graft placement [6].

Hemostasis of the donor site is achieved using local hemostatic measures – i.e., bone wax and/or microfibrillar collagen. A suction drain may be placed along the length of the surgical wound according to surgeon preference and depending on the size of the wound and hemostatic control. Alternatively, a pressure dressing may be applied after closure. Closure is completed in layers: a 3-0 resorbable interrupted suture to reapproximate the pericranium and galea followed by surgical staples or a 4-0 non-resorbable suture to reapproximate the skin [6].

R/B/A/complications

The calvarium is a favorable harvest site due to its close proximity to the surgical site, ease of harvesting, large quantities of cortical bone availability, minimal post-operative bony and soft tissue deformity, and also its ability to revascularize quickly and resorb minimally due to its dense cortical consistency and rich haversian network. Potential disadvantages/complications include: risk of dural tear, scarring, alopecia, minimal cancellous bone availability, close proximity to the surgical site limiting the ability for two surgical teams, possible contour deformity, hematoma, superior sagittal sinus laceration (causing significant hemorrhage), infection, and risk of an epidural hematoma [2,6]. In cases of dural tear, significant hemorrhage, or other intracranial injury, immediate neurosurgery consultation is advised.

Anterior iliac crest

Introduction

Anterior iliac crest (AIC) bone grafts are commonly used in maxillofacial reconstruction due to the abundant quantity of

corticocancellous bone availability ($\sim 50 \text{ cm}^3$). The anterior iliac crest is found between the anterior iliac spine (AIS) and the iliac tubercle, which is found approximately 6 cm posterior to the AIS. Vascular supply to the region is supplied by the perforating branches of the deep circumflex iliac artery and vein, located on the medial ilium. The most common source of bleeding during graft harvest is the gluteal artery. There are several sensory cutaneous nerves in the region. The lateral cutaneous branch of the iliohypogastric nerve (L1, L2) crosses over the tubercle. Coursing inferior to the iliohypogastric nerve, the lateral cutaneous branch of the subcostal nerve (T12, L1) crosses over the tip of the anterior superior spine. The lateral femoral cutaneous nerve is located more inferior and courses medially between the psoas major and the iliacus muscle, perforating the tensor fascia lata to innervate the skin of the lateral thigh. In 2.5% of people, the lateral femoral cutaneous nerve can be found to cross within 1 cm of the anterior superior iliac spine, and if encountered during dissection and damaged, the condition meralgia paresthetica (persistent dysesthesia and anesthesia to the lateral thigh) may develop. Relevant muscular anatomy includes the external oblique, tensor fascia lata, gluteus medius, and iliacus muscles [2,8] (see Figure 14.7).

Procedure

Harvesting of the AIC bone graft (AICBG) is performed in the operating room under general anesthesia. A bump is placed under the patient's hip of interest and the patient is prepped and draped in sterile fashion. The skin is retracted medially over the crest so as to result in a scar that rests lateral to the crest to avoid irritation from clothing. A skin marker is used to map out the planned incision, starting 1–2 cm posterior to the AIS and extending 4–6 cm posteriorly

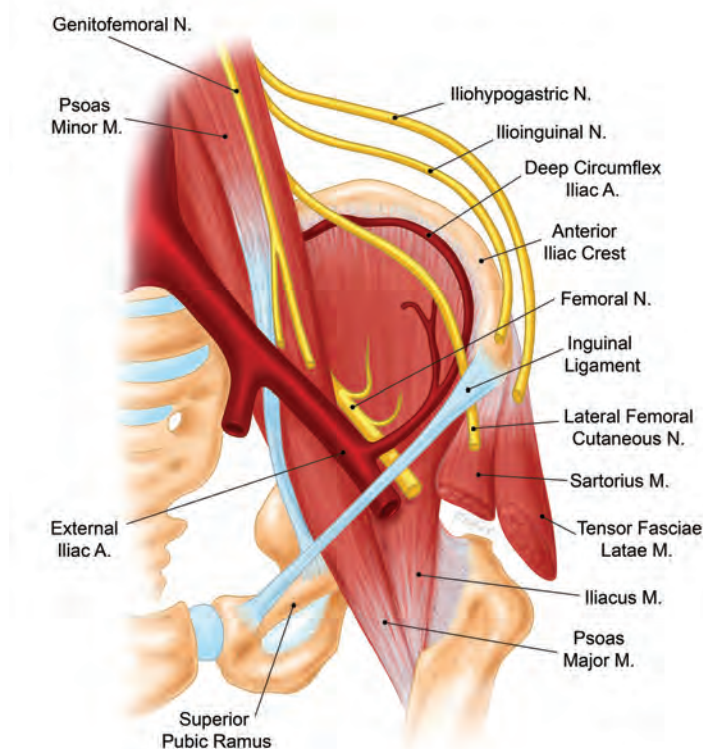


Figure 14.7 Illustration of anterior iliac crest anatomy.

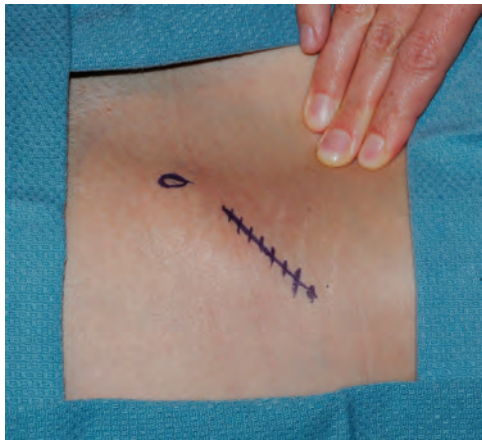


Figure 14.8 Skin markings of planned incision for AICBG.

along the crest (see Figure 14.8). Local anesthesia is administered along the length of the planned incision. Using a 10 blade, the incision is carried out through the skin, subcutaneous tissue, and Scarpa's fascia, down to the muscle layer. Dissection is continued through the aponeurosis between the tensor fascia lata laterally and the external oblique abdominal muscle medially, and then through the peritoneum. Subperiosteal dissection is performed to reflect the iliacus muscle off the medial iliac crest. It is best to avoid dissection laterally involving the tensor fascia lata, thereby minimizing the risk of gait disturbance. Care must also be taken to protect the medial musculoperiosteal layer in order to reduce the risk of intra-abdominal injury during graft harvest. This can be done using either iliac retractors or large malleable retractors [2,8].

Depending on the type and amount of bone needed, there are multiple approaches one may take for bone harvest. If only cancellous bone is required, the various approach options include: clamshell, Tschopp, trap door, and Tessier. When a block of cortical bone is necessary, a reciprocating saw is used to make a mid-crestal cut that

starts 1–2 cm posterior to the AIS and extends posteriorly up to 4–6 cm and inferiorly to a depth up to 5 cm (see Figure 14.9a and b), which is where the anterior and posterior cortical plates fuse. The reciprocating saw is used to make vertical cuts along the medial crest at the desired anterior and posterior extent of the desired graft, again down to the desired depth (maximum 5 cm from the crest). The inferior outline can be initiated with a fissure bur and further defined with a curved osteotome. Once all boundaries have been outlined, a straight osteotome is used to remove the cortical block. Bone curettes can then be used to remove cancellous bone. A total of approximately 50 cm³ corticocancellous bone is available for harvest from the AIC [2,8].

After copious irrigation, a hemostatic agent is applied into the osteotomy site, such as microfibrillar collagen, and adequate hemostasis is confirmed before closure. A surgical drain may be placed to limit post-operative fluid collection, depending upon surgeon preference. Closure is performed in a layered fashion, with a 2-0 resorbable suture to close the periosteum and musculoaponeurotic layers, a 4-0 resorbable suture for the subcutaneous layer, and then a 4-0 non-resorbable suture to close the skin. A sterile dressing is then applied over the wound according to surgeon preference. The patient is routinely admitted overnight for observation and should be self-ambulatory prior to discharge. The patient may require assistance with either a cane, crutches, or walker in the immediate post-operative period and is advised to avoid strenuous physical activity for 6 weeks [2,8].

R/B/A/complications

Advantages of the anterior iliac crest as a donor site include: large amounts of corticocancellous bone availability and ability for a two-team approach for simultaneous graft harvest and recipient site preparation. Complications include: infection, hematoma, seroma, gait disturbance, iliac crest fracture, intra-abdominal perforation/injury, ileus and sacroiliac instability, abdominal hernia, chronic pain, cosmetic contour deformity, scarring, and sensory nerve injury. Complication rates are reported between 0.7% and 25% [8].

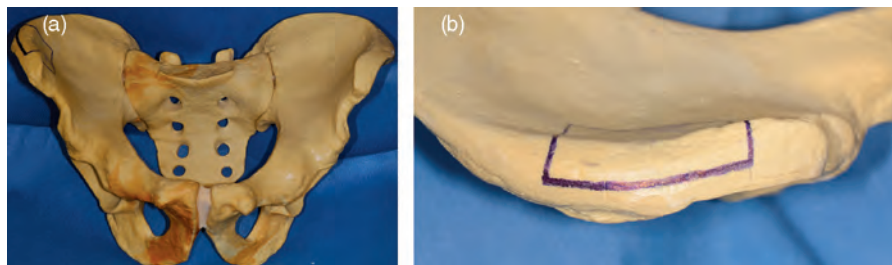


Figure 14.9 Anterior ilium with outline of planned harvest.

Case report

This case and photos are reproduced by permission of Chan M. Park, DDS, MD, FACS, OMFS, Residency Program Director, University of the Pacific/Highland Hospital, Oakland, California, USA.

A 19-year-old, otherwise healthy, male presented with a multilocular radiolucency of the right mandible extending from the right premolar posteriorly to the coronoid notch (see Figure 14.10). Biopsy confirmed the diagnosis of ameloblastoma and the patient was scheduled in the OR under general anesthesia for resection and immediate reconstruction with AICBG. The tumor was outlined and planned incision site marked (see Figure 14.11). An extraoral approach was utilized to expose the right mandible from the condyle to symphysis (see Figure 14.12) and a right hemimandibulectomy was performed (see Figure 14.13a and b). A corticocancellous block was then harvested from the left AIC (see Figure 14.14a and b), which was cut into three cortical blocks and attached to the pre-bent condylar reconstruction plate (see Figure 14.15a and b). The condylar reconstruction plate with attached cortical blocks was then positioned and secured into the right mandibular site (see Figure 14.16) and the remaining cancellous bone graft was packed around the cortical blocks. Immediate post-operative imaging was obtained (see Figure 14.17).

Six months later, repeat imaging was obtained (see Figure 14.18) and implant rehabilitation was planned. Four implants were placed into a well-formed ridge (see Figure 14.19a to d) and subsequently restored with an implant bridge (FPD) after adequate osseointegration (see Figure 14.20). The patient healed well after all surgeries and has restored form and function of his right mandible.

(continued)

(Continued)



Figure 14.10 Panoramic radiograph showing large multilocular radiolucency of right mandible.



Figure 14.11 Skin markings of inferior border of mandible, outline of tumor, and planned incision site.

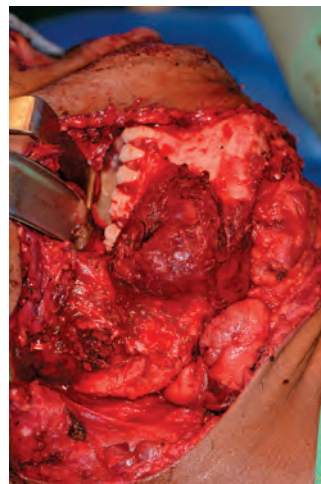


Figure 14.12 Exposure of right mandible with ameloblastoma.



Figure 14.13 Right hemimandibulectomy.



Figure 14.14 Harvesting left anterior iliac crest bone graft (AICBG).

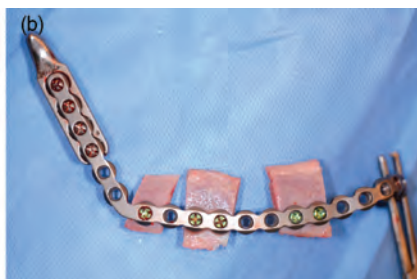


Figure 14.15 Cortical blocks secured on to the pre-bent condylar reconstruction plate.

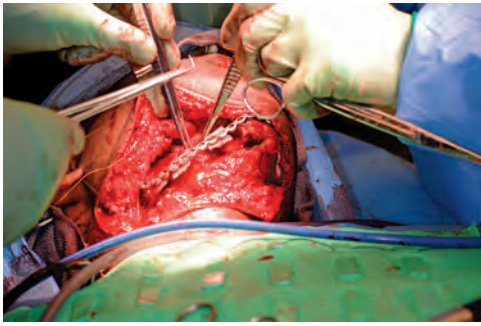


Figure 14.16 Reconstruction plate with cortical blocks secured into the proper position.

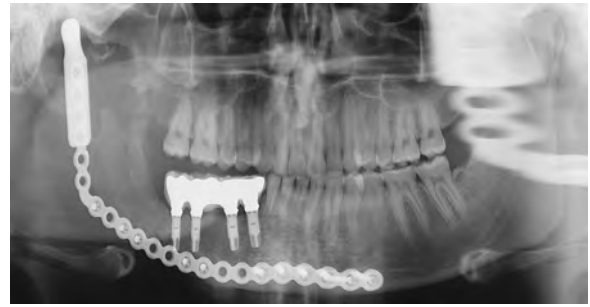


Figure 14.20 Final implant FPD prosthesis after adequate osseointegration.



Figure 14.17 Post-operative panoramic radiograph.



Figure 14.18 Six-month post-operative panoramic radiograph.

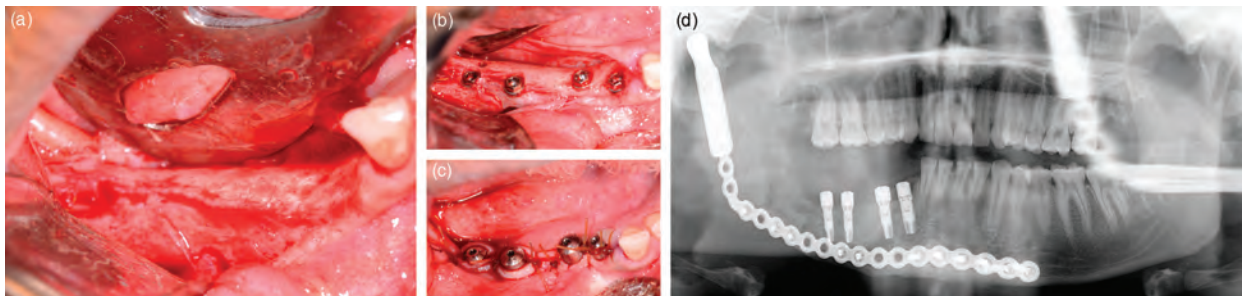


Figure 14.19 Implant surgery demonstrating placement of four implants into a well-formed ridge.

Posterior iliac crest

Introduction

The posterior iliac crest (PIC) donor site allows for the greatest volume of bone graft harvest, approximately 100–120 cm³ of uncompressed corticocancellous bone. For large ridge reconstructions requiring more than 50 cm³ of bone, it is the preferred site for graft harvest. The greatest amount of bone available for harvest can be found beneath the insertion of the gluteus maximus muscle on to a triangular tubercle adjacent to the sacroiliac joint. This tubercle measures approximately 3 cm × 4 cm and has a ridge extending inferiorly from it 10–12 cm to form the sciatic notch. Anteriorly, the gluteus medius muscle attachment can be found and further anteriorly is the attachment of the gluteus minimus muscle. The gluteus maximus muscle is not involved in a normal gait, rather it functions when one is standing up from a sitting position. As only the gluteus maximus and an insignificant amount of the gluteus medius muscles are reflected during the dissection for PIC bone graft harvest, gait disturbance is minimal to non-existent. The cutaneous sensory nerves found in this region include the superior cluneal (L1–L3) and middle cluneal (S1–S3) nerves. Vascular supply is provided by the subgluteal artery, which is a terminal branch of the deep circumflex iliac artery [2,8,9] (see Figure 14.21).

Procedure

Harvesting of PIC bone graft (PICBG) is performed in the operating room under general anesthesia with the patient in a prone position with 210° of reverse hip flexion. The patient is prepped and draped

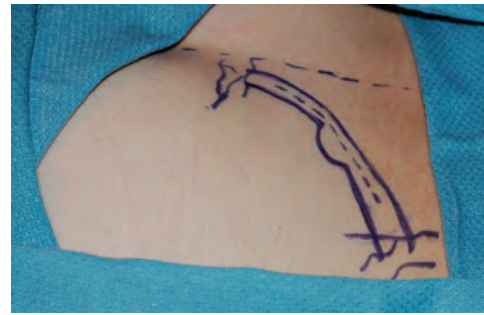


Figure 14.22 Skin markings of the relevant anatomy and planned incision for a posterior iliac crest bone graft (PICBG).

in sterile fashion. Using a skin marker, the relevant anatomy is identified, including the posterior iliac crest, tubercle of gluteus maximus attachment, patient's mid-line, and the superior and middle cluneal nerve branches (see Figure 14.22). The planned incision is mapped out; it should follow the curvature of the posterior iliac crest and be approximately 6–10 cm in length with its mid-point centered over the tubercle. The incision should remain a minimum of 3 cm from the mid-line. This incision placement centered over the tubercle should prevent injury to the superior and middle cluneal nerves [8,9].

Local anesthesia is then administered along the planned incision site. Using a 10 blade, the incision is carried down through the skin,

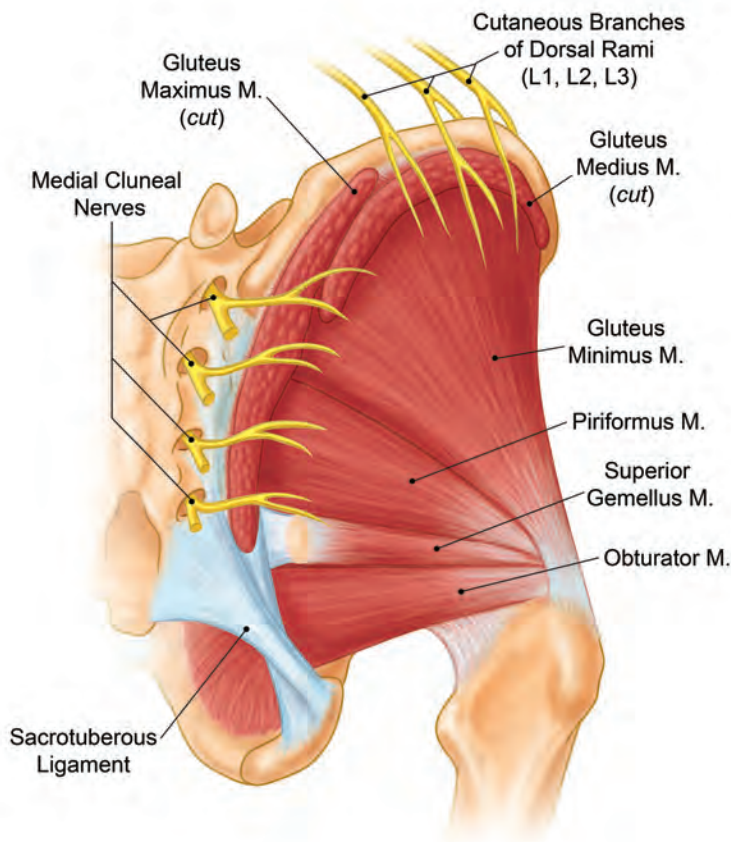


Figure 14.21 Illustration of posterior iliac crest anatomy.



Figure 14.23 Posterior ilium with an outline of the planned harvest.

subcutaneous layer, thoracodorsal fascia, and periosteum. The gluteus maximus muscle is sharply reflected from the tubercle down to the gluteal line (approximately 3 cm beneath the crest). Below this, the gluteus medius is encountered, which is minimally reflected in a subperiosteal plane to complete exposure. A posterior ilium retractor is then inserted to allow adequate exposure of the lateral posterior ilium. Using a reciprocating saw, the outline of the desired graft is made (maximum size is 5 cm × 5 cm) (see Figure 14.23). The posterior edge of the graft is at the height of the ridge of the posterior tubercle. The saw is passed only through the lateral cortex. Next, the saw is used mid-crestally, extending from the defined posterior edge anteriorly to the desired width of the graft (maximum 5 cm). The anterior edge of the graft is then made with the reciprocating saw and, lastly, the vertical limbs are then connected at the inferior margin. Once the outline of the graft is completed, the cortical block is removed using a 1-inch curved osteotome and mallet. Cancellous bone can then be removed using a bone gauge and curettes. Once the desired amount of cancellous bone has been removed, the bony edges of the harvest site should be

smoothed using a rasp. After copious irrigation, hemostasis is obtained with the combined use of cautery followed by bone wax, microfibrillar collagen, or a collagen sponge soaked in thrombin. A 7- or 10-mm bulb suction drain is recommended and is placed into the bony cavity with the point of exit being anterior enough so that the patient does not lie on it [9].

For closure, the periosteum is re-approximated with a 2-0 resorbable suture. It is important to re-suspend the gluteus maximus muscle to the thoracodorsal fascia to facilitate proper position and attachment. The subcutaneous layers and dermis are closed with a 3-0 resorbable suture and the skin is then closed with either small skin staples or 4-0 non-resorbable skin sutures. A sterile pressure dressing is then applied according to surgeon preference [9].

Patients are admitted for observation post-operatively. The drain is removed once output has slowed to an appropriate amount as deemed by the surgeon, usually about 30–50 ml per 24 hour period, which may take 2–4 days. Patients are encouraged to maintain bed rest for the first post-operative day and then to begin ambulation on the second post-operative day. It is advised for patients to avoid strenuous activities for 6 weeks, including walking up more than one flight of stairs or walking more than one city block [9].

R/B/A/complications

Advantages of the posterior iliac crest as a donor site include the great volume of bone graft availability and fewer complications compared to the anterior iliac crest harvest site. Potential complications include: seroma, hematoma, gait disturbance, compartment syndrome, ureteral injury, abdominal hernia, cluneal nerve injury, bleeding, infection, and scarring. Disadvantages of harvesting from the posterior versus the anterior ilium include: a longer operating time, need for prone positioning of the patient, risk of dislodging the endotracheal tube, and inability for two surgical teams to work simultaneously at donor and recipient sites [2,9].

Case report

This case and photos are courtesy of Chan M. Park, DDS, MD, FACS, OMFS, Residency Program Director, University of the Pacific/Highland Hospital, Oakland, California, USA.

A 44-year-old female, otherwise healthy, presented with a mixed radiolucent–radiopaque lesion of the left mandible extending from the left premolar posteriorly to mid-ramus (see Figure 14.24). Biopsy confirmed the diagnosis of ossifying fibroma and the patient was scheduled in the OR under general anesthesia for resection and immediate reconstruction with PICBG. The inferior border of the left mandible was outlined and the planned incision site marked (see Figure 14.25). An extraoral approach was utilized to expose the left mandible from the condyle to symphysis (see Figure 14.26) and a left hemimandibulectomy sparing the condyle was performed (see Figure 14.27a and b). A corticocancellous block was then harvested from the right PIC (see figure 14.28a to d), which was broken up with a rongeurs, mixed with rhBMP-2 and absorbable collagen sponge, and packed behind the pre-bent and secured reconstruction plate (see Figure 14.29). Immediate post-operative imaging was obtained (see Figure 14.30).



Figure 14.24 Panoramic radiograph showing large mixed radiolucent–radiopaque lesion of the left mandible.



Figure 14.25 Skin markings of the left inferior border of the mandible and the planned incision.

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Figure 14.26 Exposure of the left mandible with ossifying fibroma.

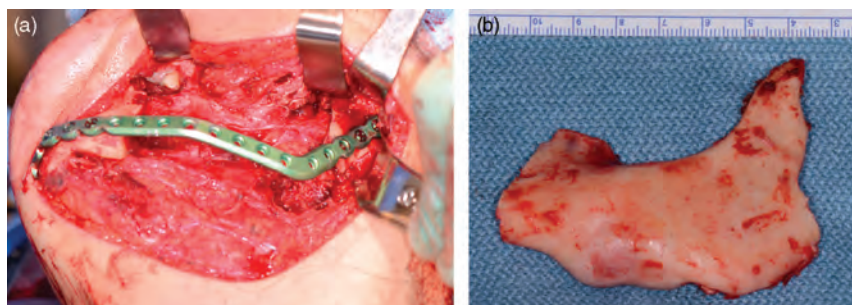


Figure 14.27 Left hemimandibulectomy sparing the condyle.

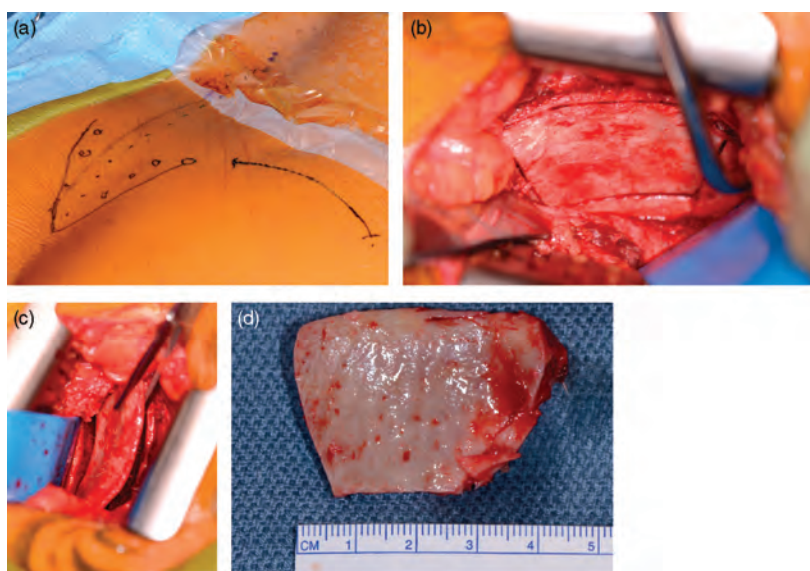


Figure 14.28 Harvesting of the right PICBG.



Figure 14.29 Corticocancellous graft mixed with rhBMP-2 and absorbable collagen sponge packed into the defect.



Figure 14.30 Post-operative panoramic radiograph.

Six months later, two implants were placed into a well-formed ridge (see Figure 14.31a to c) and subsequently restored with PFM crowns after adequate osseointegration. The patient healed well after all surgeries and has restored form and function of her left mandible.

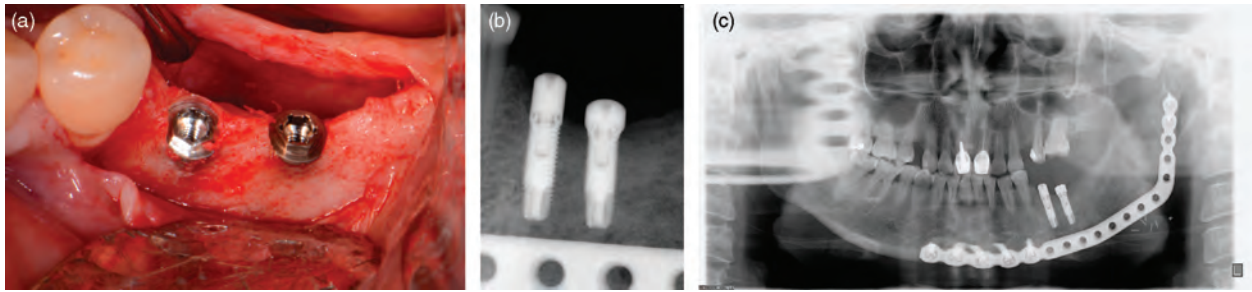


Figure 14.31 Implant surgery showing two implants placed into a well-formed ridge.

Tibia

Introduction

The tibia is another donor site option for maxillofacial bone grafts in skeletally mature patients (see Figure 14.32). It is favored by many surgeons for its simple technique and low morbidity. The more common approach is laterally, through Gerdy's tubercle,

which is easily palpable and located between the tibial tuberosity and the fibular head. There are no vital structures lying superficial to Gerdy's tubercle, allowing direct access. Inferior to Gerdy's tubercle lies the anterior tibialis muscle as well as branches of the inferior genicular artery and the recurrent anterior tibial artery. In this region, sensory innervation is supplied by cutaneous branches of the lateral sural nerve [1]. A medial approach is also possible, as described by Herford and colleagues, which allows for similar volumes of harvested bone graft (~25 ml) and similar thickness of cortex (~1.5 mm) [10]. The medial approach is preferred by some as it is more distant to any vital structures (i.e. articular surface, anterior tibialis muscle, and anterior tibial vessels) than the lateral approach, although anatomic landmarks may be more difficult to identify, especially in larger patients [2].

Procedure

Tibial bone grafts are routinely done in an outpatient setting, under either intravenous sedation or local anesthesia. The relevant anatomy is mapped out using a skin marking pen. For the lateral approach, this includes the patella, tibial tuberosity, fibular head, and Gerdy's tubercle (see Figure 14.33). The planned skin incision is also marked, extending obliquely over Gerdy's tubercle approximately 3–4 cm in length (see Figure 14.33). Local

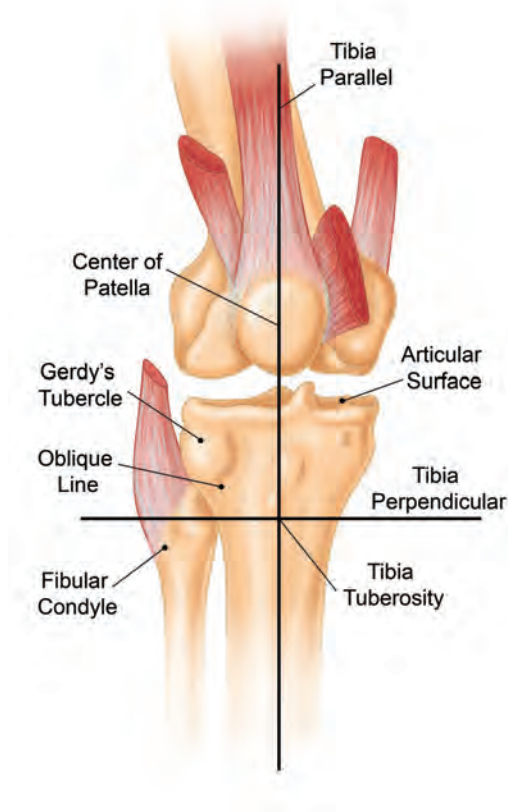


Figure 14.32 Illustration of proximal tibia anatomy.

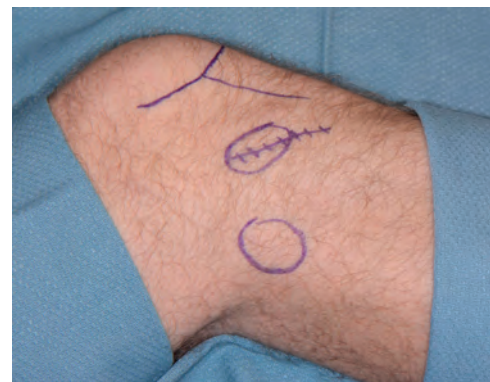


Figure 14.33 Skin markings of relevant anatomy and planned incision for tibial bone graft via the lateral approach.

anesthesia is administered along the length of the planned incision. Using a 10 or 15 blade, the incision is made through the skin, subcutaneous fat, iliotibial tract, and the periosteum. Subperiosteal dissection is performed with a no. 9 periosteal elevator to expose Gerdy's tubercle. A fissure bur is then used with copious irrigation to outline a 1–2 cm oval window through the cortex (an oval window is preferred in order to produce less stress on the surrounding bone and reduce the risk of post-operative fracture). Bone curettes are then used to harvest cancellous bone, first from across the plateau and then from down the shaft. Care must be taken when harvesting bone superiorly to avoid entering the joint space. Hemostasis is rarely an issue, but, if necessary, gelfoam or microfibrillar collagen may be placed into the cavity. Layered closure is then performed with a 3-0 resorbable suture to close the periosteum and iliotibial tract, a 4-0 resorbable suture for the subcutaneous layer, and then a 4-0 non-resorbable suture to close the skin [2,11].

For the medial approach, the relevant anatomy to mark includes the patella, proximal aspect of the tibia, mid-point of the tibial plateau, and lines extending vertically (tibial parallel line) and horizontally (tibial perpendicular line) through the mid-point of the tibial plateau (see Figure 14.34). The incision line is then marked, the center of which is to be 15 mm medial to the vertical line (tibial parallel line) and 15 mm superior to the horizontal line (tibial perpendicular line) and measures approximately 1–1.5 cm in length (see Figure 14.34). Local anesthesia is then administered along the length of the planned incision. A 10 or 15 blade is used to incise through skin, subcutaneous fat, and periosteum down to bone. Subperiosteal dissection is performed with a no. 9 periosteal elevator. Again, a 1–2 cm oval window through the cortex is made using a fissure bur with copious irrigation and then cancellous bone is removed using bone curettes. Gelfoam or microfibrillar collagen may be placed into the cavity as needed for hemostasis. Layered closure is then performed with a 3-0 resorbable suture to close the periosteum, a 4-0 resorbable suture for the subcutaneous layer, and then a 4-0 non-resorbable suture to close the skin [10].

A sterile pressure dressing is then applied over the site according to surgeon preference. The patient may ambulate immediately post-operatively (weight bearing as tolerated), but is advised to avoid strenuous physical activity for 6 weeks. Rarely, patients may be

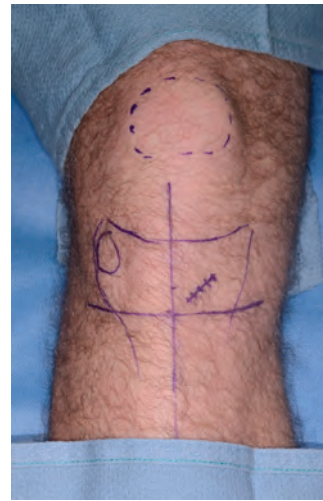


Figure 14.34 Skin markings of the relevant anatomy and planned incision for the tibial bone graft via the medial approach.

given a cane or crutches to aid in ambulation, although this is not usually necessary.

R/B/A/complications

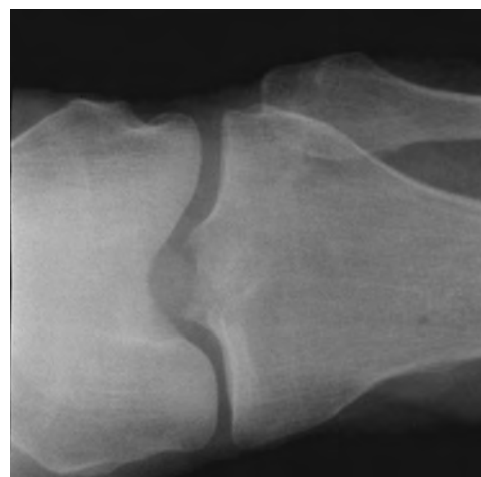
The advantages of the tibia as a donor site include: a low complication rate, minimal morbidity, a large amount of cancellous bone availability, technically simple and quick procedure, the ability for a two-team approach, and the ability to perform the procedure in the outpatient setting. Disadvantages include: limited amount of cortical bone, variable amounts of cancellous bone, and possibly decreased quality of the cancellous bone of the tibia versus the iliac crest, although this is based upon anecdotal reports of the appearance of the bone at the time of harvest and is disputed in studies comparing densitometrics of both tibial and iliac crest grafts when used in grafting of alveolar clefts, which found similar densities between the two [12]. Possible complications include: prolonged pain, gait disturbances, wound dehiscence, infection, scarring, hematoma, seroma, paresthesia, fracture, and violation of the joint space. Complication rates are reported between 1.3% and 5.5% [2].

Case report

This report is a courtesy of Dr. Vishtasb Broumand, DMD MD, Private practice, Oral & Maxillofacial Surgery, Adjunct Assistant Clinical Professor, Department of Oral and Maxillofacial Surgery, University of Florida College of Dentistry, Gainesville, FL.



Figure 14.35 The tibia bone harvest is a procedure that can be performed in the office; however, it must be performed under sterile conditions with the proper instrumentation. This is an in-office procedure that was performed with intravenous sedation although this is not absolutely necessary.



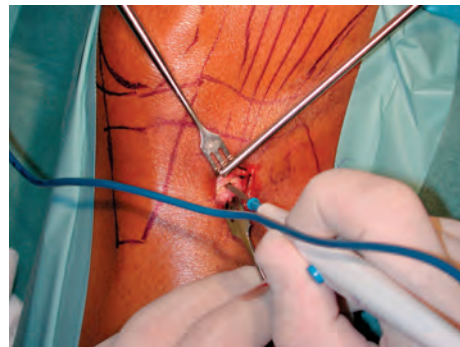
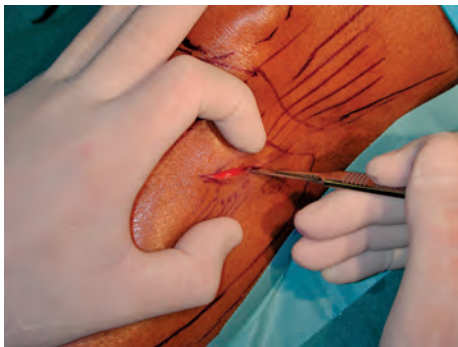
Figures 14.36, 14.37 The harvest site for the lateral aspect of the greater tibial plateau, which can easily yield 30 ml of cancellous marrow.

(continued)

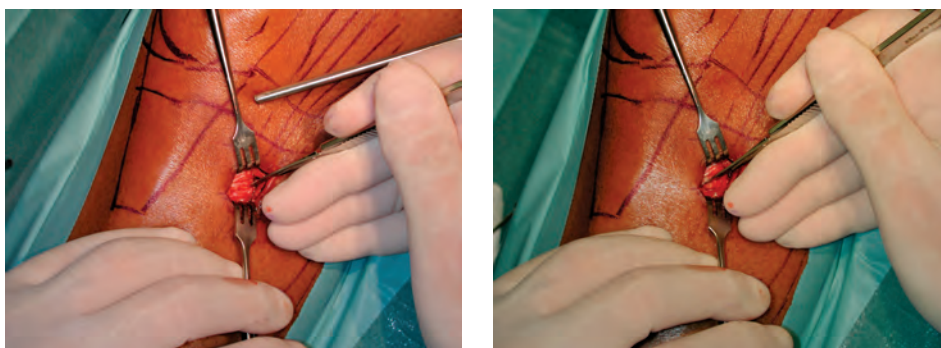
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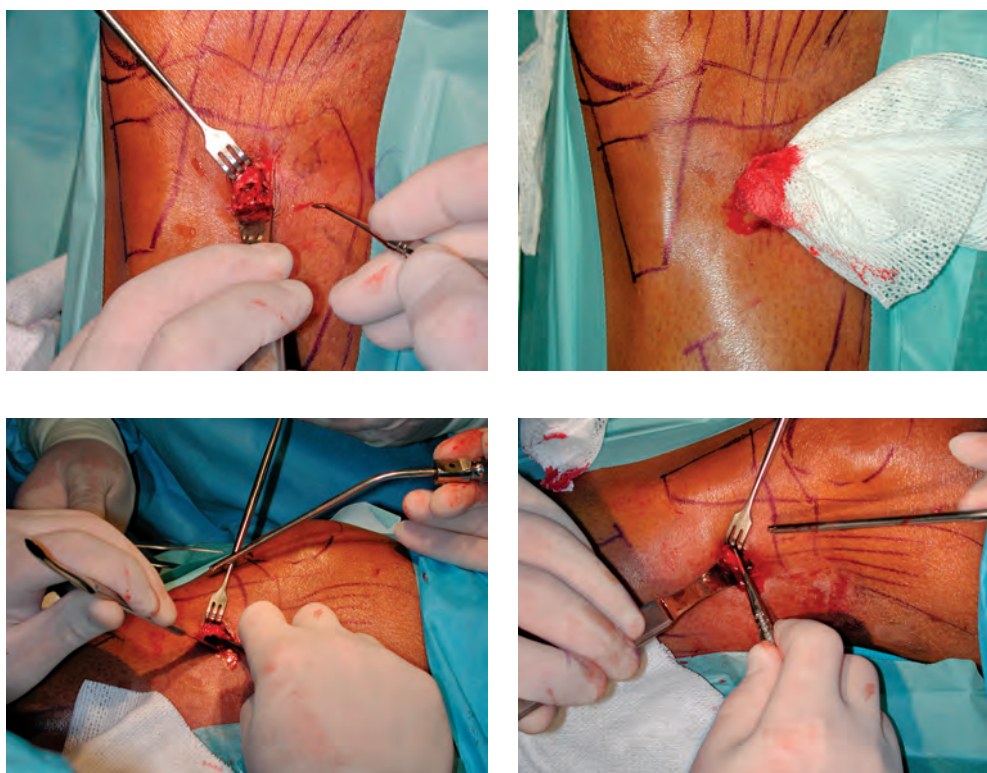
Figures 14.38–14.40 The positioning of the patient's leg is flexion of 210° . After sterile preparation is applied, Gerdy's tubercle (which is the lateral prominence over the outer edge of the tibia) is marked at the attachment of the iliotibial tract. The leg is flexed at the knee, with the surgeon noting the tibia and fibula heads (fibula = posterior and superior). The lateral tibial tubercle (Gerdy's tubercle) is 6–10 mm from the skin surface; the incision is 1.5–2.0 cm directly over the tubercle.



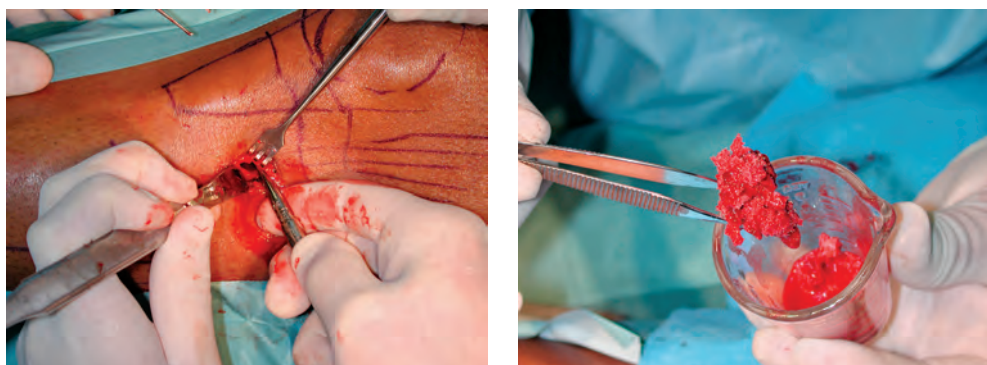
Figures 14.41–14.44 1 ml of local anesthesia is applied to a depth of 1 cm over the lateral aspect of Gerdy's tubercle. A 1 cm incision is made in an inferior-medial direction over Gerdy's tubercle down through the skin. A sharp dissection through Sharpey's fibers of tensor fascia lata band and reflection of the anterior tibialis muscle leading to the cortex. An electrocautery can be used to obtain hemostasis and, following that, reflection of the anterior tibialis muscle over the lateral aspect of the tubercle.



Figures 14.45–14.46 (Continued)



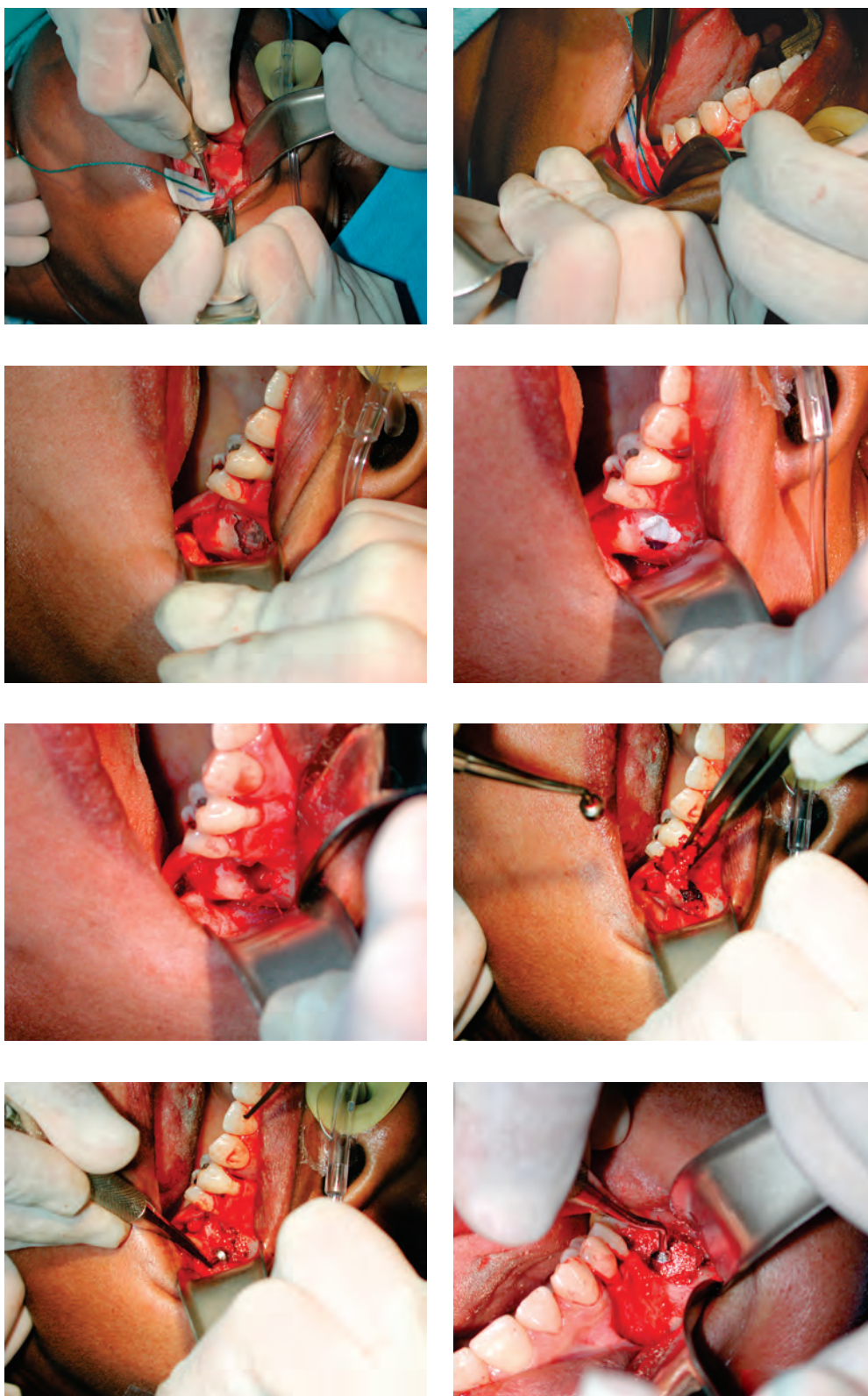
Figures 14.47–14.50 The cortex is opened with a 702 bur 1.5 cm × 1.5 cm (normally 1 cm × 1 cm), followed by removal of the cortical plug, harvesting 30 ml of cancellous marrow. The plug can be crushed and added for grafting, forming a corticocancellous autogenous bone graft. During the harvest, one must direct the curette parallel to the tibial plateau or inferior to it to avoid the knee joint.



Figures 14.51–14.52 Curettes and gouges are directed in an inferior medial direction to obtain approximately 30 ml of cancellous marrow.

(continued)

(Continued)



Figures 14.53–14.60 After a maxillary sinus lift is accomplished in a successful fashion, the bone is mixed with platelet-rich plasma bovine xenograft and applied into the subantral pocket (under the elevated Schneiderian membrane).

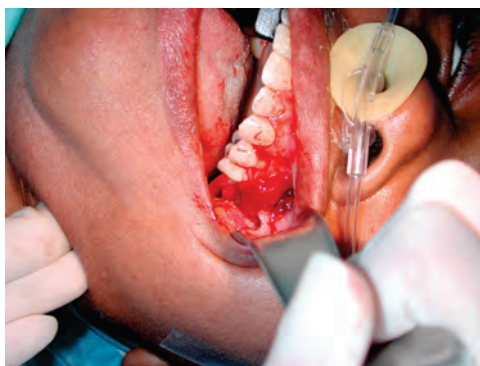
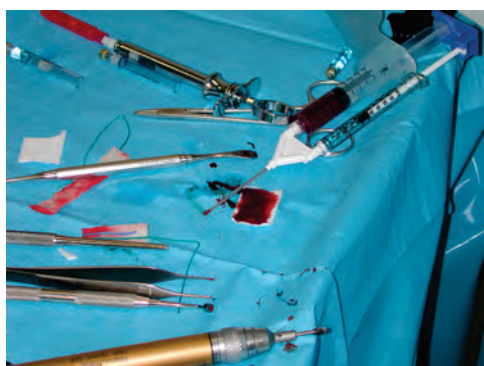
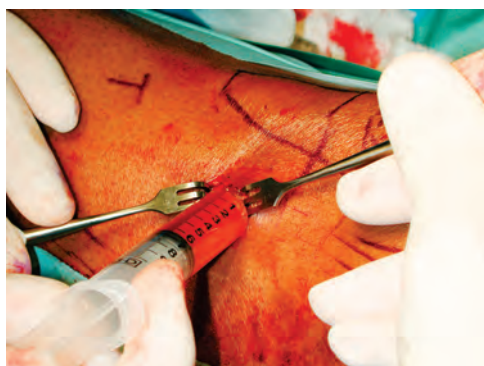


Figure 14.61 Platelet-poor plasma is used as a membrane over the maxillary sinus prior to closure. The intraoral incision is closed with interrupted 4-0 chromic gut sutures after satisfactory completion of the sinus lift procedure.



Figures 14.62–14.66 The leg wound is debrided with saline and closed after platelet-poor plasma is also placed into the donor site (tibia) to aid in healing. The leg incision is closed with Vicryl sutures in the fascial layer, with nylon sutures for the skin. A drain is rarely necessary.

(continued)

(Continued)



Figure 14.67 Radiograph of the sinus lift with the bone graft in place.



Figure 14.68 A well-healed scar is evident at three months.

Conclusion

Extraoral bone grafts from distant sites are particularly useful when larger amounts of bone are required for alveolar ridge reconstruction. The most commonly used sites include: calvarium, tibia, anterior iliac crest, and posterior iliac crest. The posterior iliac crest bone graft allows for the greatest amount of bone graft harvest, but requires the patient to be under GA and to be repositioned between prone and supine positions. The anterior iliac crest allows for the next greatest amount of bone graft harvest, but requires the patient to be under GA and has a greater risk of gait disturbance. The tibial bone graft may be harvested under LA or IV sedation in the clinic setting, but has limited amounts of cortical bone availability. The calvarial bone graft has a large amount of cortical bone availability, but a limited amount of cancellous bone and must also be done with the patient under GA. Each site has its own distinct advantages/disadvantages, and the ultimate decision of which site to use must be made by the surgeon considering these, the amount and type of bone graft needed, morbidity of the donor site, patient preference, operative time, as well as the surgeon's preference and comfort level.

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Alternative Intraoral Block Bone Grafting Techniques for Horizontal Alveolar Ridge Augmentation in Implant Dentistry

PART A: LOCALIZED ALVEOLAR RIDGE AUGMENTATION WITH BLOCK ALLOGRAFT

Joseph A. Leonetti¹ and J. Daulton Keith, Jr.²

¹Main Line Oral Surgery, Paoli and Lionville Pennsylvania, Pennsylvania, USA

²Private Practice in Periodontics, Charleston, South Carolina, USA

Introduction

Bone loss limits the ability to successfully place dental implants due to the absence of sufficient bony volume in the mandible or maxilla. The availability of adequate bone volume for dental implant placement is often diminished by trauma, pathology, periodontal disease, and tooth loss [1,2]. Bone resorption in the maxillary ridge frequently results in a knife-edged deformity, which complicates implant placement and stabilization, particularly in the posterior jaw. Grafting with autogenous bone has been documented to be highly effective in reconstructing jaw anatomy [3,4], restoring esthetics [5,6], and providing biomechanical support for the placement of dental implants [7]. Reported donor sites for harvesting autogenous bone have included the calvarium [8,9], iliac crest [10–13], tibia [14,15], fibula [16], scapula [17], symphysis [18–25], and ramus buccal shelf [26–38]. Each donor site varies in the quality and quantity of bone available for harvesting (Table 15.1) [39]. The use of block autografts is indicated primarily when an increase in ridge volume is desired, especially as part of the implant site development.

Autogenous block bone grafts have been highly successful in developing adequate bone volume for dental implant placement. Autogenous graft resorption and donor site morbidity are clinical concerns associated with autogenous grafting procedures. Membranous grafts have shown less resorption than endochondral bone grafts [40,41], which suggests that intraoral donor sites may provide an advantage in harvesting block grafts for augmentation of the alveolar ridge, and they can be easily accessed in an office setting. Predictable increases averaging 4–5 mm (maximum 6–7 mm) in ridge width [41] and 2–3 mm in vertical ridge height [42] have been documented with intraoral block grafting procedures. Clinical concerns regarding the use of the chin (mandibular symphysis) for block autografts include the potential for V-3 paresthesia, infection, loss of tooth vitality, and the post-operative appearance of the chin. Careful attention to incision design and osteotomy location has shown that these concerns are of minimal importance [5,43].

Cortical block grafts harvested from the mandibular ramus have been shown to be well suited for veneer grafting of horizontal ridge deficiencies prior to implant placement [5,44]. The advantages of this donor site over the chin include minimal potential for altered facial contour, proximity to posterior mandible recipient sites, and decreased complaints of post-operative sensory disturbances and discomfort. However, unlike the symphysis region, the ramus anatomy only allows for harvesting of a thin, mostly cortical bone segment that typically measures up to 4 mm in thickness [45–47]. Regardless of the donor site for autogenous block grafts, four to six months of healing is necessary before dental implants can be placed into the region. This staged technique using autogenous bone blocks harvested at the time of surgery is the most commonly used grafting technique, due to its general clinical success [48–53] and predictability in implant site development [54–59].

In addition to increased operating time and donor site morbidity, deficiencies in the quality and/or quantity of available bone, limitations in the sizes and shapes of available grafts, and the potential for intraoperative and post-operative complications are other drawbacks associated with the use of autografts [60–66]. One study documented that 25% of patients treated with autografts harvested from the iliac crest reported significant pain at an average of five years post-operative [54,60]. Other studies have estimated that 6% to 20% of patients tend to complain of pain, hypersensitivity or buttocks anesthesia, while 3% to 9% suffer major complications from iliac graft procedures [54,60–63]. An insufficient volume of available donor bone may be especially problematic in patients previously subjected to graft harvesting [54]. For these reasons, scientists have investigated the use of banked allogeneic (Table 15.2) and xenogeneic bone, as well as a number of alloplastic materials, such as natural and synthetic hydroxylapatite, calcium-phosphate compounds and polymer products, as alternatives or supplements to autogenous bone grafts [66,67].

Allogeneic bone possesses osteoconductive characteristics similar to those of autografts and has been widely used as a bone graft

Table 15.1 Approximate amount of available bone by donor site location [39]. Reproduced by courtesy of Zimmer Dental Inc., Carlsbad, CA, USA.

Region	Location	Approximate amount of harvestable bone (cm ³)
Iliac crest	Posterior superior	60–80
Iliac crest	Anterior superior	30–50
Tibia	—	30–40
Calvarium	—	20–25
Rib	—	10–150
Intraoral	Lateral ridge	4
Intraoral	Symphysis	4
Intraoral	Tuberosity	1

Table 15.2 Comparison of autogenous and allogenic bone graft materials. Reproduced by courtesy of Zimmer Dental Inc., Carlsbad, CA, USA.

Source	Forms	Types	Advantages
Autogenous	Fresh	Cortical, cancellous or corticocancellous	Potential for osteoinduction, osteoconduction, and osteogenesis
	Frozen		Autoimmune compatibility
Allogenic	Solvent-preserved		No donor site morbidity
	Freeze-dried		Potential for osteoinduction and osteoconduction, depending on the processing technique
	Demineralized	Cortical, cancellous or corticocancellous	

alternative. Osteoconductive allografts provide a matrix for osteoblastic proliferation and new bone formation. Mineralized block allografts have been used successfully as an alternative to demineralized bone (DBM) [68–70], to treat localized alveolar ridge defects in humans. A staged treatment approach involving localized ridge augmentation with an allogeneic iliac bone block material has been shown to be an effective alternative to harvesting and grafting autogenous bone for implant site development, most often to correct *horizontal* ridge deficiencies. The block allograft eliminates the need for a secondary surgical procedure, thereby reducing operating room time, reducing pain and morbidity, and shortening the rehabilitation time for the patient [70].

Block allograft

Clinical and histological evaluations of block allografts have shown that the trabecular pattern and porosity of natural bone is preserved during the sterilization process (Puros block allograft, Zimmer dental) [71] (Figures 15.1 and 15.2). Other bone allografts have been shown to fully remodel in a manner similar to fresh-frozen bone [72] and have been used as alternatives to autografts in orthopedic [73,74] and oral surgery applications [75–80].

Histologic results have been documented [69]. Histopathologic evaluations revealed rapid incorporation of the block allograft at 6 months, as evidenced by newly formed bone containing viable



Figure 15.1 Block allograft.

osteocytes. The newly deposited osteoid and woven bone trabeculae surrounded and focally merged with few residual graft particles, which were characterized by empty lacunae and devoid of osteocytes. Because newly formed bone consists of trabeculae of woven bone, the two structures were indistinguishable. There was also no evidence of inflammatory reaction or necrosis. To achieve successful incorporation, host bone and blood cells must appose to the three-dimensional surface and interweave through the extra cellular matrix of the allograft (osteoconduction) [81]. This phenomenon is illustrated at the histologic level in which newly formed bone surrounds cancellous fragments of the allograft; incorporation of the allograft may also be facilitated by the presence of retained collagen, which is known to facilitate fibroblast attachment [82,83].

Block allograft surgical technique guidelines

Under adequate local anesthesia, a mid-crestal to slightly palatal incision is made over the defect, extending approximately 1–2 teeth on each side with release. A full thickness mucoperiosteal flap is elevated to clearly expose the ridge defect (Figures 15.3 and 15.4). An inlay prep site is prepared to maximize bony contact and stability of the block allograft when mortised into position. This is facilitated with use of a large round/straight carbide bur with copious irrigation. The inlay site should measure 0.5 mm to 1.0 mm in depth (Figures 15.5 and 15.6). Small perforations are drilled into the recipient bone to induce bleeding. This may aid in the proliferation of growth factors and platelets, which are essential for wound



Figure 15.2 Rehydration of the block allograft.

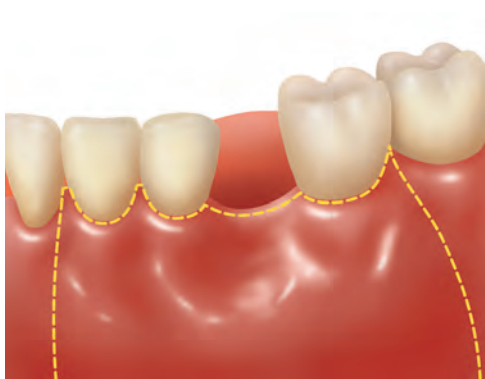


Figure 15.3 Incision design diagram; mandible. Photos reproduced by courtesy of Dr. J Daulton Keith, DDS, and Zimmer Dental Inc., Carlsbad, CA.

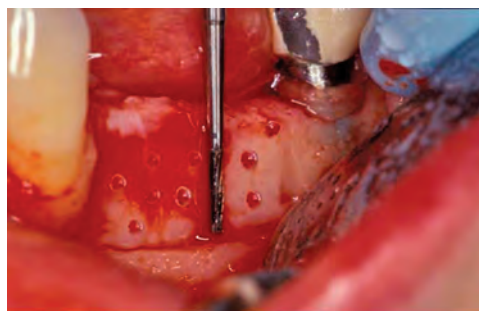


Figure 15.7 Small perforations of the recipient site.



Figure 15.4 Posterior mandible horizontal ridge defect.



Figure 15.8 Small perforation site.

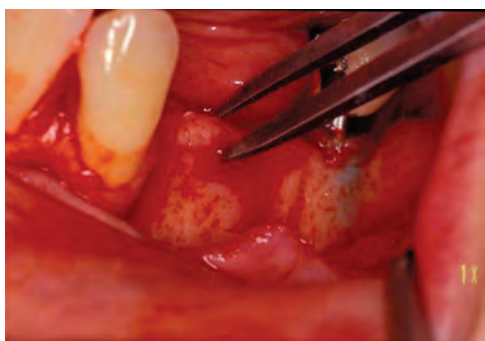


Figure 15.5 Surgical exposure of the horizontal ridge defect.



Figure 15.9 Rehydration with 60 cm³ syringe diagram.

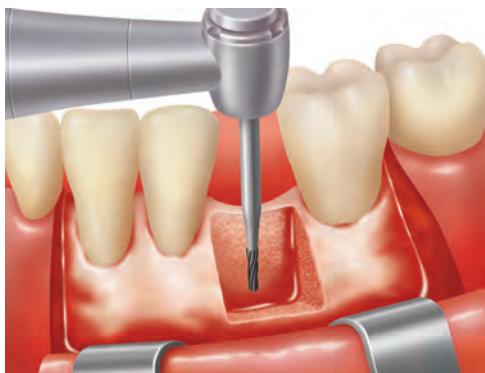


Figure 15.6 Inlay prep diagram.

healing and revascularization [84] (Figures 15.7 and 15.8). It is important to rehydrate the allograft according to the manufacturer's protocol (0.9% sterile saline solution) (Figure 15.9). This step can be completed during preparation of the recipient site. This should be followed by graft contouring with a handpiece and a large round/fluted bur. The cortical edges should be smoothed and the cancellous layer contoured until intimately adapted to the prepared defect site. Preserve enough cortical bone for rigid fixation of the graft. Care should be taken to limit or eliminate ridge-lap extension or coverage of the alveolar crest for vertical augmentation (Figure 15.10).



Figure 15.10 Block allograft contoured with carbide bur diagram.



Figure 15.12 Two-point screw fixation diagram.



Figure 15.11 Lag screw technique diagram.

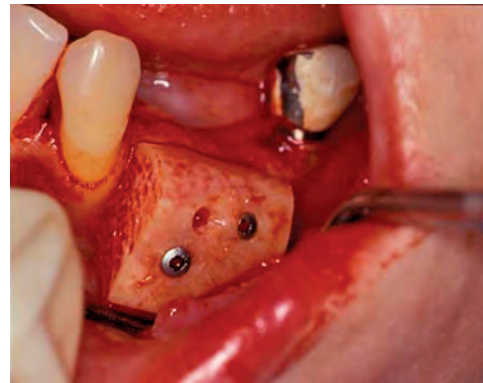


Figure 15.13 Intraoral view of block allograft fixation.

A lag screw technique utilizing a 1.5 mm diameter screw-access pilot hole is drilled through the allograft. This is followed by a 1.1 mm diameter pilot hole through the underlying recipient bone. The fixation screw is then freely inserted through the block allograft and screwed into the recipient bone to secure the block allograft in place. The use of the two-screw fixation approach helps prevent block rotations (Figures 15.11 and 15.12). The second screw should be placed obliquely to the first screw with enough separation (4 mm) to minimize the risk of stress fracture and the screws should be tightened with careful attention not to over-torque (Figure 15.13). Final contouring of the block allograft is completed intraorally to remove any sharp edges that might compromise soft tissue closure. Small voids around the block allograft can be filled with particulate allograft material and the graft site covered with a barrier membrane. Membrane technology assists with clot stabilization of the grafted area.

Soft tissue closure over the block graft is completed using an interrupted and mattress suture technique (Figure 15.14). To facilitate tension-free closure of the wound, scoring the underlying periosteum of the flap is advised as well as relaxation and development of the lingual flap. Platelet-rich plasma can also be used to assist with soft tissue healing. Post-operative protocol should include antibiotic coverage, analgesics, and antimicrobial rinse. Temporization should avoid any contact with the underlying soft tissue. The block graft is allowed to heal for 4–6 months before exposure and implant placement (Figure 15.15). Final restoration

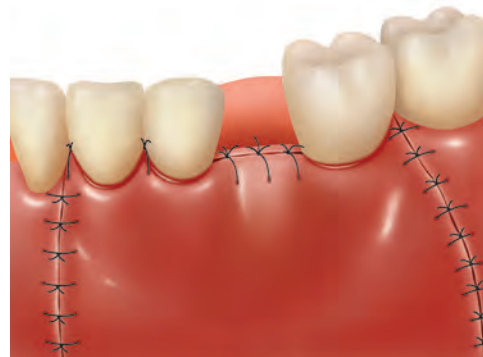


Figure 15.14 Wound closure diagram.

follows approximately 12–16 weeks after implant placement (Figures 15.16 to 15.18).

Another case of horizontally deficient anterior maxilla treated with block allograft is presented in Figures 15.19 to 15.35. Incision design is analogous with the previous description (Figures 15.19 and 15.20). Figure 15.21 of a cone beam computed tomography (CBCT) scan demonstrates an advanced horizontal ridge defect prior to surgery. An inlay development of the recipient site with box preparation and multiple perforations is shown in Figures 15.22

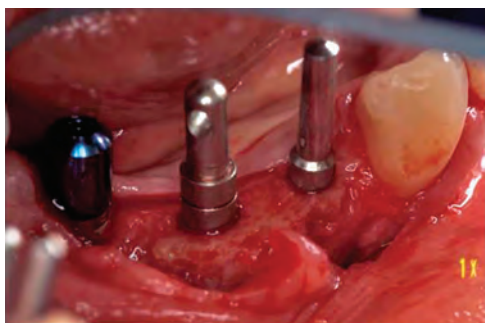


Figure 15.15 Implant site preparation in healed block allograft.

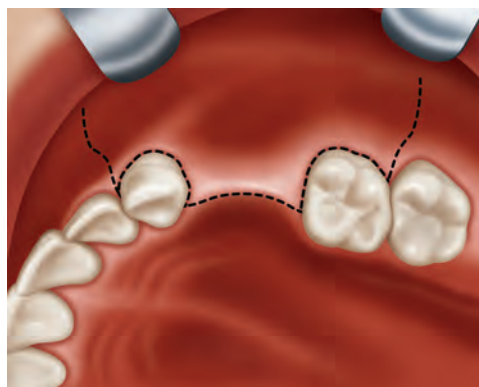


Figure 15.19 Incision design diagram; maxilla. Photos reproduced by courtesy of Dr. Gregory J. Conti, DMD, MS, and Zimmer Dental Inc., Carlsbad, CA.



Figure 15.16 Lab photo.



Figure 15.20 Maxillary horizontal ridge defect; maxilla. Photos reproduced by courtesy of Dr. Gregory J. Conti, DMD, MS, and Zimmer Dental Inc., Carlsbad, CA.



Figure 15.17 Final restoration.

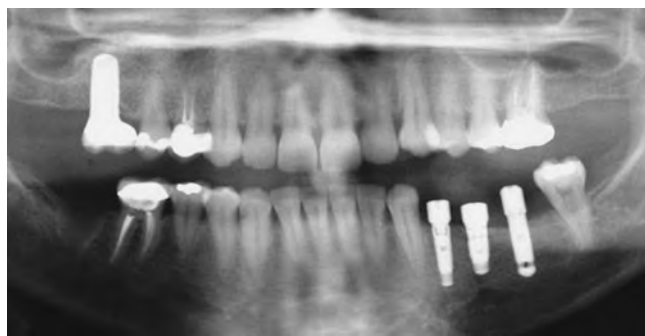


Figure 15.18 Radiograph of final restoration.

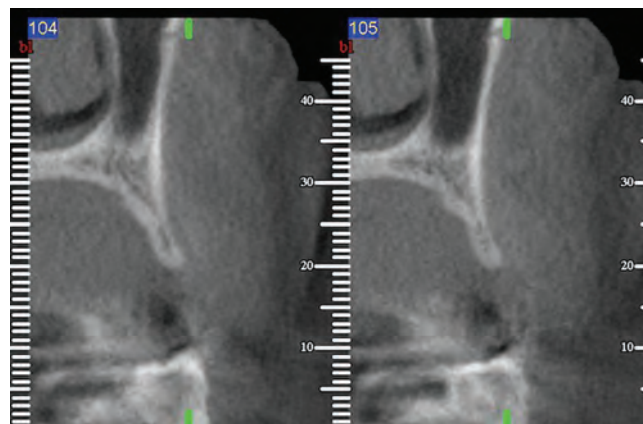


Figure 15.21 CT pre-op.

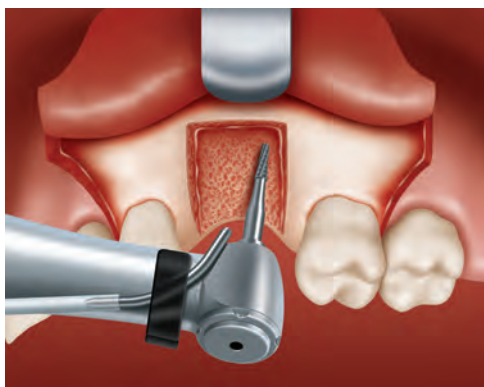


Figure 15.22 Maxillary inlay prep.



Figure 15.25 Block allograft contoured with carbide bur diagram.



Figure 15.23 Small perforations of recipient site.



Figure 15.26 Lag screw fixation.

and 15.23, followed by hydration, contouring, and two-screw fixation of the block allograft, as described above (Figures 15.24 to 15.27). Final contouring of the block allograft is completed intraorally to remove any sharp edges that might compromise soft tissue closure. Small voids around the block allograft can be filled with particulate allograft material (Figure 15.28) and the graft site covered with a barrier membrane (Figures 15.28 and 15.29). Membrane technology assists with clot stabilization of the grafted

area (Figures 15.30 and 15.31). Tension-free primary soft tissue closure is important (Figures 15.32 to 15.33). Figure 15.34 of a CBCT after surgery demonstrates significantly improved horizontal dimensions of the alveolar ridge. Implant was placed and restored successfully with an implant crown (Figure 15.35).



Figure 15.24 Rehydration of block allograft.



Figure 15.27 Clinical photo two-point fixation.

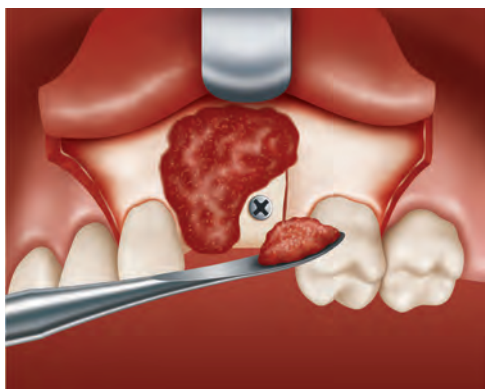


Figure 15.28 Diagram of the particulate graft to fill in voids around the block allograft.

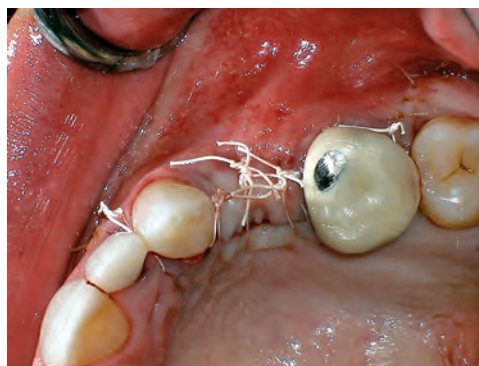


Figure 15.32 Clinical photo of the soft tissue closure.



Figure 15.29 Clinical photo of the particulate graft to fill in voids around the block allograft.

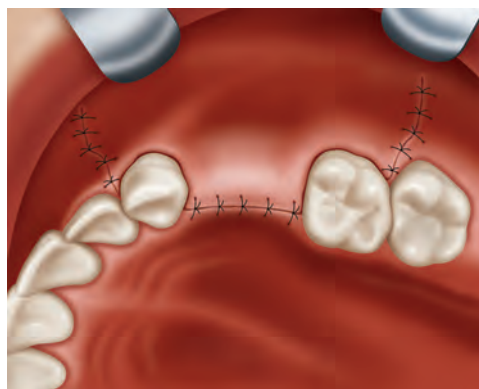


Figure 15.33 Diagram of the soft tissue closure.

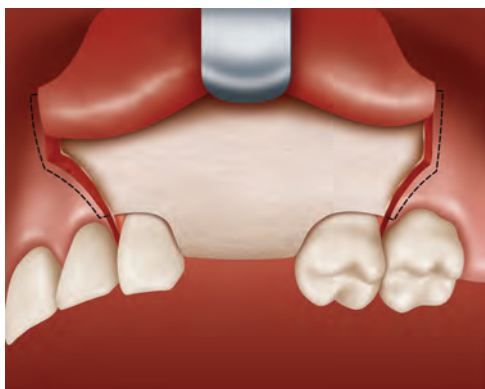


Figure 15.30 Diagram of the membrane covering the block allograft.

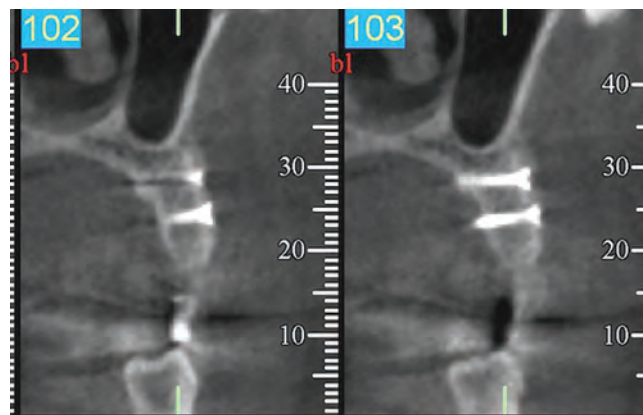


Figure 15.34 CT post-op.

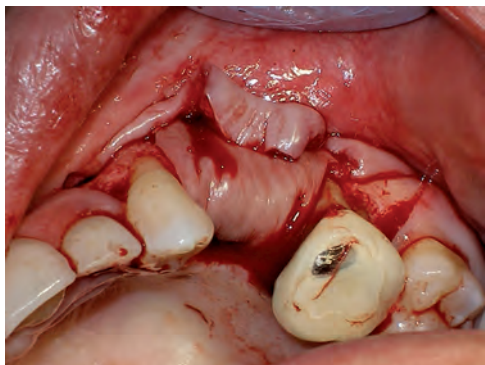


Figure 15.31 Clinical photo of the particulate graft to fill in voids around the block allograft.



Figure 15.35 Photo of the final restoration.

Case Report: Additional clinical experience**Case 1**

A 52-year-old female presents for evaluation for implant placement after extraction of the right lateral maxillary incisor. Radiographic examination revealed fractured tooth syndrome and loss of the buccal plate in the affected area. Clinical evaluation and review of the patient's past and present medical history indicated no contraindications to implant therapy. The patient expressed interest in an implant-supported restoration. She was informed a block graft was a valuable treatment option to correct the existing horizontal defect and provide sufficient bone for implant placement. The patient chose to avoid a secondary surgical site needed for autograft from either the mandibular symphysis or ramus shelf. Instead, she opted for placement of an allograft. A staged treatment procedure was planned to reduce potential complications, such as wound dehiscence and block graft fracture, which have been associated with simultaneous grafting and implant placement procedures [41,84–86]. A review of the surgical procedure including risks and complications was completed and informed consent was obtained to proceed with the surgery.

After atraumatic extraction of the tooth, the residual ridge measured 3 mm in width. A minimum of 5 mm was needed for implant placement. The block graft procedure was delayed for six weeks to allow for soft tissue closure at the site of the defect. The graft procedure was completed under local anesthesia. The incision design was slightly palatal to the mid-crestal line in the region of the edentulous ridge and extended intrasulcularly one tooth on each side of the implant site. Divergent releasing incisions allowed visualization of the graft site and assisted with tension-free wound closure and a blood supply. In addition, relaxation of the flap was further accomplished by incising the periosteum at the superior base of the flap. Once the augmentation site was exposed, the recipient bone was contoured to allow the graft to be mortised into position for maximum bony contact and graft stability as described above. A number of small holes were drilled into the recipient cortical bone to induce revascularization and the influx of growth factors and platelets [87–90].

For the augmentation procedure, an allogeneic, corticocancellous, iliac bone block material (J-Block, Zimmer Dental, Carlsbad, CA, USA) was selected. Prior to usage, the sterile allograft material was removed from its container and rehydrated according to manufacturer instructions. The allograft was placed into the barrel of a 60 cm³ syringe with a tip. The plunger was replaced and a 0.9% sterile saline solution was drawn into the syringe until the graft was completely covered. Excess air was dispelled and then the tip of the syringe was occluded and the plunger was drawn back slowly to help infuse the allograft material with the sterile solution. The excess air was dispelled again and the graft was allowed to rehydrate for 3–5 minutes prior to use (Figure 15.36).

A water-cooled, large round fluted bur was used to round the sharp cortical edges and shape it to completely conform to the defect site while preserving as much of the cortical surface as possible. The cancellous layer of the block was easily contoured to adapt to the recipient defect area, while the cortical side of the graft provided a denser surface for rigid fixation of the graft. In shaping the allograft, careful attention is given to minimize or remove any ridge-lap coverage of the alveolar crest region.

After rehydration, the prepared allograft was delivered to the surgical site and stabilized in place with a mini-screw system (Auto-Drive™ Screw, OsteoMed Corporation). Final contouring of the graft was completed intraorally. Remaining voids around the graft were filled in with particulate allograft material (Puros, Zimmer Dental, Carlsbad, CA) and the entire graft site was covered with a Type-1 collagen membrane (BioMend, Zimmer Dental, Carlsbad, CA). Soft tissue closure was achieved without tension using 4.0 sutures (Vicryl, Ethicon Inc.). A provisional removable prosthesis was placed that did not impinge on the block graft and the patient was prescribed post-operative antibiotics, antimicrobial rinse, and analgesics.

The post-operative period was unremarkable, with no clinical evidence of infection or wound dehiscence. Six months later, the patient was recalled for implant placement (Figure 15.37). Surgical exposure of the augmentation site under local anesthesia revealed a well-integrated block graft that was incorporated into the surrounding cortical bone (Figure 15.38). Minimal resorption was noted around the fixation screw, which was then removed. The implant site was prepared using a standard drilling technique and a 3.7 mm × 13 mm screw-type implant (Tapered Screw-Vent, Zimmer Dental, Carlsbad, CA) was threaded into position with a manual driver. The bone in the region of the implant preparation was noted to be stable throughout the implant placement and there was no evidence of graft separation or fracture (Figure 15.39).

An implant-level impression was made at the time of placement, as the implant was noted to be securely in position. Prior to the impression procedure, the soft tissue was reapproximated and stabilized with a suture. After trimming the ends, the suture was coated with petroleum jelly to prevent adherence by the impression material. This was designed to facilitate a good soft tissue model for the lab to prepare the final abutment. A two-stage surgical technique was planned to minimize load on the previously grafted implant site. A cover screw was placed and the soft tissue was closed with 4-0 sutures (Surgical Chromic Gut, Ethicon Inc.).

Second-stage exposure was performed at 4 months, at which time a definitive abutment and provisional restoration was completed. During the temporization phase, a soft tissue profile was allowed to mature and develop prior to final restoration. A radiograph of the final stable and functional restoration at a 2-year follow-up is illustrated in Figure 15.40 and a clinical photo at a 10-year follow-up in Figure 15.40A. Figure 15.40B shows a 10-year CBCT scan demonstrating excellent incorporation of the block graft and regeneration of the buccal bone around the implant.



Figure 15.36 Rehydration with a 60 cm³ syringe. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.37 Clinical photo of the block allograft site. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.38 Block allograft incorporated into the host bone.
(Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.39 Implant placement in the block allograft.
(Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)

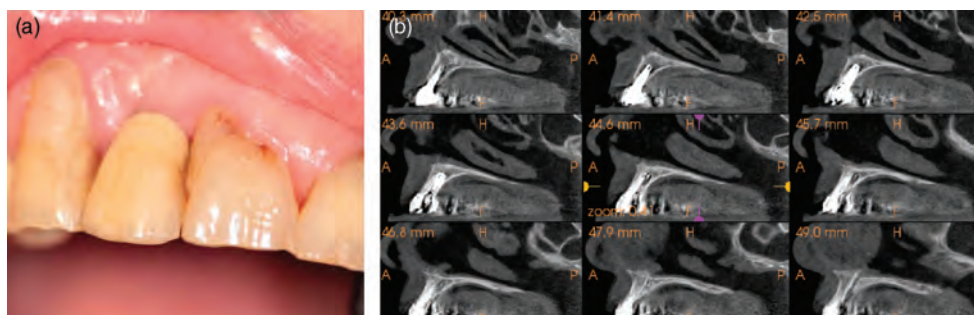


Figure 15.40 Radiograph of the final restoration (2 years). (A) 10-year follow-up, clinical photo; (B) 10-year follow-up CBCT scan.
(Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)

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Case 2

A 44-year-old man presented for horizontal ridge augmentation of the anterior mandible. One year prior, a vitreous carbon implant was removed and grafted with particulate bovine bone. Clinical examination revealed good vertical bone height in the region of the missing mandibular right central and lateral incisors; the horizontal bone dimension was deficient for ideal implant placement. The patient was consulted for block graft augmentation and decided in favor of the allograft option. Augmentation procedures were completed according to protocol.

A mid-crestal incision was made extending one tooth on either side of the graft site with release. Surgical exposure revealed a lateral defect and residual evidence of previous graft material, which was well incorporated into the host bone (Figure 15.41). A large corticocancellous block (Figure 15.42) was rehydrated according to specifications. Using copious irrigation, the block was contoured with a large round carbide bur. In a similar fashion, an inlay-type preparation at the recipient site was completed. After perforation of the host bone with a small (0.8 mm) round burr, the graft was mortised into position and stabilized with a two-point rigid fixation (Figure 15.43). Exposure of the graft site and implant placement followed at 6 months. Minimal graft resorption was noted (Figure 15.44). Implants were placed 5 months later (Figure 15.45).

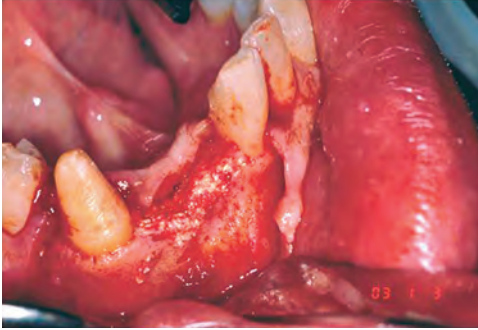


Figure 15.41 Anterior mandible horizontal ridge deficiency.



Figure 15.44 Anterior mandible block allograft after 6 months.

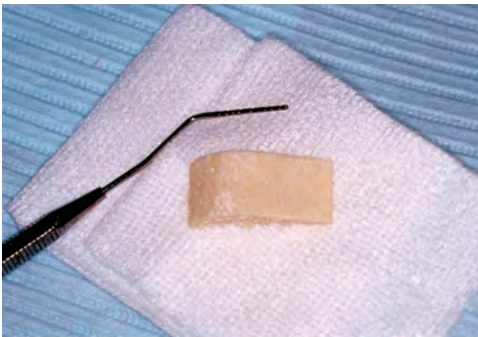


Figure 15.42 Large block allograft.



Figure 15.43 Anterior mandible block allograft with a two-point fixation.

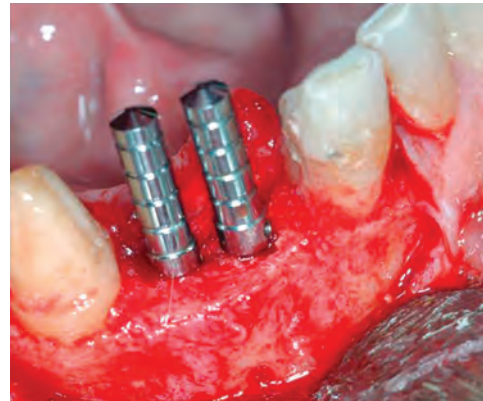


Figure 15.45 Implant preparations in the anterior mandible block allograft.

Case 3

An 80-year-old female was consulted for removal of fractured teeth and a failed bridge in the anterior maxilla (right lateral and central incisors and left central incisor) (Figure 15.46). The patient was treated for osteoporosis with a bisphosphonate medication Fosamax for more than 10 years. Pre-surgical consultation, medical evaluation, and informed consent were obtained prior to an oral surgical procedure. The patient decided to proceed with a rehabilitation treatment plan including extractions, allograft block graft, and implant-supported fixed restoration. Figure 15.47 illustrates the area of alveolar bone defect on the diagnostic model.

The procedures were completed in four phases:

Phase I: Teeth removal. Three indicated teeth in the anterior maxilla were removed using local anesthesia. The patient was placed on post-operative antibiotics and antimicrobial rinse. Follow-up was conducted every 2 weeks for two months to ensure soft tissue closure. At 8 weeks post-op, the patient was scheduled for phase II.

Phase II: Block allograft (and one lateral incisor implant) was completed using the standard protocol. There was sufficient horizontal bone in the region of missing lateral incisor to place an implant simultaneous with the block allograft procedure (Figure 15.48). The block graft was placed according to protocol without complication. The block allograft healed for an additional 5 months prior to implant placement. A temporary, non-tissue contact removable prosthesis was worn during the healing phase. At 5 months post block augmentation, two additional implants were planned to be placed in the region of the central incisors.

Phase III: Two implants placed in the area of central incisors. At week 28, the block graft was exposed and implants were placed in the region of the central incisors using the standard placement technique. The graft site was well incorporated with the surrounding bone. There was no evidence of graft separation (Figures 15.49 to 15.51). The implant fixtures were noted to be stable, but the fixtures were covered with the soft tissue flap to minimize risk of infection in this patient, who had a long history of oral bisphosphonate use.

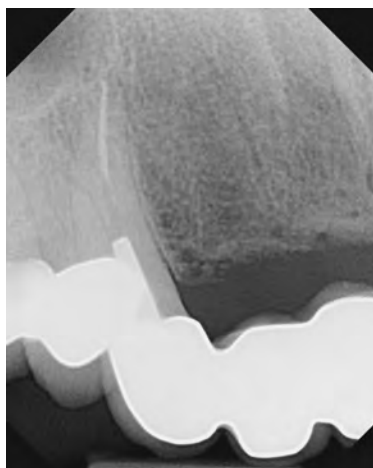


Figure 15.46 Pre-op radiograph. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)

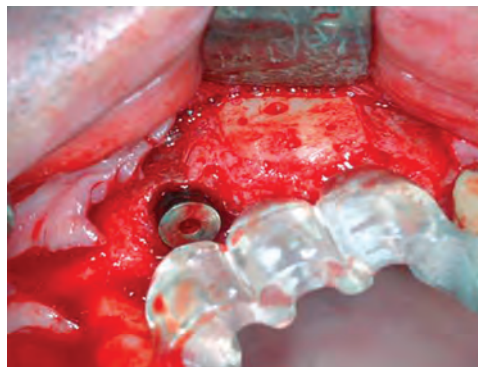


Figure 15.49 Previously placed implant 7, with the block allograft at sites 8 and 9. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)



Figure 15.47 Pre-op model augmentation of the anterior maxillary defect. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)



Figure 15.50 Implant preparation at sites 8 and 9 in the block allograft. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)



Figure 15.48 Radiograph after block allograft placement. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)



Figure 15.51 Guide pins in sites 8 and 9 in the block allograft. (Source: Dr. Richard Koups, DMD, and Mark Koups, DMD)

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Phase IV: Implant stage 2. Second-stage exposure of the implants was completed approximately 4 months after implant placement in the block graft area (Figure 15.52). The patient proceeded to the final restorative phase without complication (Figures 15.53 and 15.54). Figures 15.55 and 15.56 demonstrate a stable functional and esthetic condition of prosthesis on a 7-year follow-up.

The surgical protocol for each phase of treatment included antibiotic therapy, an antimicrobial rinse, and non-interfering removable temporary restorations. All phases were uneventful during the healing period and the total treatment time was approximately 11 months.



Figure 15.52 Healing cuffs in place after second-stage exposure of implants. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.55 Seven-year follow-up, clinical photo. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.53 Radiograph of abutments in place. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.56 Seven-year follow-up, radiograph. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)



Figure 15.54 Final restoration. (Source: Dr. Richard Koup, DMD, and Mark Koup, DMD)

Discussion

Osseous grafting has been shown to be clinically successful in the treatment of human alveolar bone defects. Successful bone regeneration requires a concurrent revascularization and substitution of the graft material with the host bone without a significant loss of strength [91]. The pattern, rate, and quality of the new bone substitution are determined, in part, by complex reactions between the healing processes of the biological host and the nature of the graft material [91].

Three paradigms have been postulated to explain the influence of autogenous bone grafts on new bone formation (Table 15.3). In the *osteoconduction* model, host osteoprogenitor cells and vascular elements utilize the graft as a scaffold to generate across the defect. As the host cells differentiate and mature within the graft, a functional skeletal network develops and replaces the graft through a “creeping substitution” process [42,54,92,93]. The commercially processed allograft material described retained the essential collagen and mineral structure of the donor bone, which rendered it osteoconductive. Collagen comprises approximately 90–95% of the organic component of bone [94,95] and is a fundamental building block in the process of new bone formation.

In the *osteogenesis* paradigm, surviving osteoprogenitor cells within the graft proliferate and mature into centers of new bone formation [54]. At the present time, it is uncertain whether the osteogenesis paradigm applies to the allograft used in the present case, although it cannot be entirely ruled out. Further research is needed in this area before any definitive statements can be made.

In the *osteinduction* paradigm, the graft actively recruits pluripotent host cells that differentiate into chondroblasts and osteoblasts [42,54,92,93,96]. It is now widely accepted that osteoinduction is at least partially controlled by matrix proteins, which are low-molecular-weight polypeptides often collectively called bone morphogenetic proteins (BMP) that have been isolated from the bones [54,96–103]. Although the allograft material used in these types of cases are incapable of osteoinduction, the clinical results are nonetheless impressive.

The ideal allogeneic bone graft material would cause new bone to form (osteoinduction) and provide a scaffold to support the regenerating host bone that will eventually replace the graft (osteoconduction) [54]. Mineralized allografts, such as described previously, generally demonstrate only osteoconductivity. With allografts in general, the host tissue may become sensitized to graft-derived antigens and the resulting lymphoplasmacytic infiltration can cause occlusion of local blood vessels and failure to revascularize the graft [54]. Secondary graft necrosis and the proliferation of inflammatory granulation tissue can thus ensue, which weakens the cortical component of the graft and interferes with new bone formation and

incorporation [54,104,105]. Freezing and freeze-drying (lyophilization) have been reported to attenuate these responses, but they may also diminish the mechanical strength of the graft [54]. In addition, enthusiasm for allogeneic bone graft material has been tempered by concern about the transmission of infectious agents, including the human immunodeficiency virus (HIV) [54,105].

None of these problems occurred with the allograft used in the case examples described here, which were processed by the manufacturer to remove cells, bone marrow, and lipid components prior to solvent dehydration and sterilization with low-level gamma radiation [67]. Post-processing studies have indicated that the allograft material retained a high collagen and mineral content and that it was free of bacterial and viral contaminants, including hepatitis B/C antigens and antibodies to human immunodeficiency virus (HIV I/II) [67]. It is unknown whether the commercial processing of the allograft in some way reduced the antigenetic response potential of the host tissue.

The use of block allografts provides the implant surgeon with a novel tool for correction of horizontal ridge defects. Technical precision is of paramount importance for success.

Ten key technique guidelines have been identified for successful use of the block allograft for horizontal ridge augmentation.

- 1 Incision design
 - (a) Mid-crestal to slightly lingual incision over defect extended 1–2 teeth on each side with release.
- 2 Site preparation
 - (a) Large round/straight carbide bur to form inlay prep
 - (b) Perforation with 0.8 mm round burr
- 3 Rigid fixation (two point)
 - (a) Utilize lag screw technique
 - (b) Round of edges of graft
- 4 Tension free closure
 - (a) Incise periosteum
 - (b) Release lingual flap
- 5 Staged implant placement
- 6 Block allograft preparation
 - (a) Re-hydrate block allograft prior to placement
 - (b) Shape block with large round burr
 - (c) Preserve cortical bone
 - (d) Intimate contact between graft and host bone
- 7 Membrane technology
 - (a) Clot stabilization of the graft area
 - (b) Osteoprogenitor cells from endosteum
 - (c) Combination with block and particulate allograft
- 8 PRP for soft tissue healing
- 9 Post-op protocol
 - (a) Antibiotic coverage
 - (b) Antimicrobial rinse
- 10 Temporization
 - (a) Avoid contact with soft tissue.

Table 15.3 The influence of bone grafts in the new bone formation. Reproduced by by courtesy of Zimmer Dental Inc., Carlsbad, CA, USA.

New bone formation process	Influence of the graft
Osteoconduction	Graft serves as an inert scaffold for the ingrowth of host bone
Osteogenesis	Graft contains surviving pre-osteoblasts and osteoblasts that proliferate and mature into bone-producing cells
Osteoinduction	Graft actively recruits pluripotent host cells that differentiate into bone-producing chondroblasts and osteoblasts

Conclusion

Mineralized allograft blocks have been demonstrated to generate effective new bone fill for implant site development and dental implant placement.

Acknowledgments

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PART B: MAXILLARY TUBerosITY BLOCK BONE GRAFT

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Maxillary tuberosity block bone graft (MTBBG)

Case report (Figures 57 to 67)

This case report and photos have been taken from an article by Tolstunov in 2009 [106] by permission of Elsevier.

A 59-year-old healthy man was referred to our practice for replacement of his missing upper right posterior teeth. The patient lost two premolars and two molars many years prior and did not use any replacement teeth (Figures 15.57 and 15.58). The edentulous area was 28 mm in length, 6–8 mm in width, and 6 mm of interocclusal height. Good attached gingival tissue was present. The patient also had a prominent maxillary tuberosity just next to the edentulous space about 1 cm in length and in width (Figures 15.59 and 15.60). A panoramic radiograph (Figure 15.58) demonstrated a good vertical amount of bone present below the maxillary sinus for implant insertion. Based on the pre-operative evaluation (Figures 15.59 and 15.60), it was determined that alveolar *width* is deficient and needs to be augmented for prosthetically guided implant placement. The treatment plan included harvesting of maxillary tuberosity block bone graft (MTBBG) for the adjacent horizontally deficient alveolar ridge, followed by delayed insertion of three implants into the right posterior maxilla 4–6 months later. A surgical template and mounted models were used to determine the exact location for the fixation of the graft and future implant sites.



Figure 15.57 Pre-operative clinical intraoral photo with four missing posterior teeth and deficient alveolar width.



Figure 15.59 Pre-operative photo of the large maxillary tuberosity available as a non-traditional source of the block bone graft.

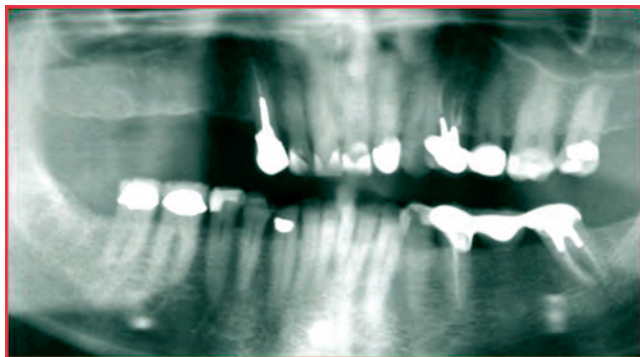


Figure 15.58 Pre-operative panoramic radiograph showing two missing premolar and two missing molars.



Figure 15.60 Diagnostic model showing the horizontal ridge deficiency.

The procedure was done under local anesthesia. A full thickness flap that included both recipient and donor sites was elevated and maxillary tuberosity of about 1 cm x 1 cm was visualized (Figure 15.61). A recipient site was prepared by mild ridge contouring and buccal cortical plate perforations for the better healing and vascularization of the graft (Figure 15.62). A mini saw was used to cleanly section the bony protrusion (tuberosity) at the donor site, reposition the graft to the prepared adjacent recipient site, and fixate it with 1.2 mm mini screws (Stryker Leibinger, Kalamazoo, USA) (Figure 15.63). The flap was repositioned back and sutured with 4-0 Vicryl sutured primarily. The patient received a 1-week course of Amoxicillin, Peridex mouth rinse, and post-operative instructions.

Six months after the first surgery, three AstraTech implants (AstraTech Inc., Waltham, MA, USA) were placed according to the surgical stent. Intraoperatively, the grafted site was visualized and showed that the alveolar width increased significantly from 6 mm to 12 mm (Figures 15.64 and 15.65). The mini screws were removed. Three implants were placed into the second molar and first and second premolar positions. After successful osseointegration, implants were restored 4 months later with a three-implant-supported four-unit porcelain-fused-to-metal (PFM) bridge to an ideal functional, occlusal, and esthetic result (Figures 15.66 and 15.67).

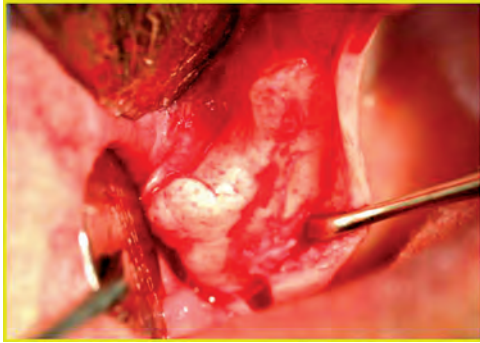


Figure 15.61 Intraoperative photo of the large maxillary tuberosity (donor site).

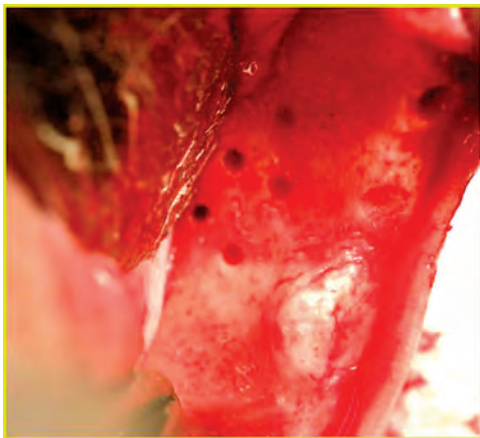


Figure 15.62 Intraoperative photo of the adjacent recipient site; the bed was prepared and perforations were made for vascular ingrowth after graft fixation.



Figure 15.63 Graft was harvested, transferred to the recipient side, and fixated with mini screws.



Figure 15.64 Diagnostic model and surgical stent for implant insertion.

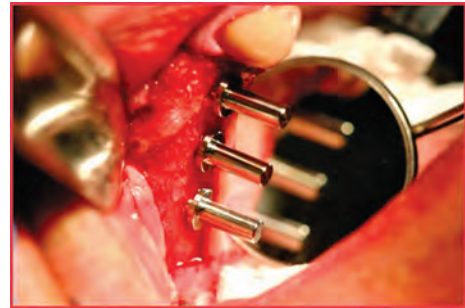


Figure 15.65 Paralleling pins prior to implant insertion at the implant surgery.



Figure 15.66 Implant completion – panoramic radiograph of an implant bridge.



Figure 15.67 Implant completion – intraoral lateral photo of an implant bridge in good function and esthetics.

Discussion

It is important to consider alternative intraoral sites for block grafting that might include bony protuberances and exostoses, like maxillary tuberosity, lingual and palatal tori, and others [107,108]. They can be conveniently located in the near proximity and might have a significant stock of needed bone for the alveolar width and height increase. Maxillary tuberosity often offers a poor quality of bone (type 4) but still can be used not only as a particulate source but, on occasion, as described in this case report, as an autogenous block graft [108]. Advantages of this intraoral block graft include convenience and lack of significant donor site morbidity, as commonly seen with more traditional symphyseal and ramus bone sources. Large maxillary tuberosity, when present, can offer a good stock of bone with little morbidity [109], which is an important goal in implant dentistry.

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Part B

SECTION IV

Ridge-Split Procedure for Horizontal Augmentation of the Alveolar Ridge in Implant Dentistry

Diagnosis and Treatment Planning

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

History

There are a variety of names that have slowly emerged over the last 50 years describing horizontal augmentation of the alveolar edentulous ridge through the mid-crestal split and separation of both cortical bone segments with or without bone grafting and/or immediate implant placement. These names include the ridge-split procedure (RSP), ridge-split osteotomy, the split-crest or crest-split technique, split-control and crest-control techniques, the extension crest method, alveolar split osteotomy, alveolar split grafting, and others. The other commonly used names are lateral bone augmentation, lateral ridge expansion, alveolar ridge widening, alveolar crest spreading, edentulous ridge expansion (ERE), bone spreading procedure, osteoperiosteal flap (Jensen), pedicle sandwich plasty (PSP) (Ewers), and others. Although there are many modifications, there is little substantial difference among these techniques. One group of names implies emphasis on technical aspects of the surgical approach (ridge split), the other on its final outcome (ridge expansion), and yet another on the biologic rationale and flap design (osteoperiosteal flap).

Applications for splitting and expansion of thin alveolar ridges to gain missing ridge width as a method of bone augmentation in implant dentistry have been reported for the partially and fully edentulous maxilla and mandible. It has been understood from the very beginning that dental implant success depends on the presence of the “orthoalveolar form” of the alveolar ridge. Another words, implant success depends on the presence of adequate and anatomically properly positioned hard and soft tissue (dentoalveolar segment). In order to have adequate bone for the dental implant reconstruction, in many cases the segment of jawbone had to be osteotomized and relocated (repositioned). Vascularization of this segment of bone plays a central role in preservation of its vitality and success of bone transplantation and eventual augmentation. Seminal work of Dr. William H. Bell’s animal and clinical studies in the 1960s (and later) on bone vascularization, bone healing, and pulp vitality [1–5] helped to establish biologic rationale for segmental and total (for example, Le Fort I) jawbone osteotomies (orthognathic surgery). Dr. Bell demonstrated that the vitality of the segment of a jaw to be osteotomized would be preserved if soft tissue pedicle could be kept intact. This principle of preservation of bone vascularization after its complete osteotomy through the *intact* periosteal (soft tissue) pedicle was adapted from Bell’s segmental maxillary osteotomies by subsequent researchers who explored the possibilities of *alveolar* osteotomies of the ridge. Many innovators

followed Dr. Bell and proposed multiple modifications of alveolar osteotomies (the ridge-split procedure).

H. Tatum [6] in the 1970s designed a root form Omni implant system (Omni R system, St. Petersburg, FL) to attempt “to maximize the use of the available bone”. To accommodate placement of his implants, he was the first to develop the technique that “allowed the manipulation of bone to form sockets in otherwise deficient areas of bone”. H. Tatum developed his tapered channel formers and D-shaped osteotomes to expand thin alveolar ridges.

In 1992, an Italian group lead by M. Simion published an article “Jawbone enlargement using immediate implant placement associated with a split-crest technique and guided tissue regeneration” [7]. This group of clinicians described five case reports (maxillary and mandibular cases) of augmentation of collapsed alveolar ridges through the bone split with no bone grafting (membranes only) and immediate implant placement. The surgical technique involved a longitudinal split of the alveolar ridge “in two parts, provoking a green-stick fracture”. The increase in the buccolingual dimension was seen in all cases and ranged from 1 to 4 mm as measured 5 months post-operatively. Investigators noticed a modest increase in the width of the mandible (1–1.5 mm), probably “because of the stiffness of the mandibular bone” and a larger increase in the width of the maxilla (2–4 mm). Although this was a small clinical prospective study, it demonstrated a possibility of a successful longitudinal bone split in the edentulous collapsed region for ridge widening, showed some differences between maxilla and mandible related to the technique, as well as introducing a concept of the immediate insertion of dental implants during this procedure.

In the same year, 1992, M. Pikos [8] described a two-stage buccolingual expansion of the maxillary ridge technique that involved ridge splitting with a closed flap, internal bone grafting as a space maintainer, and delayed implant placement.

In 1994, another Italian group lead by A. Scipioni et al. [9] published an article of a larger study and a longer follow-up titled “The edentulous ridge expansion technique: a five-year study”. In this work, a significantly larger group of patients and implants were utilized; 329 implants were placed in 170 patients after the single-stage edentulous ridge expansion (ERE). In this study, also no interpositional bone grafting was done and all implants were placed immediately. The authors reported an 88.5% success rate for Tübingen and 99% for IMZ implants and commented that “The essential feature of ERE technique is the partial-thickness flap with

preservation of its buccal blood supply” as well as that “the integrity of the periosteum must be maintained”. This study improved our knowledge of the technique further by specifying the soft tissue flap and pointing to the importance of preservation of the integrity of the periosteum and its vascularization.

In 1997, W. Engelke et al. [10] described a one-stage technique for narrow anterior maxillary ridges that involved cortical splitting, immediate interlamellar implant placement (machined-surfaced and titanium plasma-sprayed), and primary stabilization with microfixation. The 5-year cumulative success rate of 24 Branemark and 97 ITI (International Team for Implantology) implants placed in 44 patients was 86.2%, with a greater percentage of failures in machined-surfaced versus titanium plasma-sprayed implants. The mean marginal bone loss was 1.7 mm.

In 1997, Duncan and Westwood [11] presented the treatment of edentulous thin maxilla by “separating the cortical plates and widening the alveolar ridge with simultaneous placement of implants”. Sinus lift was done at the same time. GTR with filling the gaps with bone grafting material was not described in their report but was suggested as a possibility.

In 1998, L. Malchiodi et al. [12] described a new technique of rigid fixation with titanium (Ti) mesh in edentulous ridge expansion in the maxilla simultaneously with implant placement in 25 patients. The authors successfully used Ti mesh barrier instead of membranes to prevent membrane collapse and “achieve a rigid fixation of the bone segments . . . in non-space-making defects”. Of 120 implants inserted under the mesh, they reported three failures.

The same year, G. Bruschi et al [13], reported a localized management of the sinus floor (LMSF) technique as an application of the principles of the ERE. The technique comprised “the dissection of a partial-thickness flap, the buccal expansion of the residual alveolar bone, and the fracture and elevation of the sinus floor with simultaneous implant placement”; 499 implants were placed into the posterior maxilla with the LMSF approach with the success rate of 97.5%.

In 1999, the original Italian group led by A. Scipioni [14] using histologic and ultrastructural methods studied bone regeneration (hard tissue repair) at edentulous sites treated with the ERE technique with no grafting material and immediate implants in 20 humans. Their results indicated that surgical “distraction” within the confines of two cortices promoted bone formation – “osteoblasts differentiate from preexisting mesenchymal cells located on the original fissure walls, with consequent deposition of new bone in the surgically created intrabony defect”. They concluded that this procedure also promotes an osseointegration of implants.

In 2000, D. Smiler [15] described the “sandwich” split cortical graft for dental implant placement with a bone replacement graft that is “placed within the cancellous compartment and is contained by the autogenous cortical block harvested from the recipient bed”. The same year, Sethy and Kaus [16] reported a 97% 5-year survival rate of two-stage 449 implants (150 patients) simultaneously placed with maxillary ridge expansion. Also in a 2000 report, T. Vercellotti [17] presented a new piezoelectric ridge expansion technique with implants placed in a single-stage surgery. Guided bone regeneration (GBR) was done between cortical plates with the bioactive glass synthetic material and the autogenous platelet-rich plasma (PRP). At 3 months, the ridge thickness was 5 mm (from 2 to 3 mm) and all implants successfully osseointegrated. In 2006, Blus and Szmukler-Moncier [18] described a successful split-crest and an immediate implant placement procedure with ultrasonic surgery on 57 patients (230 sites). The 3-year life-table analysis of loaded implants showed a cumulative survival rate of 100%.

In 2007, F. Bravi et al. [19] gathered a large amount of data over a period of 10 years on 1715 implants placed with the ERE technique by a group of experienced surgeons and demonstrated the overall implant success rate of 95.7%. Surgeons used a partial-thickness flap and placed implants at the time of split and expansion (mostly in the maxilla) or at a separate stage (mostly in the mandible); no bone grafts (only collagen) were used. The authors’ conclusions were the following: (1) increase of failures were noticed in smokers (1.5 times); (2) parallel implants had a 2 times higher failure rate than tapered; (3) implant failures increased with an increase of implant diameter above 4 mm (larger expansion was required) and a decrease of implant length below 15 mm (showing the importance of primary implant stability at the basal bone extending beyond the split); (4) of the 73 implant failures, 60 occurred in the maxilla (especially, in the posterior maxilla, associated with a poor bone quality); (5) almost all failed implants were successfully replaced due to the “conservation of expanded bone”. Thus, this large study on ERE described the factors of importance when the technique is being planned.

In 2008, S. Koo et al. [20] described successful case reports of the ridge-split and gradual expansion in the maxilla and mandible with simultaneous placement of dental implants surrounded by the particulate bone graft. All implants were restored six months later with implant-supported porcelain-fused-to-metal (PFM) crowns. In 2010, D. Sohn et al. [21] described differences in the immediate and delayed lateral ridge expansion technique in the atrophic posterior mandibular ridge on 32 patients (84 implants were placed). The authors concluded that the delayed approach (9 patients) was safer and more predictable in patients with a denser bone and thick cortex (typical for the mandibular ridges). One of the complications of an immediate approach (23 patients) was an intraoperative malfracture of the thin buccal cortical plate (which occurred in 5 patients, 22% of cases). In 2012, F. Amato et al. [22] described a case report of a rapid orthodontic treatment that was initiated right after the RSP to “open a channel” for the tooth movement. The RSP helped to “facilitate and accelerate orthodontic movement of teeth, which is otherwise difficult in a cortical knife-edge ridge”. In 2014, B. Ella et al. [23], in a prospective 3-year study in 32 patients, described a mandibular ridge expansion through the ridge-split and simultaneous implant placement. Some patients (17 cases) had a synthetic interpositional bone graft (biphasic calcium phosphate) placed, while in some (15 cases) the gap was left unfilled. The study concluded that “a lack of bone substitute resulted in significant resorption” with the recommendation to consider a bone graft during the ridge-split procedure to prevent ridge resorption and relapse later.

Diagnosis and treatment planning

Patient selection

An ideal candidate for the RSP is the same patient who would be selected for an implant treatment: non-smoker, with a good oral hygiene and teeth in a good repair, reasonably healthy, and committed to a quality oral rehabilitation treatment.

Alveolar bone loss

After extraction of a single or multiple teeth, the alveolar ridge loses its functional role in a certain alveolar segment that leads to a slow and progressive three-dimensional bone resorption and an alveolar ridge deficiency. It is important to consider a proper use of terminology.

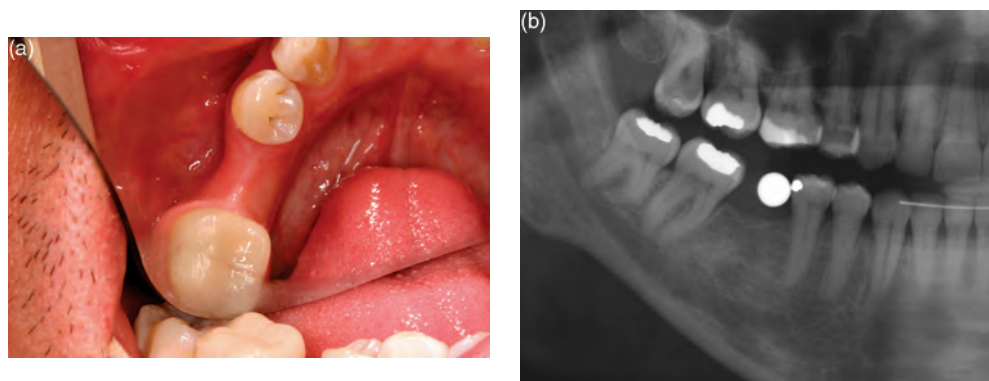


Figure 16.1 (a) Intraoral photograph of a moderate horizontal alveolar bone loss with a largely preserved alveolar height; typical indication for the ridge-split procedure. (b) Section of the panoramic radiograph related to (a) showing a largely preserved alveolar bone height.

Bone resorption can be thought of as a pure loss of hard tissue (minus effect). *Bone collapse* is often described in a sense of a “fall” of structures that lost its support and/or function. Usually after extraction of a tooth or teeth, *bone deficiency* often occurs as a result of bone resorption and collapse. It can be said that the cancellous (medullary or spongy) bone undergoes *resorption* and the buccal (facial) cortical plate undergoes *collapse* as a result of it. This process eventually leads to an alveolar ridge where both cortical plates (buccal and lingual) are proximal to each other with the presence of a minimal amount of the interpositional layer of the medullary bone. In traumatic extraction cases that can result in avulsion of bone, a true corticommedullary *bone loss* occurs. The ridge-split procedure (RSP) works best in a mild-to-moderate medullary bone resorption resulting in a partial buccal cortical plate collapse, leaving the width of the remaining alveolar ridge in between 3 and 5 mm with a largely preserved alveolar height (Figure 16.1).

Alveolar ridge defect analysis and classification

Although it is often a subjective diagnostic decision of an operator based on his/her knowledge, skill, and experience, there are certain objective criteria for an edentulous alveolar ridge to be selected for a ridge-split procedure. Success of implant treatment is based on the proper diagnosis and case selection. Before contemplating a bone grafting procedure, it is important to establish a proper diagnosis by analyzing the *ridge defect* (Fu-Wang) [24]. The first question an operator should ask himself/herself is *whether the alveolar bone defect is three-dimensional (3D) or two-dimensional (2D)*.

If based on the clinical exam and radiography (commonly, including a CBCT scan), this is a volumetric alveolar bone loss (width and height) or avulsion defect (Figure 16.2), then there is a need to use a specific treatment algorithm of repair. There are surgical procedures designed for vertical or volumetric bone repair/reconstruction (described in details in Book II on *vertical* alveolar ridge augmentation in implant dentistry). It includes the distraction osteogenesis (DO) procedure. DO procedures are known to repair both horizontal and vertical (combined or volumetric) bone defects. Other techniques are sandwich osteotomy and titanium mesh reinforced vertical bone grafting. When the bone height is gained, then at the second stage, bone width, if still needed, can be gained with horizontal augmentation techniques, like RSP or block grafting. The other approach would be to use the vertical augmentation technique simultaneously with a particulate GBR technique (for width improvement) trying to correct both height and width in one stage. This is used more commonly for many reasons, like convenience of a single surgery rather than two procedures (for the patient's benefit), inherent anatomy of the collapsed alveolar ridge as an “iceberg” that often widens down to the base and thus, when brought occlusally, may not need to be broadened further, and advantages of a particulate GBR technique that can often add 2–3 mm of bone width if done with simultaneous vertical augmentation.

If this is strictly a width deficiency (clinical exam, radiography, models), then there is a need to use specific procedures designed for horizontal augmentation. The ridge-split procedure is intended primarily for narrow alveolar ridges with preserved bone height.

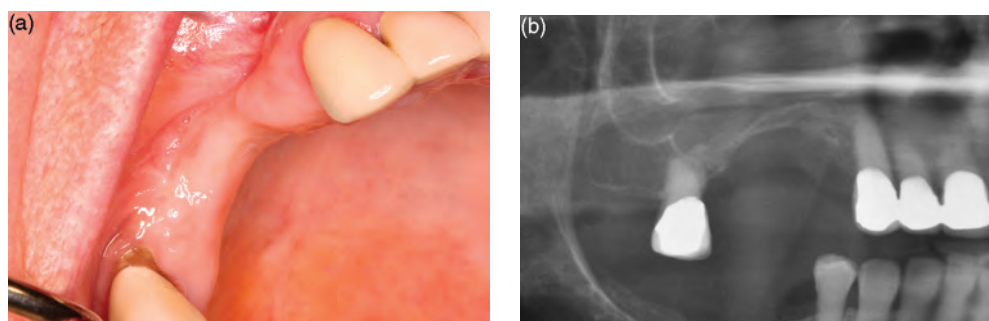


Figure 16.2 (a) Intraoral photograph of a volumetric bone loss with an alveolar bone width and height deficiency; this case is not typically suitable for a ridge-split procedure alone. (b) Section of the panoramic radiograph related to (a) showing a 3D (volumetric) bone loss with an alveolar bone width and height deficiency; this case is not typically suitable for a ridge-split procedure alone.

There are different classifications of partial edentulism for implant applications based on missing teeth and morphology of the edentulous alveolar ridge. The Misch–Judy classification proposed in 1987 [25] adapted the Kennedy–Applegate classification of partial edentulism (Class I through IV) to implant dentistry by adding Divisions A through D that describe anatomy of the edentulous region. Division A, for instance, represents a sufficient width (5+ mm) and height (10+ mm) of bone for implant placement, Division B demonstrate some bone deficiency in width (2.5–5 mm) but adequate ridge height (10+ mm), and Divisions C and D show inadequate and severe bone resorption, respectively, necessitating bone augmentation and grafting. Cawood and Howell in 1988 [26] suggested an anatomic classification of the edentulous jaws for the pre-prosthetic surgery. It details the changes that the edentulous alveolar process in anterior and posterior maxilla and mandible undergoes after teeth extraction (the pattern of resorption). Six classes were proposed: Class I – dentate; Class II – immediately post-extraction; Class III – well-rounded ridge form, adequate in height

and width; Class IV – knife-edge ridge form, adequate in height and inadequate in width; Class V – flat ridge form, inadequate in height and width; and Class VI – depressed ridge form, with some basilar loss evident. It is important to notice that Cawood and Howell observed early that, as resorption progress after the tooth loss, the width diminishes first and then the height is eventually affected. O. Jensen in 1989 [27] proposed an implant-derived site classification by bone quality and quantity and proximity to vital structures. H. Wang and K. Al-Shammari in 2002 [28] described practical (therapeutically oriented) classification of alveolar ridge defects – HVC (horizontal, vertical, and combination) proposing the ERE for the horizontal and combination defects of the alveolar ridge.

In this book, the author would like to offer a clinically and surgically relevant anatomic classification of horizontal alveolar ridge deficiency that might help in cases where the implant-related RSP is contemplated. This classification (shown in Table 16.1) was first published in the *Journal of Oral Implantology* in 2014 [29]. There are clinical (assumed) alveolar width

Table 16.1 Classification of the alveolar ridge width. Reproduced by permission from the *Journal of Oral Implantology*, vol. XL/Special Issue, 2014 [29].

Alveolar ridge width (based on CBCT scan)	>10 mm	8–10 mm	6–8 mm	4–6 mm	2–4 mm	< 2 mm
Alveolar ridge deficiency	No deficiency	Minimal	Mild	Moderate	Severe	Extreme
Class	0	I	II	III	IV	V
Schematic diagram						
Indications for surgery	Hard tissue surgery is not indicated. Occasionally, alveolar width (buccal convexity) can be improved for esthetic reasons with a soft tissue graft	Hard tissue surgery is rarely indicated. Occasionally, alveolar width can be improved by particulate bone graft or palatal soft tissue graft for esthetic or prosthetic reasons	Particulate (GBR) grafting or ridge-split are often needed to improve labial bone projection and proper occlusal implant position	An ideal width for the ridge-split procedure that can be done in a single- or two-stage approach (Figure 16.1a). Block graft or GBR can also be done	Ridge split and onlay block bone graft are procedures of choice (based on surgeon's experience)	Large extraoral block graft is a preferable surgical choice. Alternative: multiple surgical augmentation procedures
Immediate implant insertion	Yes	Yes	Yes/No Depends on presence of apical bone for primary implant stability	Yes/No Depends on presence of apical bone for primary implant stability (Figure 16.1b)	Not recommended	No
Operator experience	Basic	Basic	Basic	Basic-to-advanced	Advanced	Advanced

Alveolar ridge width (based on CBCT scan)	6–10/2–4 mm	2–4/6–10 mm
Alveolar ridge deficiency	"Hourglass" (undercut) (buccal or lingual)	"Bottleneck"
Class	VI	VII
Schematic drawing		
Comments	GBR at the mid-ridge level can be done	Ridge reshaping or GBR at the top of the ridge can be done
Immediate implant insertion at the time of the split	Yes/No, depends on the severity of the undercut	Usually Yes, depends on the morphology of the alveolar crest
Operator experience	Basic	Basic

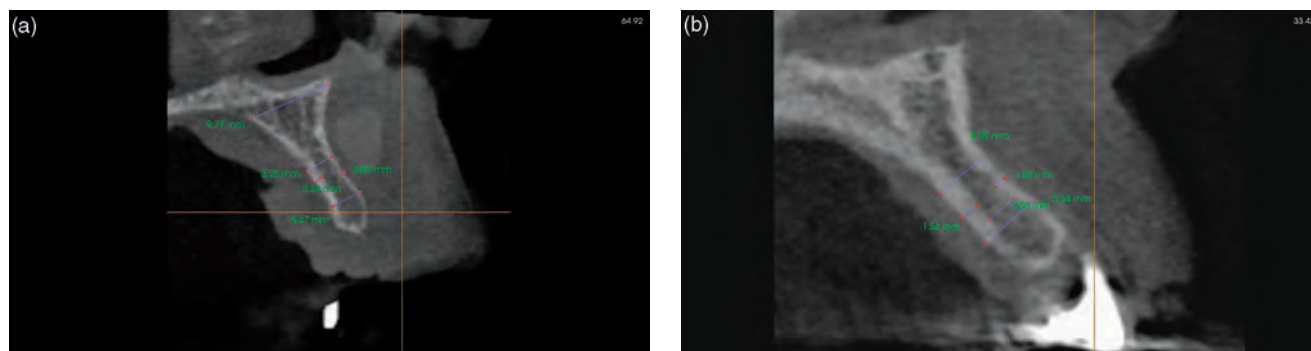


Figure 16.3 (a, b) Cone-beam computed tomography (CBCT) scan (coronal slice) of an ideal case that can be treated with a ridge-split procedure: 3–5 mm of the remaining width of the ridge with a 2–3 mm of the trabecular bone, the layer where the split occurs.

measurements (thick soft tissue can camouflage an accurate bone thickness) and true (actual) alveolar ridge measurements based on a CBCT/CT scan. This classification is based on the true CT-derived measurements of the width of the alveolar ridge for the placement (immediate or delayed) of root-form endosseous dental implants. Table 16.1 demonstrates the classification of a progressive horizontal alveolar bone loss where each ridge has an assigned Class (from 0 to VII), accompanied with a schematic diagram, indications for surgery (RSP or block bone grafting), the possibility of an immediate implant placement, and a suggested operator experience.

If the answer to the first important question (3D or 2D) is 2D and a *horizontal component* is predominant, then an operator should select a procedure for alveolar *width* improvement (based on his or her comfort level). For this chapter, we will select the ridge-split procedure.

An obvious parameter of the alveolar ridge contemplated for an RSP would be its *bone width or thickness*. As mentioned above, the most common alveolar thickness chosen for the RSP is 3–5 mm. A 3 mm alveolar bone forms an “alveolar sandwich” consisting of about 1 mm of a (collapsed) buccal cortical plate, 1 mm of medullary bone, and 1 mm of (intact) palatal/lingual cortical plate. CBCT studies [30,31] demonstrated that the average buccal plate thickness could vary from 0.75 to 1.75 mm with a palatal plate that is slightly thicker. In experienced hands, a 3 and even a 2.5 mm alveolar ridge could be divided. A 2–2.5 mm alveolar ridge practically represents two adhered cortical plates with little or no medullary bone in between. It is an obvious surgical challenge to separate these cortical plates successfully during the RSP. *The medullary (trabecular or spongy) layer is the layer where an actual split occurs*. The wider this layer, the easier it is to divide the cortical plates. For the novice surgeon, the author recommends choosing an alveolar ridge of 4–5 mm width that has an observable (2–3 mm) medullary layer (Figure 16.3). The clinically relevant classification of the alveolar ridge *width* deficiency can be read in Table 16.1.

It is important to understand that the morphology of a collapsed alveolar ridge often resembles an “iceberg” with its thinner portion at its oral/crestal region and slowly widening to the basal bone portion (Figure 16.4). On occasion, it might be acceptable to lower the top (crestal) portion of the ridge slightly (by about 1–2 mm) to get a wider ridge that can be acceptable for implant insertion without grafting. If this leads to a vertical discrepancy with the adjacent teeth, then the taller permanent abutments might need to be used (occlusal requirements still have to be met). This approach would be called a prosthetic correction and may not be acceptable in every case. A patient’s refusal of a bone grafting procedure can be one of the reasons for the prosthetic correction.

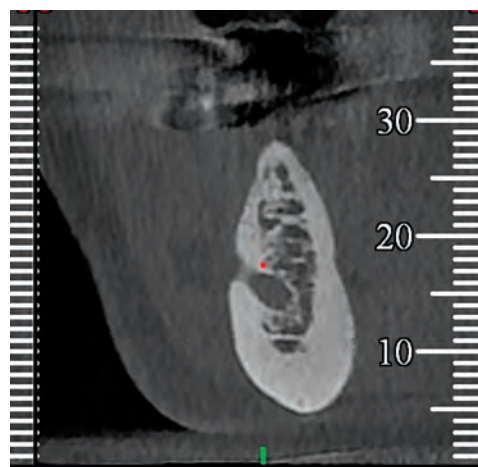


Figure 16.4 CBCT scan (coronal slice) of a common pattern of alveolar width loss, an “iceberg” cross-sectional configuration of the ridge with significant width loss at the top of the ridge and slow *improvement* of the ridge width towards the basal bone.

Surgical correction methods without lowering the top of the ridge but using some type of ridge augmentation instead (idealizing the case) are described in this book.

It is also important to notice that some alveolar ridges appear to have an appropriate width for an implant placement from a surgical prospective (6–7 mm of bone width) but esthetically or prosthetically still show insufficient buccal projection of the alveolar crest and thus can still be considered for the ridge-widening procedure, like RSP. A surgical-restorative team with a philosophy based on prosthetically driven implant dentistry can help to identify these cases.

From an esthetic point of view, this means that although the ridge might have 6–7 mm width and an implant can be inserted, there is a significant degree of labial collapse present in the particular patient with a high smile line and/or a high esthetic demand that this patient might benefit from correction (Figure 16.5). Correction of this concavity can be done either with a hard tissue procedure, like a ridge-split, or with a soft tissue procedure, like a connective tissue graft (described in Section VI of this book). Depending on the case and an operator’s decision, either approach can recreate a more convex and esthetically pleasing buccal ridge profile. If this is a mild esthetic issue, soft tissue augmentation is usually adequate.



Figure 16.5 Intraoral view of the horizontally deficient alveolar ridge in the anterior maxilla that potentially could be restored with an implant without the ridge widening, although esthetically it would have a suboptimal result.

From the prosthetic point of view, although the ridge might have a surgically appropriate width for an implant placement, it can still be width deficient restoratively for the Class I occlusion with an appropriate overbite and overjet, and an implant might emerge more lingually or palatally than the occlusion calls for. This can also be a consideration to “move” the ridge more buccally, possibly utilizing a ridge expansion technique (Figure 16.6).

Surgical phases and stages

It is important to have a clear understanding of surgical phases and stages in the implant-driven bone augmentation. There are three phases and two stages in bone grafting and implant reconstruction of the deficient alveolar ridge. Phase I (pre-implant phase) is a bone grafting and alveolar ridge reconstruction prior to implant placement. In this book, we describe a ridge-split or edentulous ridge widening procedure as a bone augmentation technique. The RSP itself can consist of two stages (they can be done simultaneously in some cases): Stage 1 – corticotomy and Stage 2 – split and graft. On



Figure 16.6 Intraoral view of the horizontally deficient alveolar ridge in the posterior mandible that potentially could be restored with an implant without the ridge widening, although prosthetically (occlusally) it would have a suboptimal result.

occasion in advanced cases, both the RSP and implant treatment can be done at the same time. Phase II (implant phase) is a bone grafting that is done simultaneously with implant treatment. The implant treatment itself consists of two surgical stages: Stage 1 – implant insertion and Stage 2 – placement of a temporary healing abutment. This is followed by the restorative stage. Phase III (post-implant phase) is any bone (or soft tissue) grafting procedure that is done after the implant has been fully restored and in a function and is usually performed as a salvage procedure for an ailing or failing implant in a condition of peri-implantitis.

Diagnostic work-up for the RSP

The diagnostic work-up for the RSP consists of a thorough clinical examination and appropriate radiographic imaging. A comprehensive approach in a diagnosis is always beneficial and will not allow a clinician to miss anything. Author demonstrates an example of a work-up of these cases in Table 16.2. A pre-operative clinical

Table 16.2 Ten-step pre-operative diagnostic work-up for the ridge-split procedure.

1. Skeletal maxillomandibular relationship (I, II, III).
2. Prosthetic profile:
 - a. Class of malocclusion (I, II, III)
 - b. Type of occlusion in a sense of protective features: cuspid disclusion or group function
 - c. Opposing dentition (presences of super-eruption) and contralateral side (presence of premolar–molar teeth for the anticipated unilateral function during the recovery)
 - d. Temporization options (fixed: temporary crown and bridge, Maryland bridge; removable: stayplate, Essex appliance, others)
3. Esthetic profile: gingival biotype, presence of keratinized (or attached) tissue (in mm) and the depth of vestibule, shape of teeth, smile line, and gingival show
4. Periodontal profile: perio evaluation and oral hygiene, smoking, bruxism, and other unfavorable habits
5. Edentulous region evaluation:
 - a. Alveolar length, alveolar width, and interocclusal height (IOH)
 - b. Manual/digital palpation of the ridge: thickness, uniformity, presence of undercuts, condition of the buccal and palatal (lingual) plate
 - c. Ridge mapping: using calipers and gauges (optional)
6. Radiographic exam:
 - a. Panoramic radiograph (PA, occasionally): position of adjacent teeth, teeth collapse into the edentulous region, alveolar height, position of the inferior alveolar canal (IAC) and mental foramen, maxillary sinus; use calibration with metal bearing to correct the panoramic image magnification
 - b. CBCT scan (preferred): alveolar width and position of IAC or mental foramen, maxillary sinus, ridge widening and undercuts, thickness of cortical and medullary layers of bone
7. Lab: wax-up, mounted diagnostics models, surgical stent, or guide
8. Short diagnosis:
 - a. Missing functional tooth (teeth): number ...
 - b. 2D bone defect with deficiency of alveolar width. Alveolar width is . . . mm, height is . . . mm
9. Treatment plan considerations:
 - a. What is the bone augmentation procedure of choice? (ridge-split)
 - b. If RSP: single-stage (limited flap), two-stage (open FT flap), PT flap, combination flap
 - c. Papilla-preservation incision or not?
 - d. If a two-stage approach is chosen: when will the stage 2 be performed (3–5 weeks later)?
 - e. What type of bone graft (xeno- versus allograft, or mixed) and membrane (resorbable versus non-resorbable) will be used at the time of the split?
 - f. When should an implant phase be planned: simultaneously with split/graft? Delayed? If delayed or postponed, when?
 - g. Should a soft tissue procedure (connective tissue graft?) be considered now? In the future?
10. Team and time: surgical and restorative stages and doctors, patient is part of the team and should accept the plan (motivation and comprehension), timing and stages



Figure 16.7 Intraoral photograph of the collapsed alveolar ridge: digital palpation of the ridge can help to assess the ridge “thinness” and presence of bone undercuts, plate perforations and irregularities, bone defects, and soft tissue thickness.

examination helps to determine the correct candidate for the procedure at hand. It is important for a full team to evaluate the occlusal, prosthetic, esthetic, and periodontal status of the patient, and assess the edentulous ridge. Digital palpation of the ridge with two fingers sliding along the alveolar crest helps to develop a tactile sense of the ridge “thinness” and the presence of bone undercuts (which can be crucial in the surgery), plate perforations and irregularities, bone defects, and the soft tissue thickness (Figure 16.7). A sufficient thickness of the soft tissue can camouflage true alveolar ridge deficiency. The length of the implant fixture and position of the inferior alveolar canal or mental foramen (in the posterior mandible) ultimately determines the vertical dimension of the split.

At the clinical evaluation stage, different calipers and gauges can help to measure the ridge width (Figure 16.8). A ridge mapping with sharp gauges (Boley gauge, for example) that penetrate the soft tissue requires local anesthetic for a proper evaluation of bone



Figure 16.8 View of different calipers and gauges that can help to measure the ridge width and perform ridge mapping. Source: Tolstunov 2013 [32]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.

thickness. A radiographic value of 2D imaging (panoramic, periapical radiographs) is limited. These radiographs can show only height but not width, which is the key component in the RSP evaluation. Occlusal radiographs are also suboptimal. Development of computer tomography (CT) and cone-beam CT (CBCT) made ridge mapping under local anesthesia less common and significantly enhanced 3D bone evaluation and appreciation of width of the alveolar ridges.

CBCT

A cone beam computed tomography (CBCT) scan (Figure 16.9) can show the thickness of the buccal and lingual cortical plates, thickness of the trabecular layer of bone, and the width of the alveolar ridge along the edentulous region.

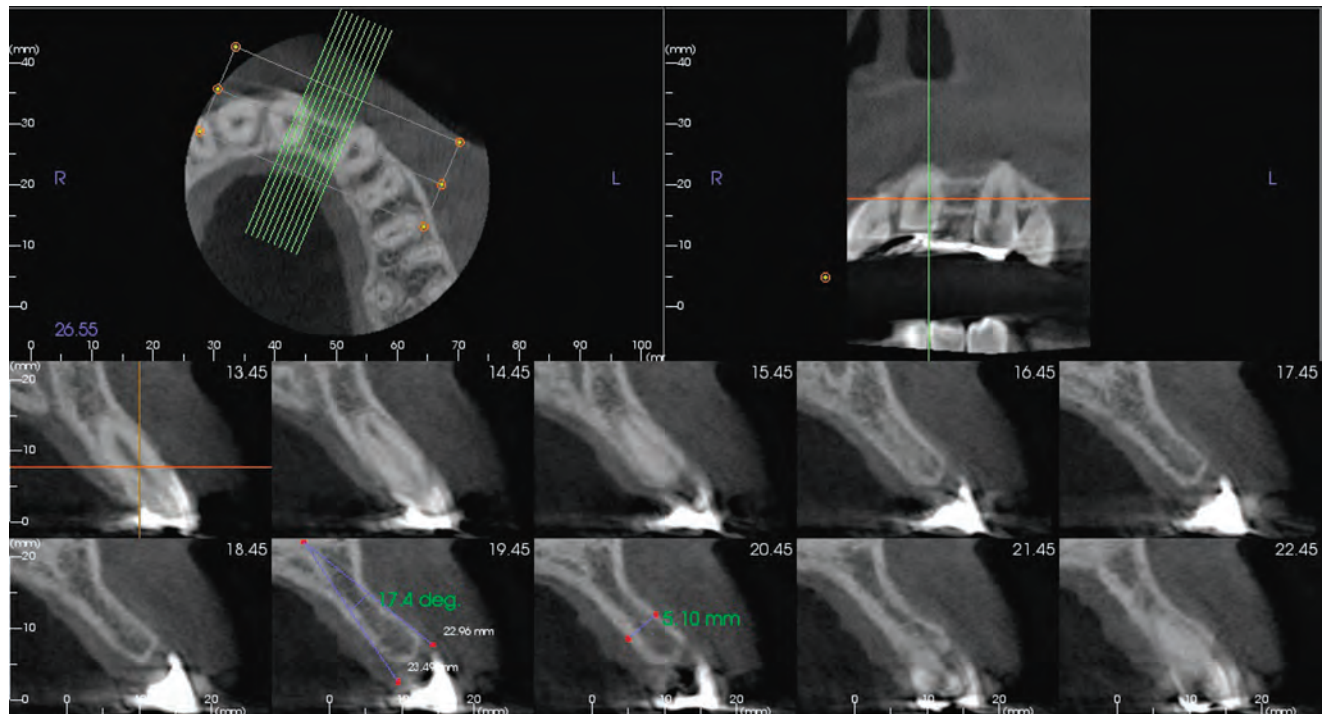


Figure 16.9 Multiple coronal slices of CBCT scan that show thickness of the buccal and lingual cortical plates, thickness of the trabecular layer of bone, and the width of the alveolar ridge along the edentulous region. Source: Tolstunov 2013 [34]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.

thickness of the cancellous layer of bone, width of the alveolar ridge along the edentulous region, presence of bone undercuts and irregularities, and proximity of the mental foramen, inferior alveolar nerve (IAN), maxillary sinus, and inferior border of the mandible. All this can help in diagnosis and treatment planning of the RSP. Sometimes, comparative CBCT scans taken pre-operatively and post-operatively can help to compare the results of the bone augmentation procedure and evaluate the bone for implant placement (if it was not done at Phase I) (Figure 16.10).

It is important to “work” with the CBCT scan to get a complete understanding of the edentulous region morphology. The author recommends choosing the CBCT image layout that shows simultaneously a coronal (frontal or panoramic), axial, and several sagittal (cross-sectional) slices for a full hard tissue analysis of the ridge. First, by sliding the horizontal line up and down on the panoramic window view, an examiner should evaluate the axial window for changes in the thickness (width) of the alveolar ridge. Then, by sliding the vertical line along the edentulous fragment of the image right and left, keep your eye on a single coronal or cross-sectional slice to observe the difference in bone thickness along the edentulous arch (its length). Combining both observations should help in understanding the 3D anatomy of the collapsed area, bone presence or bone deficiency, and, most importantly, suitability of the edentulous ridge for the RSP.

Surgical stent

An important part of the diagnostic work-up for the bone augmentation procedure prior to implant placement also consists of diagnostic models, wax-up, and a surgical stent (Figure 16.11). More about it is described in Chapter 4 of this book. Although a surgical stent is often utilized at implant insertion, it is helpful to have it available at the bone augmentation stage (Phase I). A surgical stent helps to ensure proper planning for the widening of the ridge (proper buccal plate expansion or lateralization) necessary for the future restoratively driven implant placement. At the implant insertion stage, the same surgical stent can also be utilized. Computer-guided surgery is a modern option of utilization of digital technology in implant dentistry and is also described in Chapter 6 in this book.

Instrumentation

Instrumentation is a matter of preference or availability. The author would like to suggest some general instruments that can be used (used in his practice) for the ridge-split procedure. General familiarity with ridge-split instrumentation now will help the reader to understand the description of the procedures that follow in future chapters.

Instruments that can be used for bone osteotomy or corticotomy include: a thin fissure bur (such as the 701 bur), small round burs, piezoelectric cutting tips, small oral surgical saws with oscillating, reciprocal, and sagittal movements, diamond disks, lasers (such as erbium:yttrium–aluminum–garnet), and others. Instruments that are helpful for bone splitting include: 15 (or 15C) scalpel blades, progressive (incremental) chisels, osteotomes or ridge splitting/expanding chisels, ridge spreaders, mallets, and others. The author has collected several instruments over the years and made his own set (Figure 16.12). It consists of the following instruments: scalpel (15), ridge splitting/expanding

chisels (3 and 5 mm with markings at 6, 8, 10, and 12 mm), mallet, Tatum “D” spreader, and periostomes.

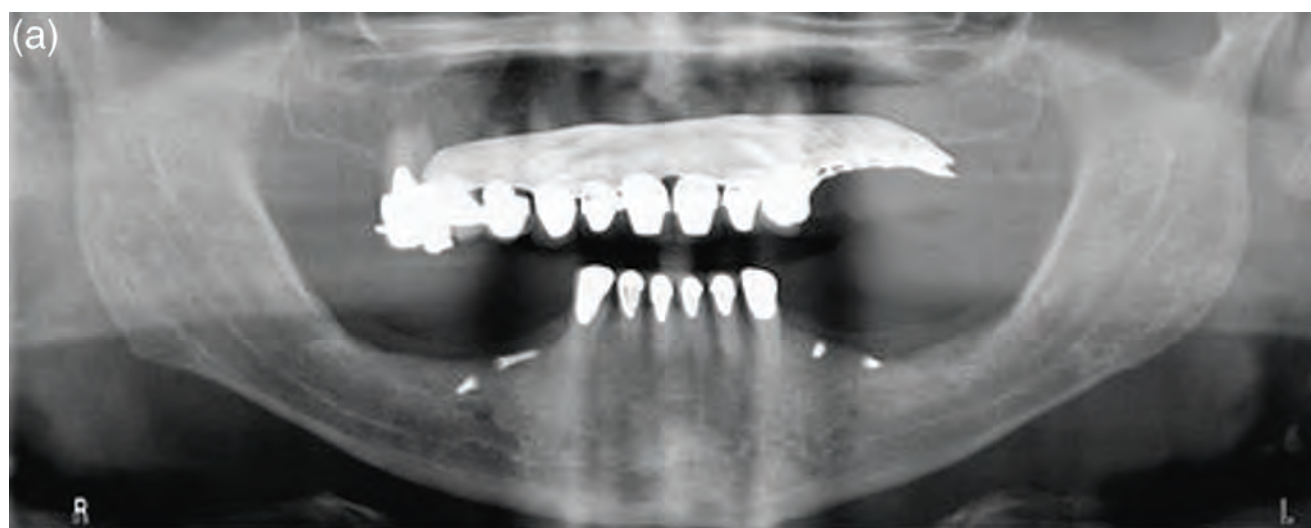
The key instrument for the RSP is a chisel or osteotome, sometimes called a chisel osteotome or splitting (expanding) chisel. When a surgeon selects a comfortable set for the practice, he/she should consider the following. Razor-sharp bone chisels are important for the ridge-split procedure to be successful. Chisel osteotomes should have a relatively small size, should have a comfortable handle that fits nicely in your hand, and should have a tip/blade with a sharp edge for engaging and splitting thin ridges. An important feature of a good splitting and expanding chisel is a design of the blade that should have a flat palatal (lingual) side (to prevent movement and insure stability of the lingual or palatal cortical plate) and a curved buccal or expanding side similar to a D-(Tatum) osteotome (see Figure 16.12). A comfortable surgical mallet needs to be chosen for gentle and precise blows to the chisels or osteotomes.

Salvin Dental Specialties, Inc. (Charlotte, NC, USA) offers several convenient sets for the RSP. One is a traditional set of four ridge splitting chisels (3, 4, 5, and 6 mm) in a cassette (Figure 16.13). There is also a set of expanding osteotomes for simultaneous implant placement. The company also offers multiple crest splitting piezo tips for atraumatic ridge splitting. Meisinger kits (Meisinger, Jacksonville, FL) have a few sets of instruments for osteotomy, ridge splitting, spreading, implant placement, and bone grafting. Spreading of bone is achieved at one stage either by using adjustable spreaders in a crest control system for the mandible or by a series of non-cutting (and condensing) bone spreaders with increasing diameters in a split control system for the maxilla. Biedenis Technologies, Inc. (Richmond, BC, CA) offers a good color-coded Waveline Offset ridge-split kit containing a convenient set of sequential bone spreaders with directional gauges that are helpful for an atraumatic buccal bone-sparing lateral bone spread, especially in cases of larger edentulous segments (two, three, and more) (Figure 16.14).

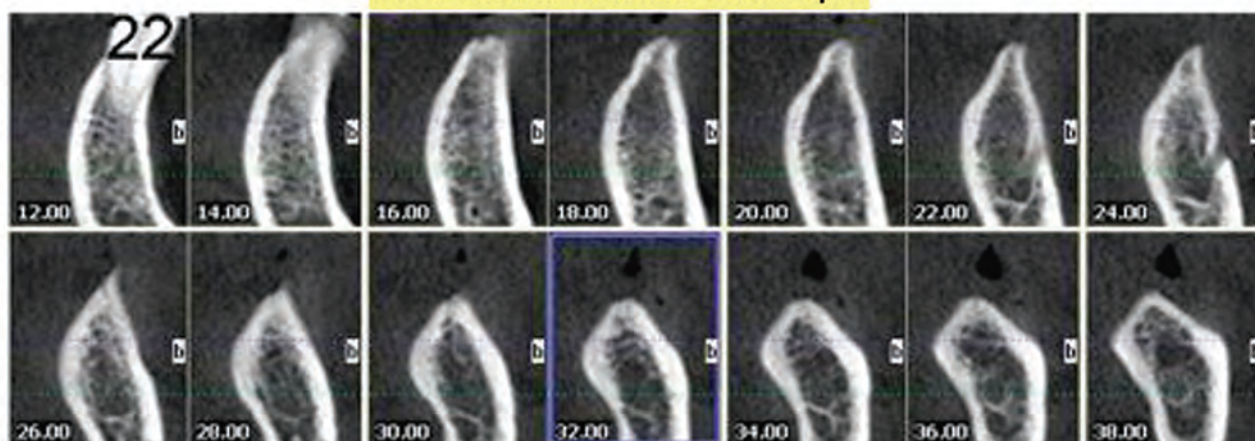
Another way to approach the ridge-split procedure is by utilizing piezoelectric instrumentation. Although slightly slower, it is an accurate way to perform bone cuts. In a 2000 report, T. Vercellotti [17] presented a new piezoelectric ridge expansion technique with implants placed in a single-stage surgery. GTR was done between cortical plates with bioactive glass synthetic material and autogenous platelet-rich plasma (PRP). At 3 months, the ridge thickness was 5 mm (from 2–3 mm) and all implants were successfully osseointegrated.

Danza et al. in 2009 [33] showed a similar success of implants placed into a piezo split (not grafted). Holtzclaw et al. [34] in their retrospective observational study demonstrated a successful reconstruction of posterior mandibular alveolar ridge deficiencies with the piezoelectric hinge-assisted ridge split technique. In their report, 13 patients with 17 horizontal ridge deficiencies had an overall mean gain in horizontal width of 4.03 mm after the procedure. The author uses the Osada piezoelectric ultrasonic system (OSADA Inc., Los Angeles, CA, www.osadausa.com) in many RSP cases.

There are many other instruments that can be successfully used for the RSP. An operator preference often determines what is the most comfortable for him/her that offers the best tactile (digital) sense as well as variability in the application of the same kit for different quadrants of the jaws and large and small edentulous bony defects.



Left Posterior Mandible Before Split



Left Posterior Mandible After Split

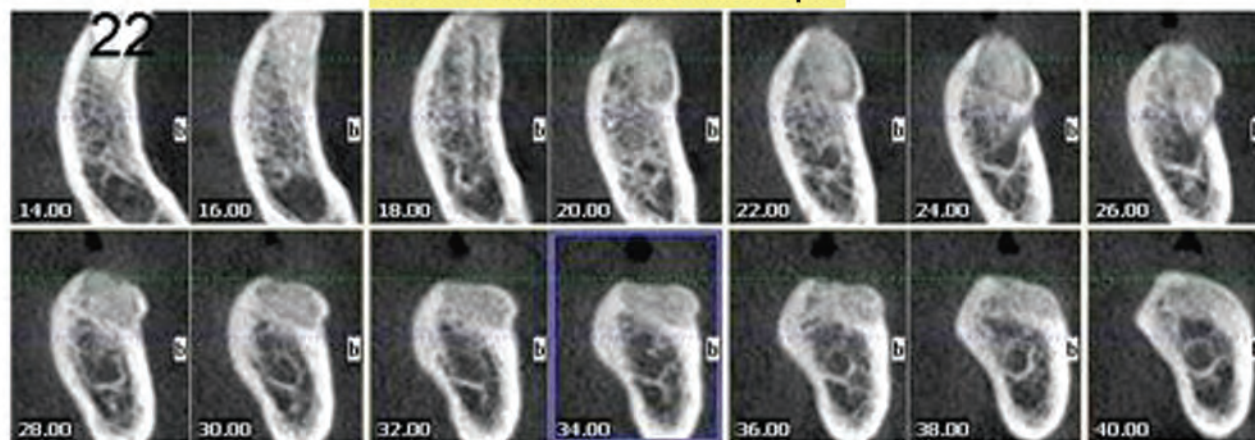
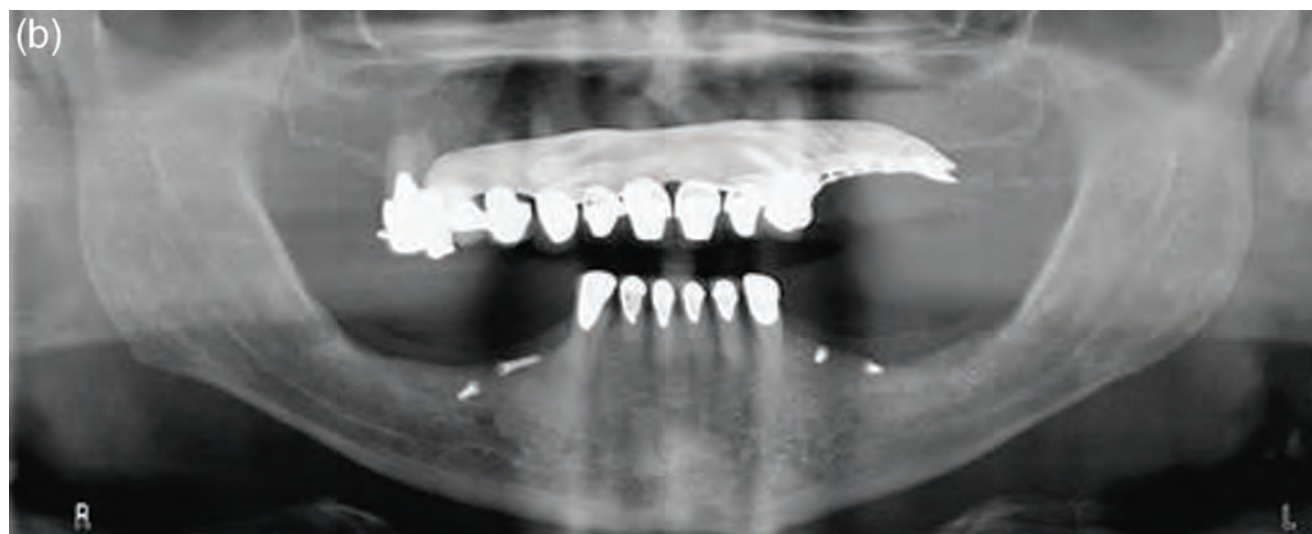
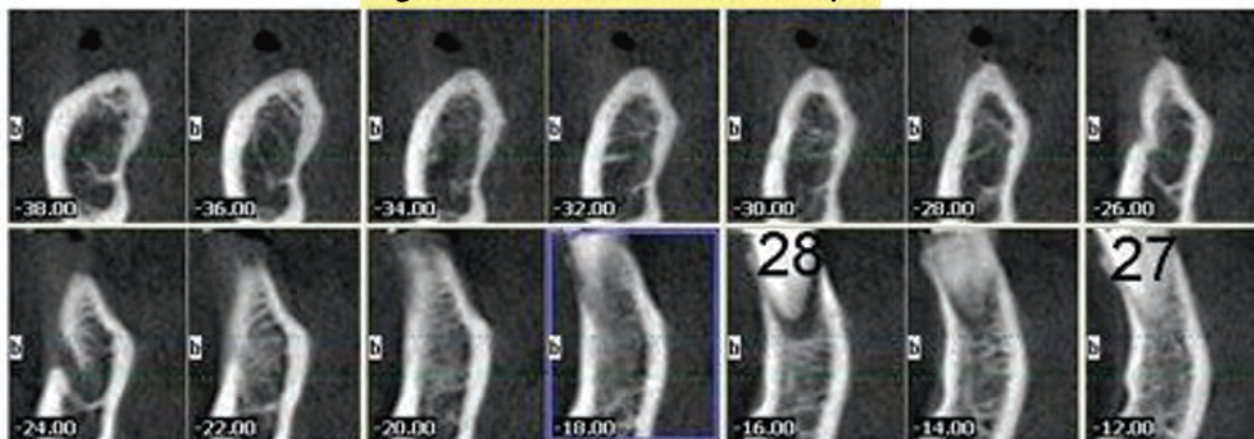


Figure 16.10 CBCT scans taken pre-operatively and post-operatively to compare results of the bone augmentation procedure and evaluate the bone for implant placement. (a) Left posterior mandible before and after the split. (b) Right posterior mandible before and after the split. (Source for (a) and (b): Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)



Right Posterior Mandible Before Split



Right Posterior Mandible After Split

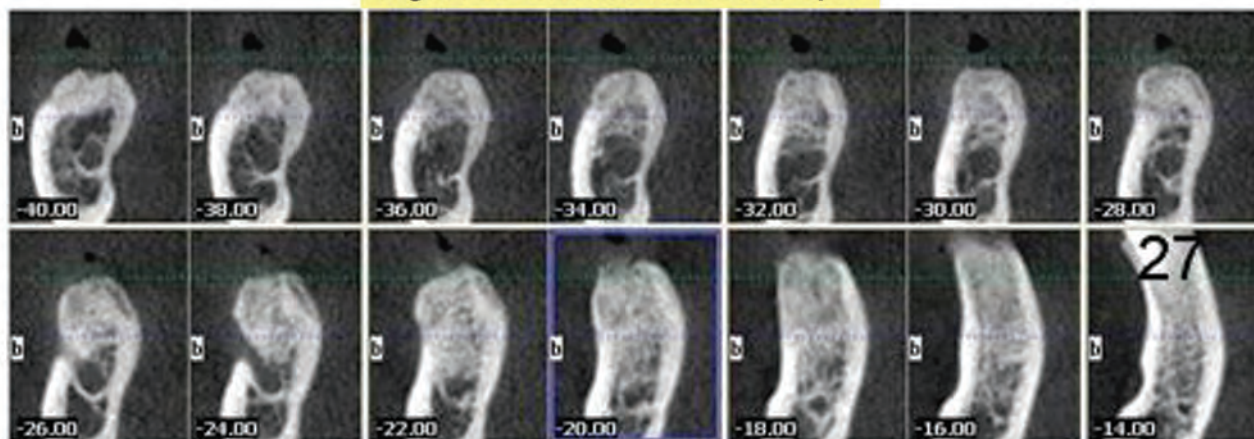


Figure 16.10 (Continued)

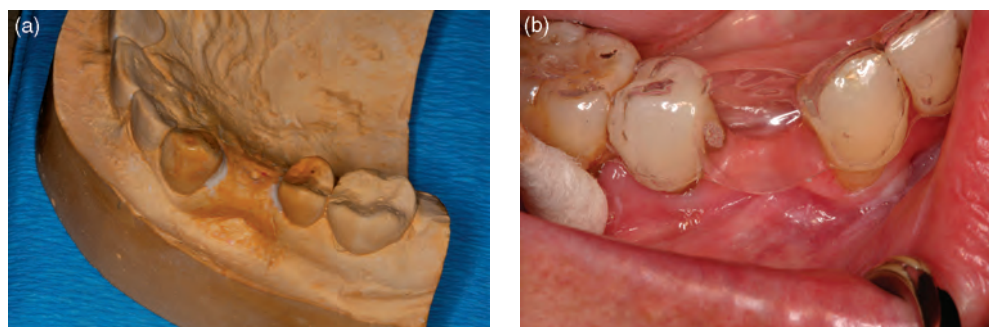


Figure 16.11 (a) Diagnostic model and (b) surgical stent as part of pre-operative diagnostic work-up for the ridge-split procedure. Source: Tolstunov 2013 [32]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.



Figure 16.12 The author's surgical instrumentation for most segmental ridge-split procedures.



Figure 16.13 Salvin ridge-split procedure kit (Salvin Dental Specialties, Inc., Charlotte, NC, USA) offers ridge-split instrumentation consisting of four ridge-split incremental chisel-osteotomes in a cassette.



Figure 16.14 Bionix Technologies, Inc (Richmond, BC, CA) offers a good color-coded Waveline Offset ridge-split kit containing a convenient set of sequential bone spreaders.

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Surgical Principles of the Ridge-Split Procedure

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Introduction

There is some variability of surgical approaches to accomplish an alveolar ridge-split and expansion in implant dentistry. Most of the techniques are based on a controlled force of an operating surgeon in the process of mobilization of a thin facial (buccal or labial) bony fragment, usually in a closed-flap (partially “blind”) environment. Thus, this is a technique-sensitive procedure that relies on the tactile sense of a surgeon, and requires practice and time to master.

For anyone interested to learn this technique and often for an experienced practitioner, it is important to consider adhering to certain surgical principles or rules and clearly define biologic rationales of the procedure to decrease failures, prevent complications, and avoid disappointments and frustration. Among many surgical principles, there are five important considerations of the ridge-split procedure (RSP) that the author would recommend to consider. They are the following:

- 1 Vascularization is a key principle in the RSP and a vascular bone flap is developed in the process.
- 2 RSP utilizes the healing potential of bone similar to an extraction socket. Healing by secondary intention is emphasized.
- 3 Osteocondensation often occurs, especially in maxillary RSP cases.
- 4 Osteomobilization of the buccal cortical complex always occurs and is an inherent principle of the RSP.
- 5 There are some important differences in the RSP performed on maxillary and mandibular alveolar ridges based on bone density. Below is a detailed discussion of each surgical principle.

1. Role of vascularization in the ridge-split procedure: vascular periosteal flap

Vascularization of the osteotomized and mobilized segment of the jawbone plays a dominant role in preservation of its vitality and success of bone transplantation. Pivotal work of Dr. William H. Bell's from the 1960s and beyond on bone vascularization and bone healing [1–3] helped to establish biologic rationale for jawbone osteotomies in orthognathic surgery. Dr. Bell demonstrated that the vitality of the segment of a jaw that was osteotomized would be preserved if a soft tissue pedicle could be kept intact.

From the early research on bone mobilization procedures, like distraction osteogenesis or alveolar ridge-expansion, the importance of blood supply to the moving fragments of bone has also been emphasized [4–6]. In 1994, A. Scipioni et al. [6] noticed that “The

essential feature of ERE technique is the partial-thickness flap with preservation of its buccal blood supply” as well as that “the integrity of the periosteum must be maintained”. Formation of a buccal or lingual (palatal) full-thickness (FT) mucoperiosteal flap (FTMPF) leads to detachment of all soft tissue on one side from its base – the alveolar bone. Development of a partial-thickness (split-thickness) (PT or ST) mucoperiosteal flap (MPF) leads to a partial detachment of some soft tissue (mucosal and submucosal layers only) on one side, preserving the periosteal attachment to the bone, an important mechanism of bone protection and its vascularization. When an FTMPF is raised on one side of the ridge, the other side should always maintain the soft tissue attachment to preserve vitality of bone and integrity of its blood supply. Failure to do so in any surgical procedure will result in a loss of bone and often failure of the operation.

There are two types of blood supplies to maxilla and mandible – central and peripheral [7] (see also Chapter 2 of this book). Central vascularization is accomplished through the external carotid artery with its branches: maxillary, lingual, and facial arteries. Peripheral vascularization that is formed by the muscular-periosteal network also plays an important role. Periosteal vascularization during bone graft transportation has been shown to improve graft survival in the craniofacial region by early vascularization of the grafted bone [8]. Periosteum plays a crucial role in vascularization of the buccal cortex as well as in graft osteogenesis. J. Gray et al. [9] came to the conclusion that at least one-third of an early graft osteogenesis could be attributed to the buccal periosteum alone. The viability of bone through the peripheral vascularization by the soft tissue attached to it has been proven in many studies by fluorescence microscopy, vessel injection (arteriography), histologic sections, segmental osteotomies, etc. [10–14].

During the RSP, both PT and FT flaps (PTFs, FTFs) are employed. FTFs are performed more frequently. Another FTF modification that is routinely used during RSP is called a limited (partial or closed) FTF. In this case, although the FTF is initiated, it is limited to the top 3–5 mm of the alveolar crest on the buccal side, leaving the remaining flap attached to the ridge and intact, preserving a periosteal-to-bone connection. During an RSP, a greenstick fracture with the periosteum attached to the buccal bone fragment is created. The buccal FTF (if used) consists of all the soft tissues on the buccal (facial) side (attached periosteum and gingivomucosal complex) plus a subfractured and mobilized buccal bony fragment. The soft tissue flap provides vascularity to the attached bone (the vascular bone flap). To prevent risk of bone devascularization

during the RSP (a known complication), most of the mandibular RSPs are done in stages (see a detailed description of the technique in Chapter 12) and mostly maxillary RSPs are done in a single stage with a limited FTF or split-thickness flap (SPF) (Chapter 13). Meticulous tissue manipulation preserving the periosteum and peripheral vascularization is especially important when a single-stage RSP is performed.

A vascularized intraoral hard-soft tissue buccal flap can be developed in different ways based on the attachment of bone to its base (the alveolar process). It can either be open like a book rotating about its base (binder) [14] in a hinged manner (still connected to its base, like a greenstick fracture), called a “book flap” (Figure 17.1) or be fully separated from its bony base (free-floating) but still connected to the soft tissue called an “island flap” [15,16] (Figure 17.2). The biologic rationale in both types of bone flap development is the maintenance of the periosteal blood supply (intact soft tissue flap) to the osteotomized buccal bony fragment in the process of an alveolar split [14]. The combined hard-soft tissue buccal flap (“book flap” or “island flap”) is often called a vascularized osteoperiosteal flap (VOPF) or vascularized mucoosteoperiosteal flap (VMOPF), which has a preserved periosteal (peripheral) blood supply to all its components. The differences in two flaps are based on the degree of osteomobilization needed. Obviously, an “island” flap can be displaced laterally to a larger degree than a “book” flap and can be repositioned vertically, potentially correcting not only horizontal but some vertical alveolar bone deficiency.

“Book” Flap (greenstick-fracture)

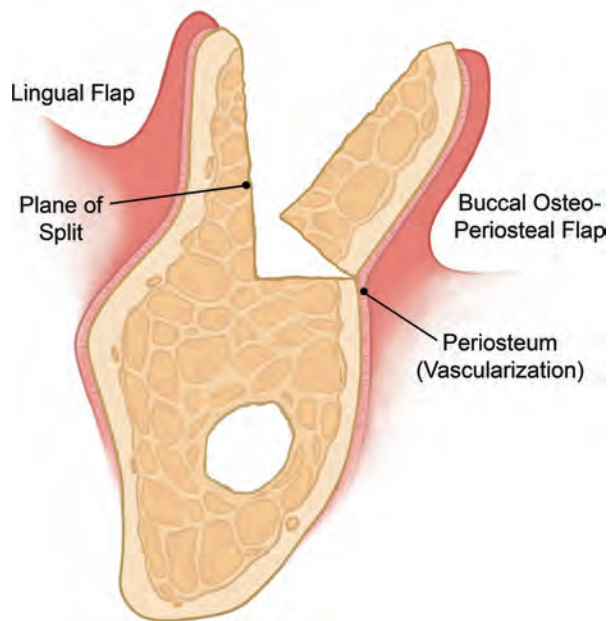


Figure 17.1 Illustration of a vascularized hard-soft tissue (osteoperiosteal) buccal flap during the ridge-split procedure in a manner of a “Book” flap (Jensen) rotating about its base (binder) in a hinged manner (still connected to its base, like a greenstick fracture).

“Island” Flap (fracture-displacement)

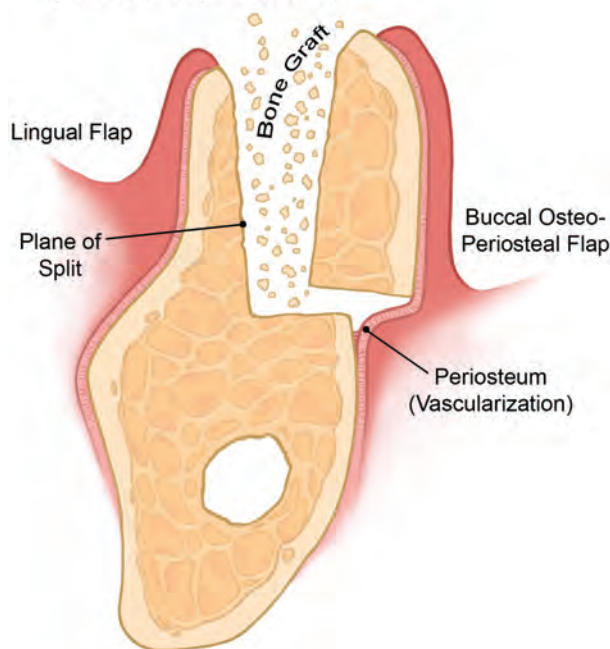


Figure 17.2 Illustration of a vascularized hard-soft tissue (osteoperiosteal) buccal flap during the ridge-split procedure in a manner of an “Island” (“I”) flap (Jensen) being displaced laterally with a complete separation from its bony base (free-floating) but still connected by a soft tissue pedicle with preserved periosteum (like a displaced fracture).

2. Wound healing is similar to ridge preservation in socket bone grafting procedures

As the name implies, during the ridge-split or ridge-widening procedure the bony fragments of the alveolar ridge are separated and the ridge is expanded laterally. In the ridge-split bone grafting (RSBG) process, an *internal* bone space (gap) is formed. When bone grafting is done, it is done “internally” as an interpositional, inlay, or “sandwich” grafting [17,18] in a similar fashion to the socket bone grafting (SBG) in the ridge preservation following tooth extraction. In both cases, the particulate bone grafting material (replacement graft) is positioned inside the gap with a light incremental pressure-condensation following the principles of the ridge-preservation by guided bone regeneration (GBR) [19,20] (Figure 17.3). “Horizontal space maintenance” concept allows grafting of ridge-split gaps similar to a four-wall extraction socket [21]. A collagen membrane or more advanced GTR membrane is frequently placed on top of the graft to protect, contain, and isolate the graft from the oral environment. The more socket walls that are present, the more chance there is for the graft to be contained or protected within the space of a socket or split/gap during the healing period.

The Bio-Col technique for the ridge preservation after tooth (teeth) extraction described by A. Sclar [22] can also be applied for the ridge-split procedure. Bio-Oss® (Geistlich Pharma North America, Inc., Princeton, NJ) and CollaPlug® (Zimmer Dental Inc., Carlsbad, CA) are used as a bone graft material and protective dressing (membrane), respectively. Biologic adhesive, like Iso-Dent™ (Ellman International, Inc., Oceanside, NY), can help at the completion of the procedure to seal the socket and protect the graft in the initial stage

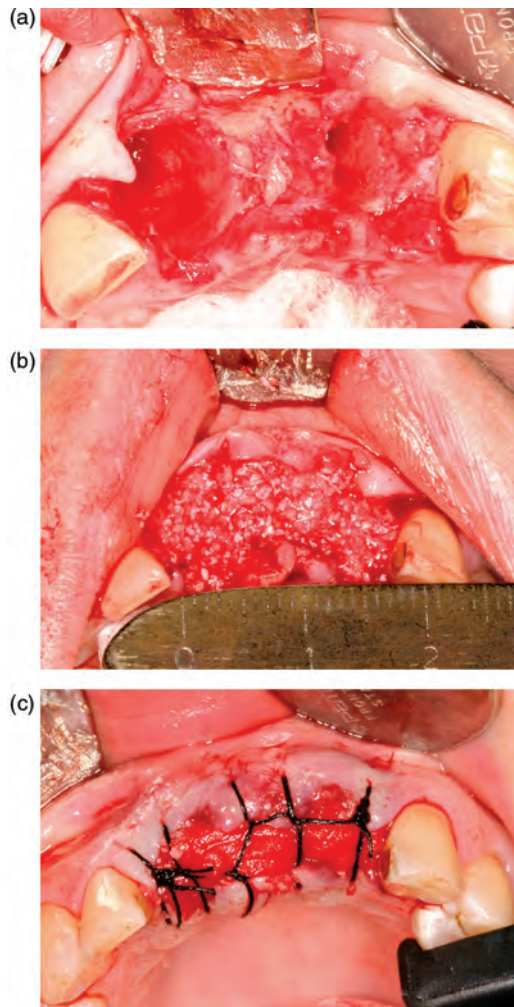


Figure 17.3 (a) Intraoperative clinical picture of the ridge preservation procedure: extraction sockets are being filled with a particulate bone grafting material. (b) Intraoperative view of the ridge preservation procedure: a particulate graft is being covered with a protective membrane. (c) Intraoperative view of the ridge preservation procedure: the wound is approximated (not fully closed) with sutures for healing by secondary intention. This wound treatment approach is similar in the ridge-split procedure. Source: Tolstunov 2013 [23]. Reproduced with permission of Douglas P Sinn, DDS. Editor in Chief, SROMS.

of healing from food debris. The same modified Bio-Col technique can be used for filling the open gap after the RSP. Instead of CollaPlug®, a Colla-Tape or other collagen membrane can be used to cover the particles of the graft (Figure 17.3).

In the majority of cases, the alveolar split is done in the edentulous (healed socket) region of a thin (width-deficient) ridge. This is a more stable (ideal) environment for the ridge-split procedure. On occasion, it is possible to plan and execute an immediate socket split right after the extraction of a tooth (or teeth) when anticipating a future buccal wall collapse. The presence of a preserved buccal wall after tooth extraction is mandatory in these cases. This approach can be done in a planned manner by splitting the buccal wall of the tooth socket and moving it laterally (rotating as a “book” or displacing as an “island”) right after the tooth extraction. A particulate graft should follow in a routine manner of ridge preservation. This technique can help to anticipate unavoidable bone collapse of a post-extraction socket by “overcorrecting” its width with an immediate “socket-split”, possibly preventing a future need for bone augmentation. Paying attention to a buccal soft tissue pedicle is extremely important in preserving vitality (vascularization) of the buccal wall of the socket.

Primary versus secondary intention in wound closure in the RSP

Primary closure of the surgical wound results in a full approximation of its edges. Secondary closure (closure or healing by secondary intention) leaves the surgical wound open and relies on a potential of the wound edges to grow and the wound to eventually heal (close) with a scar formation. Although tension-free primary closure is advantageous in GBR procedures in general, the ridge-split is an exception from this rule, and GBR during the ERE is usually intended to heal by secondary closure. In fact, in the majority of RSP cases, it is difficult to accomplish the primary closure due to the enhanced volume of the post-surgical wound. As with the SBG, in the RSBG the healing by secondary intention is emphasized.

Healing by secondary intention has several advantages. It preserves the soft tissue architecture around the surgical site. The buccal attached gingival soft tissue is not detached from its bony foundation and is not forced onto the alveolar crest to achieve the primary closure. This ensures the presence of the attached gingiva and keratinized tissue on the facial side of an implant (similar to a natural tooth) and provides a proper maintenance and hygiene years after completion of the procedure. The vestibular depth is also preserved. There is frequent “gain” of tissue that can be seen in wounds healed by secondary intention. This can be seen in Figure 17.4, which shows

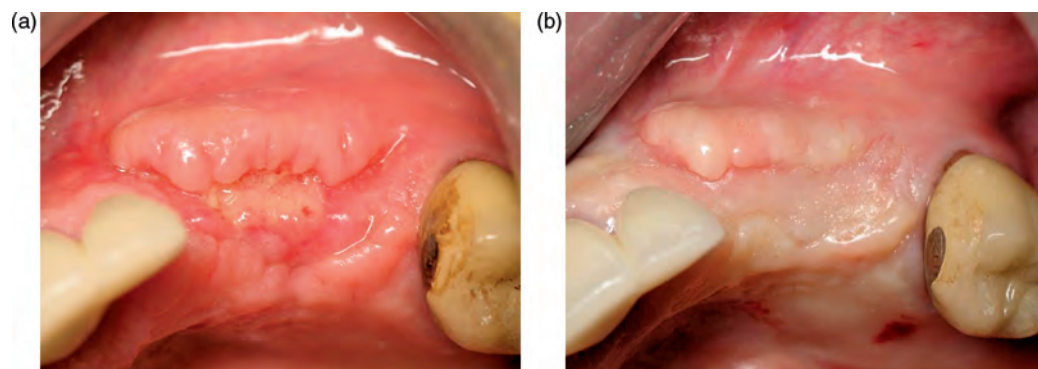


Figure 17.4 Typical healing by secondary intention that is recommended in the majority of ridge-split cases: (a) 2 weeks post-surgery and (b) photograph taken 2 months after the previous image shown in (a). The attached gingiva and vestibule are preserved. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

results taken 2 months apart. Other considerations in avoiding primary closure are: avoidance of the buccal soft tissue tension and associated post-operative pain and swelling, as well as risk of the injury to the mental nerve in cases of mandibular premolar sites when the buccal flap advancement may cause temporary or permanent numbness [24].

Common disadvantages of healing by secondary intention known in general surgery and related to a skin wound closure are: longer periods of healing, scarring, and contraction of soft tissue in the closed proximity to the wound. These disadvantages do not play a (significant) negative role in the oral cavity, especially in cases of the closure of soft tissues on top of the alveolar ridge. There is no noticeable contraction of elastic intraoral soft tissues. Although there is a longer period of healing when treating wounds openly (by secondary intention), the advantages of preserving the attached alveolar soft tissue position as well as gaining some extra soft tissue on top of the ridge in the process of healing (scar) outweighs disadvantages in the majority of cases.

Secondary healing through the “open” wound environment relies on membrane protection (described below in the subsection on regenerative materials). Doubling of a membrane (placing as a double layer) can improve the protection of the graft. In this case, a simple collagen membrane (CollaTape®, for example) can cover the bone graft as a first and internal layer followed by a true GTR membrane, which would be a second (external) layer covering the first layer and providing a better resistance to the absorption of saliva and better protection from food debris. This double-layer membrane can also be helpful in cases where a patient is a smoker, has poor oral hygiene, or is suspected not to follow post-operative dietary instructions. Any membrane(s) of choice is usually trimmed to fit the created defect, with some excess to be tucked underneath the buccal and lingual (palatal) flaps. Due to the importance of the buccal flap attachment to bone, the membrane is just slightly tucked underneath the buccal flap. There should not be any restrictions on the lingual (palatal) side. A lingual FTF can be raised and the membrane can be placed underneath and wrapped around to the buccal side.

Sutures should be placed on top of the wound above the membrane. The author prefers 4-0 silk sutures that provide stability of the wound for about 10–14 days and do not dimension or absorb saliva. A soft diet, meticulous oral hygiene, and chlorhexidine (0.12%) rinses in the post-operative period help to achieve satisfactory healing. Complete gingival healing of the wound treated by a secondary closure technique is usually seen within 6–8 weeks.

Secondary healing after the SBG or RSBG moves through the same stages: “coagulum” that is replaced by the connective tissue matrix or fibrin clot formation (first month), immature (woven) bone formation (second to third months), mature (lamellar) bone and bone marrow formation (third to fifth months), and the bone stabilization period (up to a year after extraction) [25]. After a period of 4–6 months in most cases, an endosseous implant can be placed into the RSBG or SBG sites.

In cases when implants are placed simultaneously with the ridge-split (this will be discussed later), it is done in a similar fashion as with an SBG by engaging the apical (basal) bone. Primary implant stability is one of the most important factors in the immediate implantation. In 1997, Scipioni, et al. [26] studied healing of implants placed during the ERE procedure with and without initial primary bone contact in dogs and demonstrated that “bone regeneration and osseointegration may occur to titanium fixtures placed in surgically-created bone defects”, i.e., the bone is able to “jump a gap” and heal on top of implants even without the initial bone contact. Rimondini et al. [27] in 2005 confirmed in a mini-pig model that implants that are placed

immediately into fresh extraction sockets achieve osseointegration without initial bone contact with the bone-to-implant contact (BIC), which increased on average at the coronal level from 0% at day 7 up to 60% at day 60 following the surgery.

At this point, it makes sense to have a small subsection on regenerative materials (bone grafts and substitutes and membranes) that can be used as GBR in the RSP. Third, fourth, and fifth surgical considerations in the RSP will follow after.

Regenerative materials

In 1999, Bruder and Fox [28] described “three basic biologic elements: cells, growth and differentiation factors, and extracellular matrix scaffolds” that are required for successful bone regeneration. Physiologically, an ideal bone graft should have osteogenic, osteoinductive, and osteoconductive abilities. Only an autogenous bone has all three characteristics for bone growth and thus is often called a “gold standard” in bone grafting and bone augmentation [29]. Most of mineralized and demineralized allografts and xenografts form a new bone largely by the process of osteoconduction when the graft provides a scaffold on which a new bone gradually forms from the periphery (bone margins), replacing the graft over time in a process called creeping substitution [30]. The principle of osteoinduction in some allogeneic bone grafting materials is based on migration and proliferation of undifferentiated mesenchymal (stem) cells to the site, with a potential of improving bone regeneration [31]. Bovine particulate xenografts appear to better preserve bone volume and have little dimensional loss over time [32].

An operator, in most cases, determines the grafting material of choice based on his/her experience. Examples of regenerative *bone grafting materials* (bone replacement grafts) that the author has successfully used for the RSP are the following. Among allografts (human cadaveric bone), they are: Puros® allograft (Zimmer Dental Inc., Carlsbad, CA), a solvent-dehydrated, gamma-irradiated human cadaveric bone that utilizes the Tutoplast® (Tutogen Medical, Inc.) process of sterilization; AlloOss™ (ACE Surgical Supply Company, Inc., Brockton, MA), a mineralized corticocancellous particulate allograft; and others. Among natural, porous bovine bone mineral (xenografts), they are: Bio-Oss® (Geistlich Pharma North America, Inc., Princeton, NJ), a natural, porous bone mineral matrix that is produced by removal of all organic components from bovine bone, comparable with a mineralized matrix of human bone, sterilized by gamma irradiation; Nu-Oss™ (ACE Surgical Supply Company, Inc., Brockton, MA) is a similar product with a slightly larger particle size; and others.

The author often uses a corticocancellous allograft or a xenograft of particle sizes varying from 0.5 to 1 mm and a resorbable membrane. For a one-tooth edentulous defect, an amount of 0.25–0.5 gm (by mass) or 0.25–0.5 ml (by volume) of the grafting material is usually sufficient in most cases for the internal grafting within a gap formed during the RSP. For a longer split, a 1–2 gm or more of a particulate grafting material may be necessary. A bone grafting material of choice is placed into the created split from the bottom up with a light condensation filling the gap to the crest of the ridge. A variety of other analogous grafting materials can also be used with great success. They should be investigated by an operator to make sure they are safe and their resorption rate is parallel to a new bone deposition rate to ensure timely bone replacement and appropriate new bone growth.

Successful guided tissue regeneration (GTR) attempts to provide space maintenance for wound healing by excluding epithelial and connective tissue cells and promoting growth of bone cells through

the usage of *biologic membranes*. Membranes that are used for this purpose can be resorbable (bioabsorbable) and non-resorbable. The original W.L. Gore and Associated (Flagstaff, AZ) membrane was made of expanded polytetrafluoroethylene (e-PTFE), a bio-compatible Teflon material, designed for periodontal purposes of bone augmentation around the roots of teeth. A later invention of –titanium-reinforced e-PTFE had a better space maintenance capacity and prevented membrane collapse underneath the soft tissue. Bioabsorbable membranes are usually made from collagen and dissolve within weeks or months after placement. They can be cross-linked, like BioMend® (Zimmer Dental Inc., Carlsbad, CA), or non-cross-linked, like Bio-Gide (Geistlich Pharma North America, Inc., Princeton, NJ). They have a slow absorption rate (months). A faster absorption rate (weeks) is found in the collagen membranes, like CollaTape®, CollaCote®, and CollaPlug® (all from Zimmer Dental Inc., Carlsbad, CA). Other examples of GTR membranes that could be used for the RSP are non-resorbable Teflon® (Kendall Curity, Tyco Healthcare, Mansfield, MA) and resorbable Bio-Gide® (Geistlich Pharma North America, Inc., Princeton, NJ).

Biologic glue, like Iso-Dent™ (Ellman International, Inc., Oceanside, NY) can help to seal the wound after placement of a membrane, improving its isolation. A light-cured flexible periodontal dressing can also be used to protect the wound from food debris in the early post-operative period.

New developments in bone morphogenic proteins (BMPs), platelet growth factors (PGFs), platelet-rich plasma (PRP), platelet-rich fibrin (PRF), and other regenerative products should help in the future to accelerate tissue healing and tissue and bone growth and regeneration. These new biomimetics are described in the last section of this book.

3. Osteocondensation of the surrounding bone

In the process of bone manipulation during the RSP, the adjacent fragments of bone are slightly compressed or condensed. It is more apparent in the maxilla due to lesser bone density (as discussed above). By comparison, in 1994 R.B. Summers introduced his osteotome technique [33] for the soft maxillary bone as an alternative to bone drilling. Many implant practitioners since have noticed some degree of horizontal bone compression that occurs with the hydraulic vertical osteotome technique that is likely to help in primary implant stability. Nishioka and Kojima in 2011 [34] described a screw spreading/crest expansion technique as an alternative to the Summers osteotome approach, commenting on a controlled and standardized dilation of the bone horizontally and an enhancement of the dental implant site due to compression of the medullary bone against the cortical wall that allows for greater initial implant stability. Khayat et al. [35] in 2011 demonstrated that placement of tapered implants in slightly underprepared sites leads to high compression forces and elevated insertion torques (up to 176 N cm), with no disturbance of osseointegration, which is important for the improvement of primary implant stability.

The RSP, especially in the maxilla with an immediate implant insertion, utilizes a similar principle of bone compression, only here it is mostly a horizontal compressing force. It is postulated that an increase in the density of bone through a moderate degree of compression might be helpful in implant osseointegration due to an increase in primary implant stability and also in the early loading protocols [36].

4. Osteomobilization of the buccal bone fragment

As the name implies, during ridge expansion the buccal cortical plate is separated from the underlying medullary or spongy bone and is moved buccally (labially, in anterior cases). As mentioned above, the buccal cortical bone fragment is attached to the periosteum and, thus, is vascularized. This partially or fully detached fragment of the buccal portion of the alveolar ridge is repositioned laterally (rotated or moved). The amount of movement can be different and is dictated by many functional and esthetic factors. As discussed above, a vascularized intraoral hard–soft tissue buccal flap can be developed either as a book *rotating* about its base (binder) [14] in a hinged manner (still connected to its base, like a greenstick fracture), called a “book flap” (Figures 17.1 and 17.5), or be fully separated (disconnected from the “mother” bony fragment) from its bony base (*free-floating*) but still connected to the soft tissue called an “island flap” [15,16] (Figures 17.2 and 17.6). The most important criterion in these implant-driven cases is a capability of an augmented bone eventually to accommodate a root-form endosseous implant in a prosthetically or esthetically favorable position.

Mobilization of a bone fragment surgically separated from its base can happen in two distinctive ways: static and dynamic. The static way of bone mobilization is described in this chapter and a whole section of the book. It is the basis of the ridge-split procedure. The static method is when surgical bone displacement is accomplished in a single move. The dynamic method is typical for the distraction osteogenesis (DO) procedure when incremental bone movement is emphasized. During the DO procedure, the bony segment moves slowly (about 1 mm a day), driven by a rotating mechanism. Distraction osteogenesis and its advantages are described in a separate part of this book.

5. “Maxilla is not an upside down mandible”

It is well known in the profession that the quality of mandibular and maxillary bones is not the same and that “the mandible is not an upside down maxilla” and vice versa. Lekholm and Zarb [37] in 1985 published an alveolar bone *qualitative* classification in relation to implant insertion and initial (primary) implant stability. In their bone quality classification, four types of jawbone were distinguished: types I and II, a denser compact/cortical bone, often found in the mandible, and types III and IV, a softer and less density bone, often found in the maxilla.



Figure 17.5 Intra-operative photograph of maxillary “Book” osteoperiosteal flap in progress.

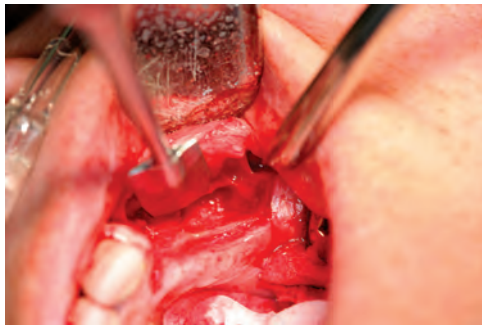


Figure 17.6 Intraoperative photograph of a maxillary “island” osteoperiosteal flap in progress. Source: Tolstunov 2014 [38].

Both maxilla and most of the mandible undergo intramembranous ossification (similar to the flat bones of the skull), which starts at about the tenth week of gestation [39]. During intramembranous ossification, bone develops directly from and within two layers of fibrous connective tissue membrane (embryonic, undifferentiated, condensed mesenchyme) in the process of primary ossification and arranges in sheet-like layers resembling membranes. This type of ossification is typical for bones that are not required to perform early supporting (loading) functions (flat bones of the cranium, clavicle, maxilla, body and ramus of the mandible). The differences in bone density among maxilla and mandible appear to develop during embryogenesis at the time of “layering” of bone and bone calcification (osteogenesis), bone vascularization (angiogenesis), formation of the upper respiratory structures (nose, pneumatized sinuses), and early functions. Mature maxillary bone with a little supporting (loading) function and inherently attached to other pneumatized bones of the skull ends up being a “softer” bone. Mature mandibular bone with a more loading functional capacity “separate” from the remaining bones of the skull ends up being a “harder” or denser bone. These differences in bone density are important in bone manipulation during the RSP. Due to this important factor, during the RSP in the *maxilla*, a single-stage surgical procedure can be done in the majority of cases when bone osteotomies, split, expansion, and grafting are done simultaneously. Even implants can be done at the same time, on occasion. On the contrary, the mandibular RSP is frequently performed in a staged manner with bone osteotomies done at the initial preparatory stage and split and graft at a separate stage weeks later (details are discussed in later chapters).

Conclusion

The main principle of bone augmentation is in the process of osseous reconstruction to attain bone that is similar, if not identical, in quality and quantity to the natural bone that was present before the bone loss occurred. To accomplish this goal, a variety of surgical techniques can be offered that, in principle, differ from each other by the way the graft is attained, and by the graft or flap vitality and vascularization. Based on vascularization of the graft, R. Ewers proposed a biologic classification of the alveolar bone augmentation [40]. All bone augmentation techniques, according to E. Ewers, can be divided into five classes: Class I: microanastomosed free bone flaps (iliac crest, fibula); Class II: distraction osteogenesis (vertical, horizontal); Class III: pedicled segmental osteotomies (alveolar ridge-split, sandwich osteotomy, sinus graft); Class IV: bone morphogenetic induction grafts; and Class V: non-vascularized bone grafts (block graft, guided bone regeneration with a particulate graft, and others).

According to this classification, RSP, being a pedicled segmental osteotomy, belongs to Class III. From the biologic rationale (BR) point of view, the technique of segmental (horizontal or vertical) osteotomies, like ridge-split or sandwich plasty, should always have preservation of vitality to mobilized pedicled flap in mind. This means that the mobilized hard-soft tissue pedicled flap is a vascular flap and, therefore, the interpositional grafting is “protected” and the post-operative bone loss or resorption is minimized. This periosteal (peripheral or centripetal) vascularization is a main source of vascularization in these cases. The other additional source of blood supply is an endosteal one (central or centrifugal) and comes from split or osteotomized trabecular vascular (bone marrow) bony surface(s) (See also Chapter 1 and Table 1.1). Next two chapters will demonstrate the ridge-split technique for maxillary and mandibular alveolar ridges.

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Mandibular Two-Stage Alveolar Ridge-Split Procedure

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Introduction

Due to variations in bone density, the RSP is often performed differently in maxilla and mandible. A segmental staged alveolar ridge-split procedure for the mandible is described in this chapter with Stage 1, corticotomy, and Stage 2, splitting with bone expansion and grafting. Modifications of the main technique, as well as advanced approaches for the RSP are presented in following chapters.

Stage 1: Corticotomy (preparatory stage)

This can be considered a preparatory stage. A superficial osteotomy of bone made only through its cortical (dense) layer is called corticotomy (cortical trough or cut through the cortex only). It is similar to a surgically assisted orthodontic tooth movement when, in some cases, corticotomies are made to facilitate tooth movement. The goal of corticotomy in the RSP is to weaken a dense mineralized rigid cortical layer of bone in the designated (key) areas. Seaming or creating a trough through the cortical bone prior to split is particularly important in the mandible, where bony cortex appears to be especially dense. Figure 18.1 illustrates the cross-section of the mandibular bone with the segment of bone that would be eventually split and moved laterally (plane of the split). Crestal and apical corticotomies (in addition to vertical ones) are where the cortex needs to be cut to allow future segment rotation or displacement (that usually happens at the separate stage). The buccal flap and periosteum are reflected and will be repositioned back (see an explanation later).

Attention to detail and atraumatic performance of this initial stage is important and determines the success of the final bone expansion. Corticotomy is done as a bony window (similar to a lateral sinus lift procedure) with usually four (occasionally, three) bony cuts shaped in a form of rectangle. Two parameters of the corticotomy should be discussed – height and length. Figure 18.2 illustrate the bony cuts that need to be completed at this initial preparatory Stage 1 of the ridge-split procedure done in the mandible (and occasionally, in the maxilla).

A corticotomy *height* between two horizontal cuts called crestal and apical is mainly determined by the implant fixture (its length), which can be placed immediately or in a delayed fashion. Generally, it is a 10–12 mm distance. Rarely, there is a need to extend the apical cut beyond 12 mm from the crestal. The reason is that in implant dentistry there is rarely a need for a fixture longer than 12 mm. There is also frequent widening of the alveolar ridge toward its base,

which removes the need to go too far to the base of the ridge because the alveolar width becomes sufficient. Another reason is anatomic limitations in the jaws, like the presence of the inferior alveolar nerve (IAN), mental foramen, or maxillary sinus. It is also important to remember that in atrophic edentulous mandibles (often, in the elderly population) the height of the bony window should not extend beyond 70% of the total bone height to prevent significant weakening of the mandible and even a mandible fracture.

A corticotomy *length* between two vertical bony cuts depends on the alveolar length of the edentulous area to be reconstructed. The RSP can be done for a single edentulous and collapsed ridge, a few adjacent edentulous spaces, an edentulous quadrant, or even a full edentulous arch (Figures 18.3 and 18.4). The shortest anterior–posterior (A-P) ridge length that is safe to reconstruct is about 7 mm. The procedure performed on a shorter than 7 mm ridge might be challenging and can compromise periodontal health of the adjacent teeth. It is always beneficial to attempt a papilla-preservation flap approach to keep the adjacent papillae and bone next to adjacent teeth roots intact during the RSP (more on the flap design below).

For the segmental RSP of a single edentulous area (one tooth missing, one implant planned), length–height corticotomy proportions can be remembered as a “7–8–9–10 rule” where a minimum of 7–8 mm of bone length space between vertical cuts and a minimum of 9–10 mm of bone height distance between horizontal ones are necessary for a single implant of average dimensions (fixture = 4 × 10) (Figure 18.2b).

Finally, the *width* of the split needs to be considered. An operator should proactively (prior to the surgical procedure) think about the expansion of bone he/she would like to achieve. The final width of the ridge after the RSP is also ultimately defined by the diameter of an implant fixture that is planned for the area. A standard 4–5 mm diameter dental implant requires 7–8 mm respectively of the eventual alveolar width. This takes into consideration at least 1.5 mm of bone that is expected to be present on both lingual and buccal sides of an implant for its good stability and, therefore, long-term success. Collapsed ridges that are diagnosed and treatment planned for the RSP often have a 3–5 mm width. In these cases, the goal would be to double the width of the existing ridge by the end of the procedure. Due to a small degree of possible long-term relapse (about 10%), the author recommends that a 2–3 mm overcorrection be considered by expanding thin ridges to about 10–12 mm. The 10–12 mm alveolar ridge is also a normal width of a dentate alveolar process in the majority of cases.

Ridge-Split Corticotomies

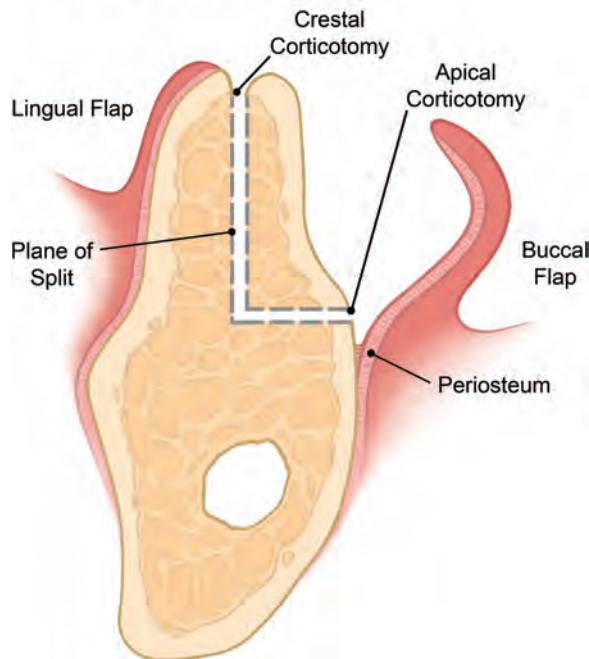


Figure 18.1 Schematic illustration of a cross-section of mandibular bone demonstrating a plane of split of buccal fragment of bone during the preparatory stage (Stage 1) of a ridge-split procedure; four bone cuts (corticotomies) are needed (two of which, the crestal and apical, are shown).

The surgery can be done under local anesthesia or IV sedation. A good oral hygiene should be reinforced prior to the surgery. Antibiotics are given pre-operatively as a loaded single dose one hour before the procedure (Amoxicillin 2 gm or Clindamycin 600 mg, or other antibiotics of choice). A Chlorhexidine 0.12% rinse is recommended 2 or 3 times a day for 3 days prior and 1 week following the surgery.

Surgical procedure

This stage starts with reflection of a buccal full-thickness (FT) mucoperiosteal flap (FTMPF) consisting of the crestal and two vertical releasing incisions. The crestal incision should be slightly off the center and more towards the lingual side. The vertical releasing incisions should start at 90 degrees from the adjacent teeth (mesial line angle) and diverge slightly towards the depth of vestibule. A papilla-preservation incision, when possible (7+ mm of edentulous length), is always beneficial. Attention to the position of the mental foramen when working in the premolar region is crucial to avoid post-operative neurosensory complications. The reflected flap should expose the buccal bone of a sufficient length and height. The soft tissue flap should always be 1–2 mm wider than the osteotomy window.

After the appropriate buccal bone exposure is achieved, peripheral corticotomies outlining a bony window are performed. The corticotomies can be performed with a thin fissure bur (such as a surgical 701 bur) or with a help of piezoelectric tips. As mentioned above, there are four corticotomies (bone cuts) that are routinely done: two horizontal and two vertical. Horizontal corticotomies are called crestal and apical. Crestal corticotomy is scored on the alveolar crest of the edentulous segment and apical is placed parallel to the crestal 10–12 mm away (apically positioned) on the buccal cortex. Two vertical corticotomies connect horizontal ones, forming

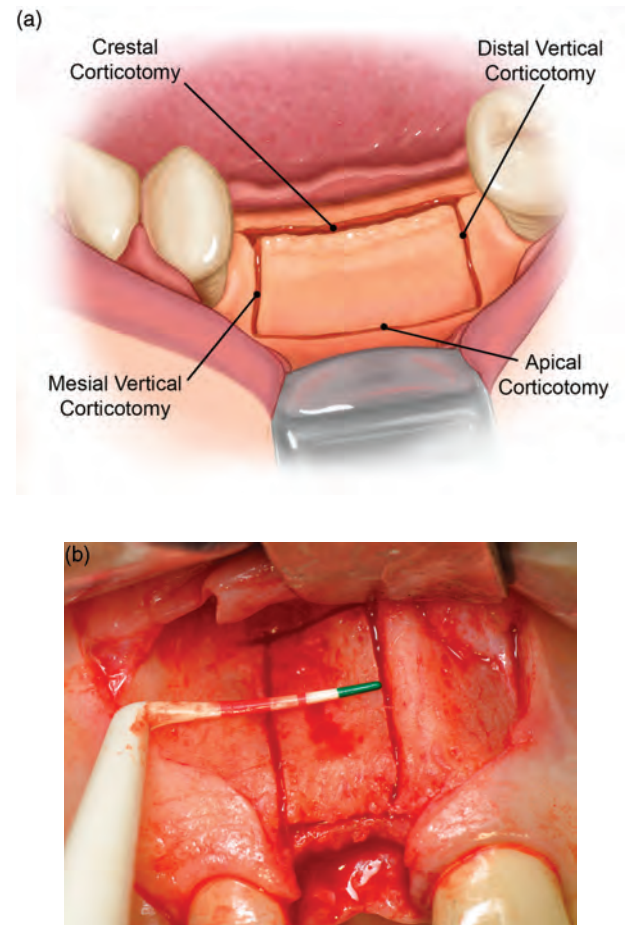


Figure 18.2 (a) Illustration of four corticotomies at the initial preparatory Stage 1 of the ridge-split procedure that is done in the mandible (occasionally, in the maxilla): crestal, apical, mesial vertical, and distal vertical. Size requirements: minimum of 7–8 mm of bone length space between vertical cuts and minimum of 9–10 mm of bone height distance between horizontal ones are necessary for a single implant of average dimensions. (b) Clinical photograph of four corticotomies at the initial preparatory stage 1 of the ridge-split procedure that is done in the mandible or maxilla. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

a bone window (“trapdoor”) that resembles a rectangle. Due to a slight divergence of two vertical corticotomies, in many cases the actual geometric shape of the bone window is reminiscent of a trapezoid (Figures 18.2a and 18.5).



Figure 18.3 Single edentulous area with a width-deficient alveolar ridge suitable for a segmental ridge-split procedure.

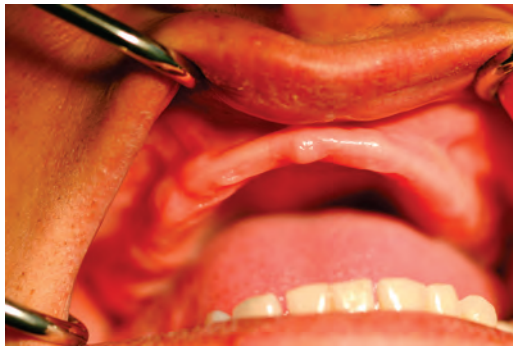


Figure 18.4 Full edentulous arch with a horizontal collapse that can also be suitable for a ridge-split procedure. Tolstunov 2013 [1]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.



Figure 18.5 Intraoperative photograph of two vertical corticotomies connecting two horizontal ones and forming a bone window (“trapdoor”) that resembles a rectangle at Stage 1 of the ridge-split procedure. Note the full-thickness (FT) buccal flap and bone cuts that are extended evenly into the medullary layer of bone all the way around. (Source: Tolstunov 2013 [1]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.)

The crestal corticotomy can be initiated with a 15 blade, or very sharp chisel, or a small figure bur (701), or a piezoelectric tip. Crestal corticotomy is crucial; it is the only area that will be “revisited” or reopened and used for the initiation of the split at the following surgical stage. It is recommended that the crestal corticotomy be positioned at mid-crest or slightly towards the lingual side to increase the thickness of the buccal plate that will become subfractured or greenstick fractured and moved laterally at Stage 2. If there is not enough thickness of the buccal plate, it can develop multiple fractures and will not be able to be repositioned laterally in one unit.

All four corticotomies have to be done as a continuous, interconnected, smooth, and uniform trough with a certain width and depth. The width of the trough is usually 1–1.5 mm and is narrower when corticotomy is performed with piezoelectric tips. The depth is determined by the thickness of the cortical layer (usually, within 1.5–2 mm). The corticotomies are extended through the cortical layer into the medullary layer of bone evenly (Figures 18.2a and 18.5). An operator, while performing this surgical stage, should run a perio probe along the trough and experience a feeling of “drop” into the spongy bone as a confirmation of even perforation of the cortical layer (a proper corticotomy depth) along the whole bony window. Bleeding is another visual confirmation of an exposure of the spongy bone. It is better if all four corticotomies are interconnected with slightly rounded corners, paying particular attention to two apical corners.

At this point, the preparatory stage is complete and the buccal flap is repositioned back and closed with 4-0 or 5-0 chromic gut sutures. The patient is dismissed and the next stage is scheduled in about 4 to 5 weeks. Antibiotics are optional in the post-operative period. Post-operative discomfort is usually minimal and the patient may require only non-steroidal anti-inflammatory drugs (NSAIDs), such as Ibuprofen. An icepack and pressure dressing on the cheek are recommended on the day of surgery. The patient is usually seen 10 days post-operatively and again for Stage 2 of the RSP in 4 to 5 weeks.

Common question

Some novice surgeons may ask why the flap was closed and surgery was not progressed further to the actual split. In some advanced cases, this is actually possible to do. The main requirement for the split to happen at this stage is preservation of the periosteal attachment to the buccal surface (Figures 18.1, 18.2b, and 18.5). In the majority of cases, the author recommends the two-stage approach for the mandible. If the buccal surface of bone is fully uncovered and a split was to be performed at this stage, the buccal fragment of the denuded and devascularized bone could have been fully fractured off from its base and the procedure would have been abandoned. That is why repositioning of the buccal mucosal-periosteal flap back after the bone cuts are done is important in order to re-establish the blood supply to the buccal segment of bone. At the next stage, the actual split will occur with the buccal soft tissue flap attached to the bone.

This is entirely opposite to block grafting, where a monocortical block of buccal bone is purposefully removed from one (donor) site and attached to the other (recipient) site. In the RSP, the donor and recipient sites are one. Read more about the differences between the ridge-split and block graft in the Chapter 21.

Stage 2: Splitting, expansion, and grafting

The second stage of the RSP is usually done 4 to 5 weeks after Stage 1. If the first stage of the mandibular RSP can be considered as preparatory (or preliminary), the second is a main or principal stage. At this stage, the osteomobilization of the osteotomized buccal bone is performed through the actual split or division (greenstick fracture) along the medullary layer of bone between the cortical plates, with a rotation or movement of one (buccal) cortical plate away from the other (lingual) plate. If the buccal bone is *evenly* weakened by the continuous trough (bony window) at Stage 1, the split can progress without complications. It is often a matter of careful and progressive lateral force with a help of special osteotomes and spreaders to create a greenstick fracture of the buccal plate and then widen the split.

It is recommended to use antibiotics for Stage 2 of the RSP, starting with a loaded dose of Amoxicillin (2 gm) or Clindamycin (600 mg) one hour prior to the surgery, followed by 500 mg of Amoxicillin or 300 mg of Clindamycin three times a day for about 5 days. A Chlorhexidine (0.12%) rinse is administered for 3 days prior and 1 week following the surgery. This stage also can also be done under local anesthesia or IV sedation. IV sedation can be beneficial at this stage due to some discomfort from the use of mallet and chisel-osteotomes.

Surgical procedure

This stage is done with a semi-open or limited FTF. After administering local anesthesia, the crestal incision is done in a similar

fashion to Stage 1 but the vertical incisions are either not done or are very limited (small) to prevent an accidental FT flap reflection. The goal is to open enough just to visualize the crestal osteotomy done at the previous stage. It is important at this stage to preserve the buccal periosteal vascularization within the flap [2–4]. This buccal flap, which was stripped from the bone 4 weeks earlier, is now lightly connected to the bone and has to stay that way to assure its vascularization. An overzealous reflection of the FT flap at Stage 2 by a novice or inexperienced surgeon will lead to an inadvertent stripping of the buccal flap off the bone and accidental exposure of the bone, thus losing its soft tissue coverage and, therefore, its source of blood supply. The surgeon should keep the buccal flap in its place but free to elevate the lingual flap for better visualization. The bone split that follows should be initiated at the center of the crest and through the crestal bone cut or corticotomy groove made at the previous stage.

An alternative approach is to use a buccal split- or partial-thickness flap (PTF) [5–8], leaving the periosteum attached to the buccal surface of the alveolar ridge and reflecting only the supra-periosteal soft tissue (mucosal and submucosal layers). An operator ultimately determines the choice of a flap. Both flap techniques (limited open FT or PT) are intended to preserve necessary vascularization to the bone at the time of the split and graft.

N. Elian et al, [9] advocated a *combination* flap that consists of an “FTF at the crest of the ridge, which is then transitioned into a split-thickness flap along the buccal plate”. T. Kang et al. [10] also advocated the FT flap with no vertical bone incisions. According to both authors, an FTF at the crest of the ridge *only* helps the visualization of the split and expansion if it is done at the same stage without an inadvertent risk of buccal cortical bone fracture with no soft tissue attachment and if a completely open FTF is developed.

A surgeon should identify the crestal corticotomy trough made at the previous stage. The best way to do this is by using a 15 (15C) scalpel blade that an operator can drop into the crestal groove. A slight pressure by the scalpel blade makes an indentation in the cancellous bone and helps the transition to the next set of instruments – osteotomes. Figure 18.6 demonstrates the limited FTF and the developing split at this surgical stage.

There are many sets of progressive chisel osteotomes specifically designed for the ridge-split procedure. Figure 18.7 demonstrates an example of instruments, including osteotomes, that can be used for the RSP at this stage. This includes a scalpel, ridge splitting/expanding chisels (3 and 5 mm), a Tatum “D” spreader protecting the lingual plate and expanding the buccal, periostomes, and other instruments.

Split

Tapping the spatula or chisel osteotomes into the crestal cut initiates the split. A continuing gentle tapping with larger (wider) progressive sharp chisels (osteotomes) accompanied by a controlled lateral force will first create a greenstick fracture of the buccal segment of bone. This is followed by a gradual widening of the split (Figure 18.6) with a soft tissue flap still attached to the buccal bone (the muco-osteoperiosteal flap by Jensen). The buccal bony fragment is subfractured and pushed laterally in one unit with the attached soft tissue, preserving the periosteal blood supply to the buccal bone.

In the previous chapter, two modifications of the buccal osteoperiosteal flap – “Book” and “Island” – were presented and described in detail [11,12]. An I-flap (“Island” osteoperiosteal flap) [12,13] is a modification of a “Book” flap when a complete fracture of the buccal plate from the top to the bottom (the whole buccal bone fragment) is made, forming a free-floating osteoperiosteal flap (see Figures 11.1

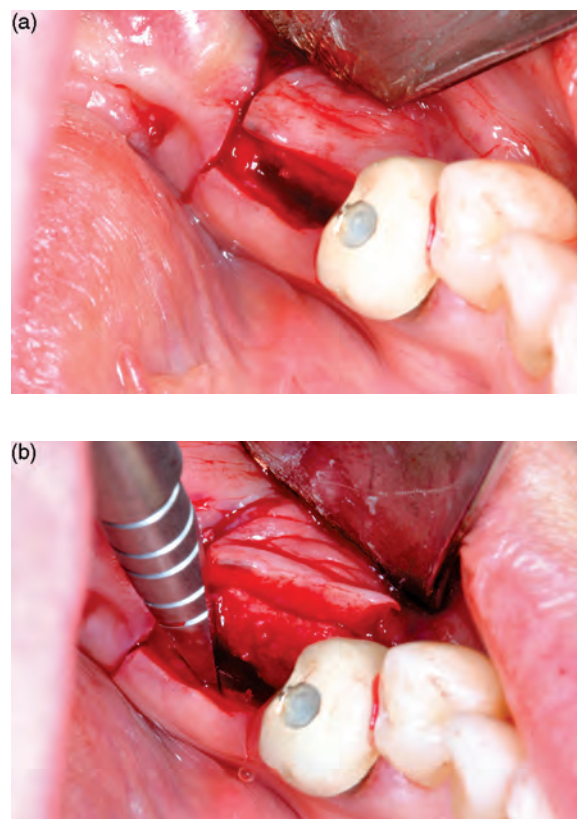


Figure 18.6 Stage 2 of the mandibular ridge-split procedure through the limited FT flap. (a) The crestal osteotomy (corticotomy) is being exposed for initiation of the split. (b) The buccal fragment of bone is being subfractured and then slowly displaced (repositioned) laterally with a sharp chisel osteotome.



Figure 18.7 View of the author's ridge-split surgical tray with a variety of instruments that can be used for the RSP at this stage. Source: Tolstunov 2013 [1]. Reproduced with permission of Douglas P Sinn, DDS. Editor in Chief, SROMS.

and 11.2 in Chapter 11). According to O. Jensen, “Once the I-flap is freed, it can be moved in any direction . . . Movement of 3 mm is easily accomplished”. Thus, a freed muco-osteoperiosteal flap (MOPF) can be positioned laterally and slightly crestally, correcting not only the horizontal bone deficiency but also potentially some degree of a vertical bone collapse. The preferred thickness of the buccal cortical plate in an I-flap is at least 2 mm [14]. The facial plate with a thickness less than 2 mm appears to have a higher risk of subsequent resorption in any bone grafting or implant procedure. N. Casap et al. [13] in 2011 analyzed the histogram of the rabbit tibia (eight rabbits were used) at 4 to 6 weeks after I-flap mobilization (as a free floating osteoperiosteal flap) and interpositional grafting with xenograft. They demonstrated successful healing by both appositional modeling and creeping substitution remodeling (“interpositional osteogenesis”), and a stable volumetric augmentation. An “Island” technique, according to the authors, can increase both the horizontal and vertical dimensions of the alveolar ridge.

O. Jensen et al. [15] analyzed marginal bone stability using three different flap approaches for the alveolar split expansion with immediate implant placement (1-year clinical study on 40 patients with 65 split procedures). In the alveolar split procedure, the authors demonstrated the significance of periosteal vascularization for the osseous pedicle flap. The medullary (trabecular) source of blood supply played a less important role, healing relatively to the less important medullary blood supply. The authors concluded that: (1) the implant osseointegration success rate of 92.5% was for the osteoperiosteal (“Book”) flaps, 93.3% for the PT flaps, and 94.4% for the FT flaps; (2) all splits had an increased alveolar width; and (3) FT flaps increase bone resorption and thus should not be routinely recommended at the time of the split.

Grafting

After split and expansion are accomplished, the following step is bone grafting using a bone graft substitute of your choice. Selection of a grafting material is based on the preference of the operator and varies from an autogenous to allogeneic to xenogeneic to alloplastic (synthetic) material. It seems logical to choose a grafting material that can better preserve an open state of a split during the healing period. The author often uses either human allograft (cortico-cancellous) or bovine xenograft, or both (composite graft). These grafts provide osteoconductive qualities as well having a “body” of the interpositional graft needed to maintain the dimension (volume) of the widened ridge in the initial stage of healing. The following are examples of the grafts that can be utilized for this purpose: Puros®, Allo-Oss®, Bio-Oss®, and Nu-Oss® (a more detailed description of these grafts was given in the previous chapter). The packing of bone material into the alveolar split has to be done in a similar fashion as socket bone grafting from the bottom up with a light compression until the entire gap is filled (Figure 18.8a). To isolate the graft from the oral environment, a membrane is used in a similar manner to that done for a socket grafting. A GTR membrane is advisable. If a GTR membrane is chosen, Teflon® PTFE membrane can be used as an example. The resorbable membrane should be operator-friendly (pliable) and should be gently tacked underneath the reflected lingual flap and very lightly to the buccal flap (Figure 18.8b). Placement of a double-layer membrane (Collage membrane underneath with GTR on top) is commonly practiced for increased protection of the grafting material. The thicker GTR membrane on top will not absorb oral fluids easily into the wound and provides a good barrier. Then 4-0 or 5-0 Chromic gut or silk sutures in a figure-8,

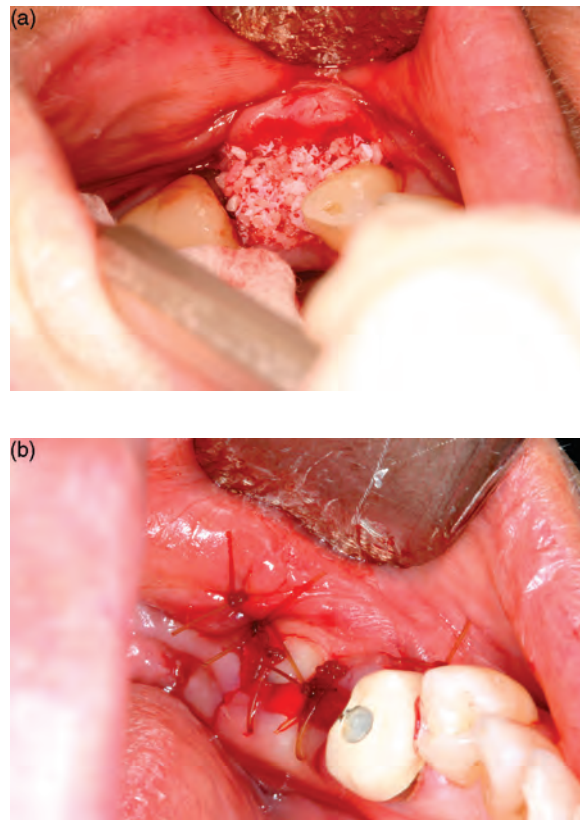


Figure 18.8 Intraoperative view of the bone grafting step of the ridge-split procedure (a) when a particulate graft is packed into the gap (split) and (b) with a protective membrane and sutures being placed on top for healing by secondary intention (similar to a ridge preservation of an extraction socket).

interrupted, or “X” manner are used after the membrane placement to secure and approximate both buccal and lingual flaps. If vertical incisions are made, sutures are placed there also. The crestal wound can be left to heal by secondary intention if primary closure is not feasible. It is not recommended to forcefully mobilize the flap and pull it occlusally to achieve primary closure. A biologic adhesive (glue), like PeriAcryl® (GluStitch Inc., Delta, BC, Canada), can be used for extra wound protection. On occasion and prior to grafting, a self-tapping mini-screw(s) (10–12 mm in length and 1.0–1.5 mm in diameter) can be used to stabilize a displaced buccal plate (Figure 18.9). Figure 18.10 demonstrates the quality of bone that can be achieved after the ridge-split described and visualized at the implant stage later.

At this point, the surgery is complete. No radiographs are necessary. A CBCT scan can be taken (optional) at about 4–6 months after Stage 2 to appreciate the change in the morphology of the widened alveolar ridge. If a non-resorbable membrane was used, it is expected to be removed at any time in the post-operative healing period, usually 3–4 weeks following the surgery.

Post-operative instructions include continuation of antibiotics for 5-to-7 days, such as Amoxicillin 500 mg 3 times a day, pain management that may require only NSAIDs, such as Ibuprofen, and occasionally, narcotic analgesics, such as Vicodin (hydrocodone). A Chlorhexidine 0.12% rinse is recommended 2–3 times a day 1 week following the surgery. The patient should stay on a soft diet and maintain good oral hygiene.



Figure 18.9 View of a self-tapping mini-screw that can be used to stabilize cortical plates in some cases prior to grafting. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

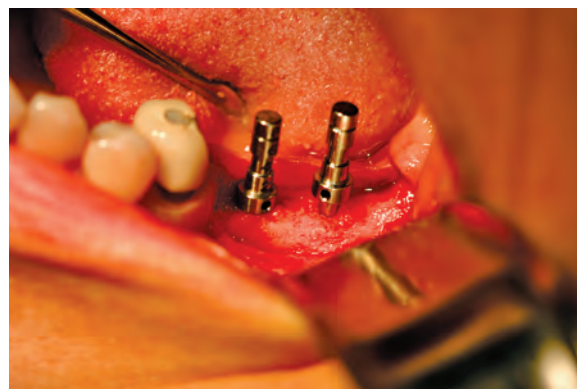


Figure 18.10 View of the alveolar ridge at the implant stage, demonstrating the quality of bone that can be achieved after the ridge-split procedure.

Case report of a mandibular staged ridge-split procedure (Figures 18.11 to 18.15)

A 60-year-old healthy female presented to the oral surgery office with a retained non-restorable lower left first premolar root. A 3-mm narrow mandibular alveolar ridge was measured clinically in the second premolar–first molar region. The RSP treatment was suggested and accepted by the patient. It included the removal of the retained first premolar root, exposure of the buccal cortex, and a staged ridge-split procedure in the premolar–molar region. During the first surgery (Stage 1), the premolar root was removed atraumatically and the corticotomies were placed as described above from the canine to the second molar, forming a bony window (Figure 18.11). The flap was then repositioned and sutured. Stage 2 of the RSP was done 4 weeks later.

At Stage 2 with a limited flap, the crestal osteotomy was identified and the sequential chisel osteotomes were used in a progressive manner by tapping into the depth of the split. The buccal plate was carefully subfractured and the fully mobilized “island” muco-osteoperiosteal flap was repositioned laterally (Figure 18.12). In this case, Puros cortical and cancellous allograft 1:1 was utilized as the graft material of choice (Puros®, Zimmer Dental Inc., Carlsbad, CA). Teflon non-resorbable GTR membrane (Kendall Curity, Tyco Healthcare, Mansfield, MA) was tucked a few mm under the reflected FT lingual flap. The membrane was then wrapped around and tucked under the limited buccal flap. The flaps then were closed with 4-0 chromic gut sutures (Figure 18.13). Phase II of the implant placement was done 6 months later: 3 Replace Select implants (Nobel BioCare, Yorba Linda, CA) (two premolar 4.3 mm x 13 and one molar 5.0 mm x 13) were placed in the position of the second and first molars and the second premolar (Figure 18.14). All implants were allowed to osseointegrate. They were restored 6 months later with three separate PFM implant-supported crowns to a fully functional occlusion (Figure 18.15).

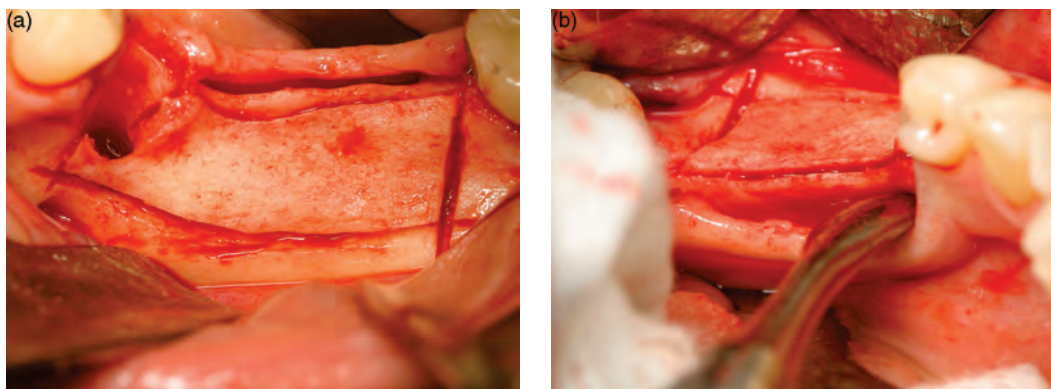


Figure 18.11 Intraoperative photograph of a case report demonstrating, at Stage 1 of the ridge-split procedure: (a) a lateral (side) view of thin posterior mandibular ridge with typical mandibular corticotomies; a non-restorable premolar was removed at the same time; (b) an occlusal (top) view of thin posterior mandibular ridge and typical mandibular corticotomies; a crestal corticotomy and buccal cortical plate are clearly visible. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

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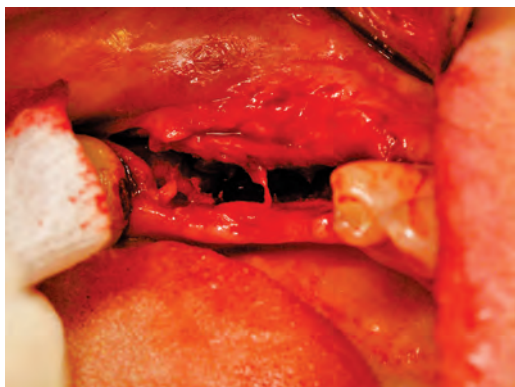


Figure 18.12 Intraoperative photograph of a case report showing the subfracture and full lateral repositioning of the buccal fragment of bone as an "Island" muco-osteoperiosteal flap. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)



Figure 18.13 Intraoperative photograph of a case report showing interpositional grafting after the split and displacement of the buccal bone flap (Puros® grafting material, Teflon membrane, sutures). (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)



Figure 18.14 View of the implant Stage 2 at 6 months after the surgery. (Source: Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

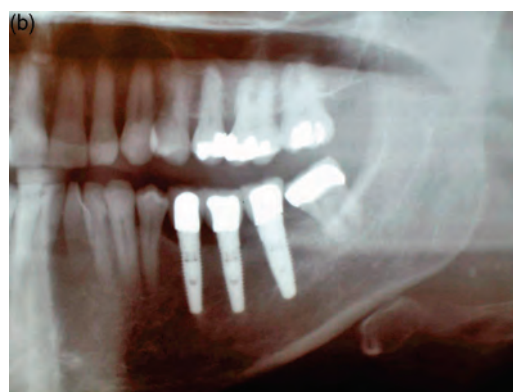


Figure 18.15 (a) Intraoral photograph and (b) a section of the panoramic radiograph of the restorative stage demonstrating three porcelain-fused-to-metal (PFM) crowns at the completion of the case. (Source for (a) and (b): Dr. Bruce Hicke. Reproduced with permission from B. Hicke.)

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Maxillary Single-Stage Alveolar Ridge-Split Procedure

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Introduction

Although the maxillary ridge-split procedure can be performed identically to the mandibular staged approach discussed in the previous chapter, due to elasticity or “softness” of maxillary bone (types 3 and 4 bone) [1] in many cases it is done as a single stage. If the procedure is contemplated using a single-stage approach, the following technique is recommended.

The ridge selection criteria are the same. In the maxillary ridge-split, there is *usually* no need for four interconnected corticotomies performed at the preparatory stage. In fact, the preparatory stage is often not needed at all. Only a full crestal corticotomy with limited vertical cuts is routinely performed through a limited FT or split-thickness flap followed by an actual split at the same procedure (single-stage approach) (Figure 19.1).

Initially, a crestal incision in the edentulous area is made that extends either as an envelope incision to two adjacent teeth or made with two small releasing incisions (limited releasing, approximately 5–6 mm length) extending into the vestibule (preferred). A *limited* open (sometimes called closed) FTF is often carried out. The buccal flap is reflected just enough to visualize the top of the alveolar crest plus 2–3 mm of the buccal bone. Positioning of the crestal incision slightly more to the palatal side helps to visualize the alveolar crest better, which is important at this stage.

The intact buccal flap with its periosteum carries the blood supply to the flap and thus should be left attached in its bulk to the bone (preserved). An alternative approach, as described in the previous chapter, is to use a partial thickness buccal flap [2], leaving the periosteum attached to the buccal surface of the alveolar ridge and reflecting only the supraperiosteal soft tissue or a combination flap when the full-thickness flap transitions into split-thickness. The choice of flap is based on the operator’s preference.

The next step is to make a crestal corticotomy (trough or bone cut) similar to the one done at Stage 2 in the mandibular RSP. The difference is that it is done now (single-stage in the maxilla) and that it will *not* be supplemented by other corticotomies creating a typical box that would require a wide-open flap. Instead of a box of four corticotomies, it is more like a “staple” that has one full corticotomy (crestal) and two small vertical limited bone trough extensions within the limitations of the partially reflected buccal flap (Figure 19.1). This can be done with a piezo instrumentation or a small round or 701 bur. An operator does *not* want to open the buccal flap wide (it is important to protect vascularization to the buccal bony fragment) but at the same time does want to initiate the

split. Crestal osteotomy (corticotomy) helps to create the bone cut or trough where this split can be initiated. Supplementing two limited vertical bony corticotomy extensions helps to limit the forthcoming fracture propagation towards a vertical component and not a horizontal one. In other words, limited (small) vertical bony cuts help to direct the forming greenstick fracture upwards (in the maxillary alveolar crest) and not A-P/width-wise to adjacent teeth.

A “blind” (limited open) approach of a single-stage technique can be challenging for a novice operator. O. Jensen [3] stated, “The surgeon must have a good conceptualization of the alveolar anatomy to not miss the midpoint of the alveolus as the osteotome is advanced in the splitting procedure, which must extend to the vestibular depth.” It is important to remember that the maxillary bone is softer, and a surgeon has to be careful, when entering the medullary bone layer and progressing into the depth of about 10 mm, to preserve intact cortical plates on both sides of the developing split.

The crestal corticotomy can be initiated with a 15 blade, or very sharp chisel, or a small figure bur (701), or a piezoelectric tip. The best way to start the split is to use a 15 (or 15C) surgical blade to make a small initial indentation in the center of the alveolar ridge, trying to get access to the medullary bone [4]. Slight pressure by the scalpel blade into the cancellous bone helps to transition to the next set of instruments – osteotomes. Chisel osteotomes are carefully tapped into the depth of bone to widen the split by progressive displacement of the buccal plate laterally.

During the procedure, it is a good idea to follow a surgical hint to protect the fragile buccal (labial) fragment of bone, especially in small edentulous areas (6–8 mm, lateral incisor region, etc.). It is helpful to stay parallel and close to the palatal cortical plate. This will direct the split of the maxillary alveolar ridge superiorly and prevent its buccal tipping and buccal plate thinning and its unfavorable fracture(s) formation.

As the buccal plate is forced laterally, the fracture line will propagate with less clear borders comparatively to the mandibular two-stage procedure, where the bony window was demarcated at the preparatory Stage 1. As mentioned above, small vertical (half) corticotomies on each side of the crestal cut help to guide fracture propagation in a more vertical direction rather than in all directions. This can also help to preserve periodontal health of adjacent teeth (protect the roots, if they happen to be close) by creating a controlled greenstick fracture. In small edentulous areas, an operator might need to use a piezoelectric tip or a small saw. To increase

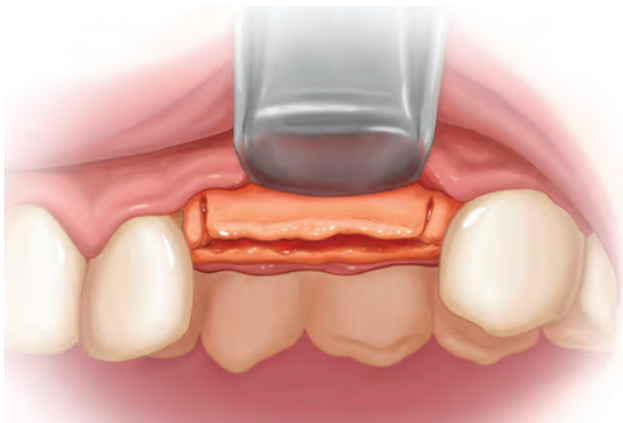


Figure 19.1 Illustration of a maxillary single-stage ridge-split procedure showing a partial full-thickness (FT) flap with a crestal and two limited vertical corticotomies (osteotomies).

success of the RSP, O. Jensen [5] suggested choosing longer edentulous areas, thicker bone ridges (≥ 2 mm), and modest flap movement (ridge expansion) to prevent flap tension and relapse.

After a split (division) is initiated, the slow and careful expansion is done in a similar manner to the mandibular split, forming a gap (opening) (Figure 19.2). A persistent tapping and light lateral force of the mallet and consecutive chisel flat osteotomes progress until the buccal fragment's fracture occurs. This buccal combined flap consists of the buccal bone fragment, periosteum, and mucosa, called the buccal muco-osteoperiosteal flap (MOPF), which has its own peripheral (muscular periosteal) vascularization. Similarly to the mandibular ridge-split, the flap can be called a "Book" flap, if it is still attached to the bone on the hinge, or an "I" (Island) flap, if it is fully detached and freely floating, according to O. Jensen [5,6] (see Chapter 11). The specifics of the flap design depend on the amount of expansion needed and the operator's experience. The goal is to

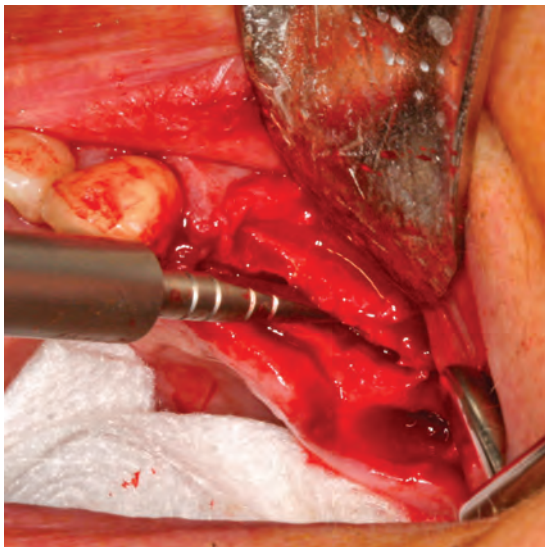


Figure 19.2 Intraoperative photograph demonstrating slow and careful expansion of the maxillary ridge by lateral displacement of the buccal bone segment forming a gap (opening). (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)

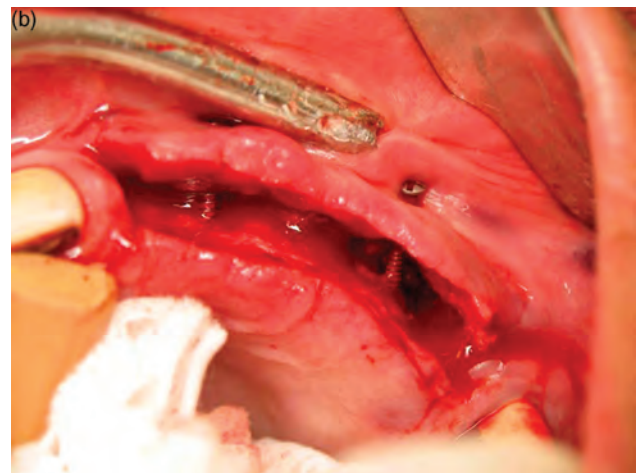


Figure 19.3 (a) Intraoperative view of the displaced maxillary bone that required fixation pins (screws) for its stabilization (done in some cases): single tooth defect and single fixation screw. (b) Intraoperative view of the displaced maxillary bone that required fixation screws for its stabilization: large edentulous area and several fixation screws. Source: Tolstunov 2013 [7]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.

drive the collapsed buccal plate facially (laterally or buccally) and away from the palatal plate without compromising its integrity.

It is important to always allow time for the bone expansion/manipulation, especially in the maxilla. During the ridge expansion, bone has to "breathe" and expand of its own accord after each session of tapping and lateral displacement. Dual-finger guidance (holding the expanding alveolar crest on both sides with a thumb and second finger) helps to "mold" and properly position the buccal fragment of bone.

In some cases of a longer alveolar ridge that undergoes a maxillary ridge-split procedure, fixation pins or ligature wire can be used to hold the mobilized buccal portion of bone to the non-mobile palatal portion of bone (Figure 19.3).

An internal gap can be grafted in a similar fashion as a socket of the tooth after extraction (ridge preservation). Unless a primary closure can be easily achieved, open management of the wound with a secondary closure is recommended in the majority of cases (Figure 19.4).

If the patient is missing several teeth or is fully edentulous, it is important to remember about the temporary restorative option

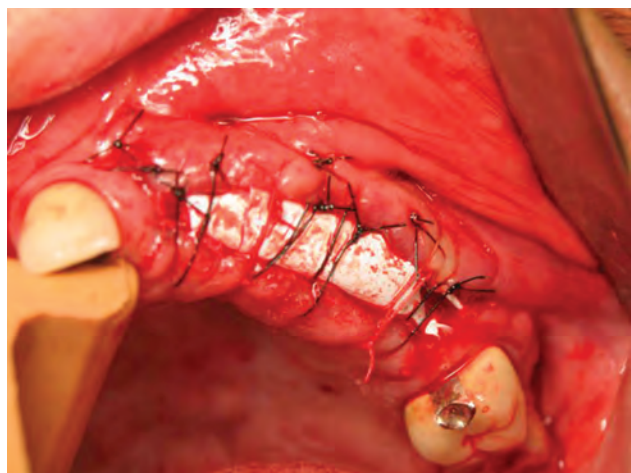


Figure 19.4 Interpositional bone grafting at the end of the ridge-split procedure similar to ridge preservation of the extraction socket (grafting, membranes, sutures with secondary closure). Source: Tolstunov 2013 [7]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.

(partial or full denture) that can be placed at the end of the surgery. The author often recommends avoiding an immediate denture placement for 4–5 days after the surgery during the time of tissue swelling, if possible. The denture placed immediately or a few days later had to be relined prior to the surgery based on the wax-up of a diagnostic model allowing a planned expansion of the buccal ridge (based on the pre-operative surgical simulation). The denture that has a narrow buccal flange will compress the expanded ridge post-operatively and compromise the results. A good surgical-restorative team is mandatory in the alveolar bone augmentation stage as much as at the subsequent implant treatment stage.

At the end of the surgery, the patient is usually instructed to complete a 5–7 day course of antibiotic therapy and Chlorhexidine intraoral rinses. Four-to-six months are allowed before an implant treatment. The described surgical technique can be successfully used for anterior or posterior maxilla, or a full maxillary arch. An immediate implant insertion at the time of the split can also be done in experienced hands.

Case report of a maxillary single-stage ridge-split procedure that was done simultaneously with an implant insertion (Figures 19.5 to 19.8)

An 82-year-old woman with a fractured upper right canine and severe alveolar ridge width deficiency in the upper right posterior quadrant presented for an implant evaluation. The patient's medical history was unremarkable. The patient's clinical and radiographic examination was consistent with missing teeth (molars and premolars) in the upper right alveolar quadrant and fractured root of an upper right canine that had a two-unit cantilevered bridge extending posteriorly (Figure 19.5). The patient had an extreme horizontal bone loss in the maxillary right premolar region and also mandibular anterior teeth with a partial lower denture extending to the first molar region in a Class I occlusion with maxillary teeth. The patient planned extended travel soon and asked, if possible, to place implants in the edentulous maxillary region at the same time as ridge augmentation.

The following plan was proposed and accepted by the patient: sectioning of the PFM bridge between the lateral incisor and the canine, atraumatic extraction of the fractured upper right canine, a ridge-split procedure in the premolar–molar region of an upper right quadrant (URQ), and possible simultaneous two-implant placement in the area. The patient consented to an intraoperative decision regarding an immediate implant placement, if possible, in addition to the RSP. The canine tooth was first removed atraumatically. A direct visualization of the edentulous ridge intraoperatively demonstrated a thin alveolar ridge of about 2.5 mm that, realistically, consisted of two interconnected cortical plates without any presence of the trabecular layer of bone in between. A careful division of two cortical plates was accomplished with only a 15 scalpel blade and thin osteotome (Figure 19.6a). A digital sense (two-finger control) was important to prevent the buccal plate from fracture and accomplish a controlled split. Two implant osteotomies engaging the apical (basal) bone were drilled atraumatically, paying special attention to protection of the fragile and thin buccal plate. Two Biomet 3i 4 mm internal hex “Certain” implants (Biomet 3i, Palm Beach Gardens, FL) were placed with a primary stability of 20 N cm between the two thin cortical plates (Figures 19.6b and c). The gap between both implants and the socket of the removed canine tooth were filled with cancellous granules of Bio-Oss xenograft (300–500 particle size) (Figure 19.6d). A layer of Colla-Tape membrane was placed on top of the graft and the wound was closed with 4-0 chromic gut sutures (primary closure was achieved in this case) (Figure 19.6e). Implants were allowed to heal for an extended period of 9 months. The surgical Stage 2 was done with placement of two healing abutments into well-osseointegrated implants (Figure 19.7). The restorative stage was completed 2 months later and consisted of the splinted PFM implant-supported bridge connecting both implants and extending as a small cantilever to the canine region (Figure 19.8a). The patient was very satisfied with the final restoration: its function, esthetics, and comfort (Figure 19.8b). This case demonstrates an advance ridge width collapse. An immediate implant placement in these cases is not recommended routinely, especially for a novice surgeon.



Figure 19.5 Case report of the maxillary ridge-split procedure, showing missing teeth (molars and premolars) in the upper right alveolar quadrant and the fractured root of an upper right canine that had a two-unit cantilevered bridge extending posteriorly where severe bone resorption was present. Source: Tolstunov 2013 [7]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.

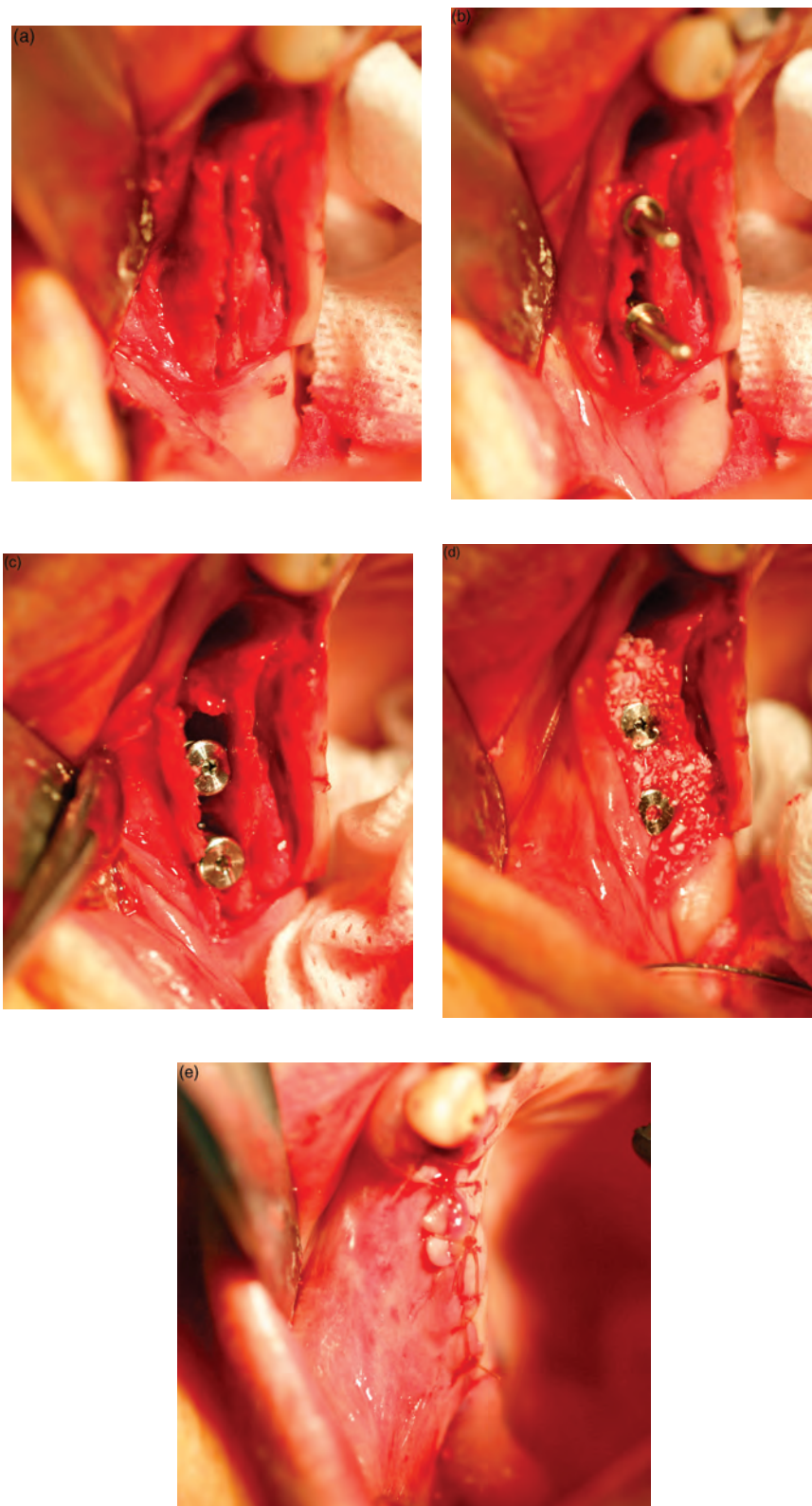


Figure 19.6 (a) Intraoperative photographs of 2.5 mm width ridge, demonstrating careful division (separation) of two cortical plates in the posterior maxilla, followed by (b) careful preparation of two osteotomies for implant placement in-between separated cortical plates, engaging the periapical bone beyond the split. (c) Two implants are positioned inside the split ridge according to the prosthetic and occlusal considerations, (d) Particulate bone grafting material (Bio-Oss, in this case) was used to fill all the gaps in between the implants and cortical plates. (e) After placement of the protective collagen membrane, the primary closure of the wound was achieved. (Source: Tolstunov 2013 and 2014 [7,8]. Reproduced with permission of Douglas P Sinn, DDS, Editor in Chief, SROMS.)

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Figure 19.7 View of the implant Stage 2 that was done nine months later. Source: Tolstunov 2013 [7]. Reproduced with permission of Douglas P Sinn, DDS. Editor in Chief, SROMS.



Figure 19.8 (a) Panoramic radiograph and (b) intraoral photograph of completion of the restorative stage implant-supported bridge connecting both implants and extending as a small cantilever to the canine region. Source: Tolstunov 2013 [7]. Reproduced with permission of Douglas P Sinn, DDS. Editor in Chief, SROMS.

Case report of a maxillary staged ridge-split procedure that was done simultaneously with a sinus lift procedure (Figures 19.9 to 19.13)

A 50-year-old man with a previous history of implant treatment (maxillary central incisor) in the anterior maxilla presented for an evaluation of the edentulous region in the maxillary ridge on the left side. A pre-operative evaluation demonstrated a missing lateral incisor, canine, and two premolars in the upper left quadrant (ULQ), a thin edentulous alveolar ridge with a width of 4 mm, and a large pneumatized left maxillary sinus extending to the first premolar location. The surgical plan included a staged maxillary ridge-split procedure with a simultaneous lateral sinus lift. A ridge-widening procedure was necessary to restore the deficient width of the collapsed alveolar ridge for the subsequent two implants in the premolar region. A sinus lift/bone graft was necessary to restore the deficient height of the edentulous region in the premolar region.

Stage 1 surgery consisted of a typical trapezoidal corticotomy ("mandibular style") and, at the same time, a separate bone window in the premolar region about 5 mm above the alveolar crest was made for the subantral augmentation (Figure 19.9). A sinus lift/bone graft with Puros® allograft was done in a traditional manner. The flap was repositioned and sutures 4-0 (4-0 chromic gut) were placed with no tension. Stage 2 of the RSP was performed 5 weeks later in a closed (limited) FT flap manner. In addition to a crestal papilla-sparing incision, two vertical realizing incisions of the buccal flap were done to prevent tearing of the soft tissue during the mobilization and lateral repositioning of the hard-soft tissue buccal flap (Figure 19.10). Puros® allograft was used to fill the gap with a Teflon® non-resorbable GTR membrane. The flap was mobilized back and sutures were placed. Healing by secondary intention was allowed (Figure 19.11). The implant stage was done 6 months later with a placement of two Nobel BioCare 5-mm implants in the first and second premolar positions (Figure 19.12). The restorative stage was done 4 months later with the placement of two porcelain-fused-to-metal (PFM) crowns (with a second premolar crown that had a small distal cantilever) (Figure 19.13). This case demonstrates a combination procedure (RSP and sinus lift). It was done in a staged fashion and both the bone height (through the sinus lift) and the bone width (through the ridge-split) were achieved. A delayed implant placement was done. Although three surgical procedures were required in this case, this staged approach tends to have the highest success and is recommended by the author.

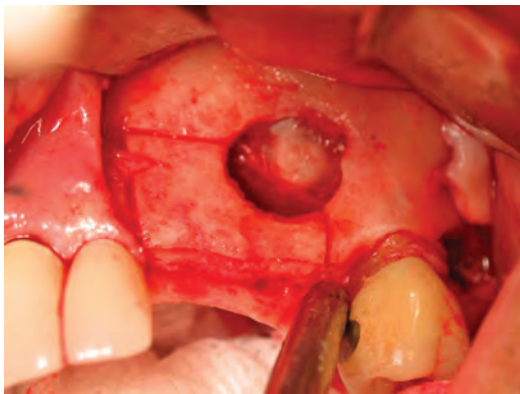


Figure 19.9 Intraoperative photographs demonstrating Stage 1 ridge-split surgery that consisted of a typical trapezoidal corticotomy with a full-thickness buccal flap; simultaneously, a separate bone window in the premolar region above the alveolar crest was made for the subantral augmentation due to a vertical bone deficiency in the premolar region that was also present. (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)



Figure 19.10 Intraoperative photograph showing displacement of the buccal segment of bone (Stage 2 of the ridge-split procedure) forming an "internal" gap for the subsequent interpositional bone grafting. (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)



Figure 19.11 Intraoral view of the healed ridge. Healing by secondary intention led to a gain of soft tissue and preservation of the attached buccal mucosa and vestibule. (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)

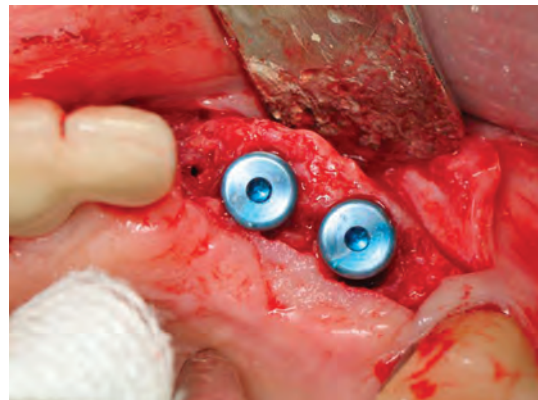


Figure 19.12 Intraoral view of the implants placed into the healed bone 6 months later. (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)

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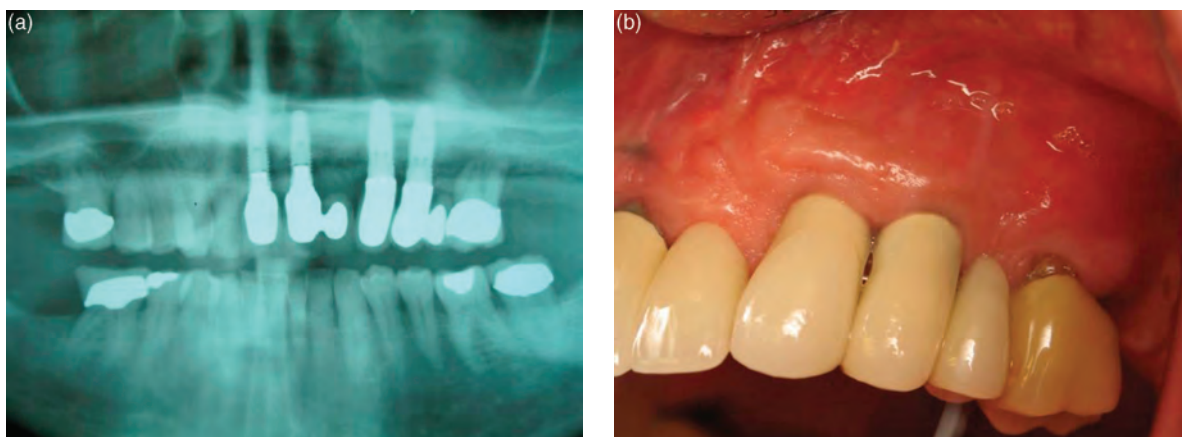


Figure 19.13 (a) Panoramic radiograph and (b) intraoral photograph showing the completion of the restorative stage with two separate premolar crowns connected as a bridge. (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)

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Advanced Ridge-Split Techniques for an Experienced Practitioner

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Introduction

The basic (classic) technique of a segmental edentulous ridge expansion that was discussed in the previous chapters (Chapters 18 and 19) includes a two-stage mandibular and a single-stage maxillary ridge-split procedure (RSP). After completion of horizontal ridge widening, an implant treatment is followed as a second (for maxilla) or third (for mandible) surgical procedure. This staged surgical treatment that, in some cases, includes three procedures before the restorative implant stage, although more predictable, is obviously prolonged and might take a year to complete. A practitioner might also encounter a patient's compliance issues related to multiple procedures, associated swelling, many courses of medications (antibiotics and pain medicine), etc.

In Chapter 22, an alternative technique of alveolar crest spreading system will also be presented when ridge widening and implants are placed at the same time. The Crest-Control system with special instrumentation (spreaders) will be demonstrated exhibiting simultaneous ridge widening, grafting and implantation.

A variety of similar techniques exists where special spreaders or ridge expanders are utilized to either create the bone gap for implants to be inserted after conventional implant osteotomies or actually create the tapered bony channel in the process of ridge widening that can accept an implant with no additional osteotomy needed. These "simultaneous" techniques, in the author's opinion, require more practice and experience and, therefore, can be called advanced techniques. An advanced ridge-widening procedure that can be done by an experienced practitioner may include different modifications of simultaneously done procedures. Below are a few examples of an advanced RSP that can be recommended for an experienced operator.

1. Segmental mandibular split-graft (S-G) approach

This is a mandibular RSP that is done as a single-stage surgery (similar to a classic maxillary RSP). In this case, maxillary-type corticotomies are done (crestal and two limited vertical ones). Split and grafting are performed at the same time (slowly) in a single-stage surgery through the limited full-thickness flap (FTF) or partial

(split)-thickness flap (PTF). Placement of an implant is performed as a separate surgical phase 4–6 months later.

- Benefits: a ridge-split is done in a single stage instead of two stages prior to an implant insertion.
- Risks: the mandibular bone is dense and was not "prepared" prior to the split (was not weakened by "bony window" Type 4 rectangular corticotomies). This technique can potentially lead to "bad splits" or comminuted fractures of the buccal cortical plate due to lack of elasticity of dense mandibular bone.
- Author: does not recommend in the beginning of learning the technique as it requires advanced skills.

2. Segmental mandibular split-graft-implant (S-G-I) approach

This is a mandibular RSP that is done as a single-stage and a single phase split, graft, and implant placement. The split and graft are done similar to the previous approach through the limited FTF or PTF, and this is followed by standard implant osteotomies and implant placement.

- Benefits: a ridge-split is done in a single-stage surgery that includes an implant procedure.
- Risks: "bad splits" and buccal plate fractures, poor implant placement with a compromise of primary stability, and, eventually, osseointegration.
- Author: does not recommend in the beginning of learning the technique as it requires advanced skills and complications are more common.

3. Segmental mandibular split-graft-implant with an open FT flap (O-S-G-I) approach

This is a mandibular RSP that is done as a single stage and a single phase, like the technique before, but with an *open* full-thickness flap. A buccal FTF is fully reflected in this case. Corticotomies are performed in a standard (4: crestal, two vertical, and apical) or modified (3: crestal and two vertical) manner. Implant osteotomies and placement with a bone grafting follow a careful split with a gap formation and ridge widening. A primary or secondary flap closure is achieved at the end of the procedure.

- Benefits: a ridge-split is done in a single surgical procedure that includes an implant insertion. This approach is helpful to those who prefer an open flap to perform all split corticotomies to weaken the mandibular bony segment.
- Risks: “bad splits” and buccal plate fractures, devascularization of the buccal fragment of bone, poor implant placement, and compromise of osseointegration.
- Author: does not recommend as this requires advanced skills, complications are common, and it is very risky.
- Benefits: single-stage surgery with bone spreading, some degree of lateral bone condensation, as well as simultaneous implant insertion.
- Risks: “bad splits”, devascularization of the fractured buccal bone fragment (usually in the mandible), lack of bone expansion (especially in the mandible), and poor implant placement, stability, and integration.
- Author: good and reliable technique for a surgeon familiar and experienced with the system.

4. Segmental maxillary split-graft-implant (S-G-I) approach

This is a maxillary RSP that is done as a single-stage and a single-phase procedure. Split widening, graft and implant placement are done simultaneously through the limited FTF or PTF.

- Benefits: single-stage surgery that includes an implant procedure.
- Risks: “bad splits” in the maxilla are possible but usually less likely, as well as poor implant placement with a compromise of osseointegration, although this is less likely.
- Author: recommends, good practice for an experienced surgeon and case selection is important.

5. Spreader-driven ridge expansion (SRE) approach

The spreader-driven ridge expansion (SRE) approach is based on the Meisinger bone spreading and condensing system (Meisinger USA, LLC, Centennial, CO) or other similar systems (see Chapter 22). In the maxilla, it is usually performed with a split-control kit with an open FT flap. It starts with a crestal and two vertical osteotomies (no apical osteotomy) at the preparatory stage followed by immediate drilling with pilot burs (they define the implant insertion areas) and then deployment of a series of successive vertical “spiral” spreaders with increasing diameters, with implants inserted at the same time. In the mandible, it is usually performed with a crest-control kit with a limited flap opening and a crestal (only) osteotomy followed by use of horizontal wedge spreaders and an immediate implant(s) insertion (Chapter 22).

6. Conical osteotome-driven ridge expansion approach

This technique is done mainly for maxilla but can be also performed for the mandible. Instead of spreaders, as in the previous approach, special conical or cylindrical osteotomes are used to spread, condense, and widen the thin ridge through the limited FT flap. This approach is similar to an osteotome technique developed by Summers [1]. Conical osteotomes have a “picked” tapered blade for better bone penetration (with the help of a surgical mallet) and slow progressive circumferential ridge expansion. In the process of ridge widening, these conical osteotomes “conveniently” create a cylindrical osteotomy similar to an implant osteotomy for an immediate implant insertion of preferably a tapered implant. Small differences in the “tunnel” diameter between the final conical spreader-osteotome and an implant helps to achieve good primary implant stability. The length of a blade of a conical osteotome (depth of osteotomy) and the length of an implant to be inserted need to be correlated.

- Benefits: single-stage surgery; bone spreading and apical plus lateral bone condensing, as well as simultaneous implant insertion.
- Risks: buccal bone perforation during the expansion, poor implant placement, stability and integration, benign paroxysmal positional vertigo related to striking or tapping by the mallet [2].
- Author: good and reliable technique for a surgeon familiar and experienced with the system.

Case report

A 22-year-old healthy female with a history of a bike accident and loss of a lateral incisor as a child presented for an implant evaluation (Figure 20.1). Clinical and radiographic evaluation with a cone beam CT (CBCT) scan (Figures 20.1 and 2) plus study models (Figure 20.3) confirmed the diagnosis of alveolar width deficiency of 2 mm (5/7–5 mm present out of 7 mm that is advised for a long-term implant success with 1.5–2 mm of bone present all around an implant). The surgery consisted of the ridge widening procedure with conical osteotomes and simultaneous implant placement. A limited FTF was elevated and the initial indentation in the ridge was done with a 15 blade scoring the cortical layer of bone along the ridge (Figure 20.4a). Then, the initial 2 mm drill was used to a depth of 5 mm in the middle of the scored corticotomy (Figure 20.4b). Then sequential conical (cylindrical) osteotomes were used to tap into the bone to the predetermined length based on the chosen implant (Figure 20.5). Due to a circumferential expansion created by progressive osteotomes, bone widening and some degree of bone compression were expected at the same time. Conical tunnel osteotomy with a diameter at the cortex of 3.5 mm was achieved (Figure 20.6). A 4.0 mm diameter and 13 mm length implant was inserted into the osteotomized tunnel to the predetermined depth (crestal placement) with a torque of 35 N cm (Figure 20.7a and b). A Stage 2 healing abutment was then put in place (Figure 20.7c). The buccal bone next to the implant platform was measured and was less than 1 mm (Figure 20.8a). This was considered deficient for a long-term implant success. A buccal pouch (space) was created by careful reflection of the periosteum (Figure 20.8a) and a bone graft material, Bio-Oss® (Geistlich Pharma North America, Inc., Princeton, NJ), was packed into the space (Figure 20.8b). CollaTape® (Zimmer Dental Inc., Carlsbad, CA) membrane was placed on top of the graft, wrapping around it (Figure 20.8c). The flap was closed by secondary intention with a 4-0 chromic gut (Figure 20.8d). The patient wore a stayplate for the time of healing (Figure 20.9). The implant was successfully restored 6 months later (Figure 20.10).



Figure 20.1 Clinical photo of the single edentulous space in the area of lateral incisor showing collapse of the alveolar ridge with ridge width deficiency after history of a bike accident.



Figure 20.3 Diagnostic models confirming the diagnosis of the horizontal alveolar ridge deficiency.

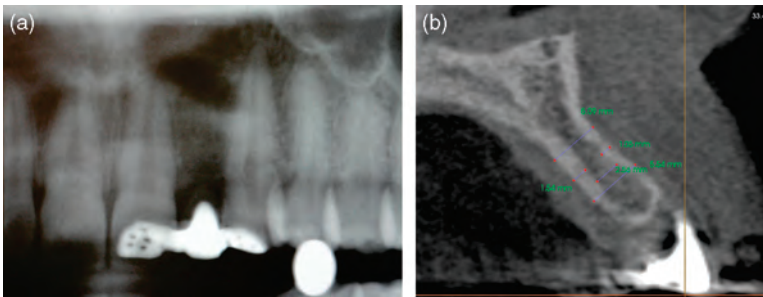


Figure 20.2 (a) Targeted panoramic image showing alveolar bone in between adjacent teeth and with good vertical bone stock present. (b) CBCT coronal (cross-sectional) image demonstrating horizontal ridge deficiency and the need for an additional at least 2 mm of buccal cortex expansion for successful implant placement.

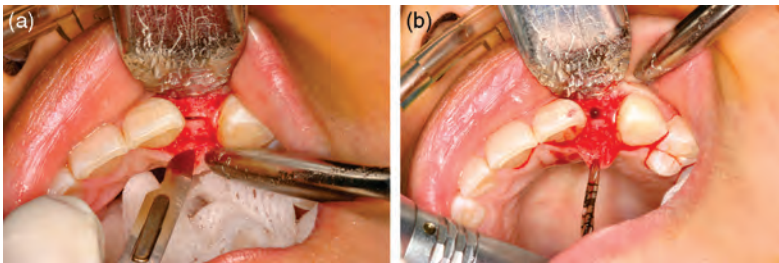


Figure 20.4 (a) Intraoperative photographs of the initial stage of the ridge-split procedure using a 15 blade and 2 mm drill to identify the middle of the ridge, perforate the cortex, and enter the trabecular layer of bone prior to ridge expansion. It is important to stay 1–1.5 mm away from the roots (PDL) of adjacent teeth. (b) Intraoperative photographs of progression of the ridge-split procedure when initial implant osteotomy is started with a 2–2.5 mm drill to the depth of 5–6 mm into the trabecular layer of bone in between the buccal and palatal cortical plates prior to ridge expansion.

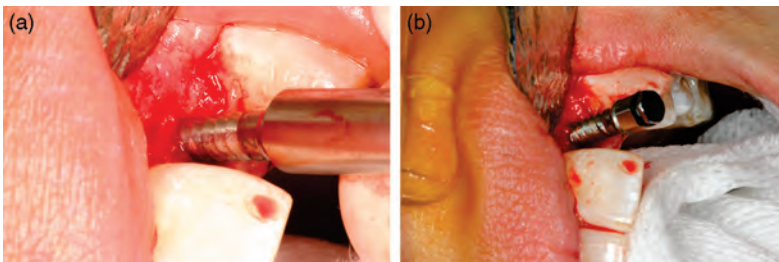


Figure 20.5 (a) Intraoperative photographs of the ridge-split in progress utilizing conical (cylindrical) osteotomes that were tapped (screwed) into the trabecular bone to the predetermined depth (based on the implant length), performing slow and progressive ridge expansion. (b) The conical (cylindrical) osteotome can also work as a paralleling pin to determine a proper direction of the osteotomy and, therefore, a prosthetically driven projection of the future implant.

(continued)

(Continued)



Figure 20.6 Implant osteotomy (slightly smaller diameter than the implant) is now ready for implant insertion.



Figure 20.7 (a) The dental implant was placed into the osteotomy prepared by the ridge expansion with an implant insertion torque of 35 N cm. (b) The dental implant was placed at mid-ridge, preserving the expanded buccal cortical plate that, ideally, should have about 1.5–2 mm in width on the labial side of an implant in the esthetic zone of the anterior maxilla (and elsewhere). (c) Single-stage implant protocol with Stage 2 healing abutment that followed implant insertion.



Figure 20.8 (a) Actual deficiency of the buccal bone (that was about 1 mm) next to the inserted implant was visualized, ideally to have 1.5–2 mm of protected bone on the buccal side. (b) Actual deficiency of the buccal bone (about 1 mm) next to the inserted implant prompted placement of an additional bone graft into the created buccal pouch. (c) Collagen membrane was placed on top of the bone graft and tucked underneath the palatal flap. (d) The wound was closed by secondary intention sutures.



Figure 20.9 The stayplate was adjusted prior to the patient's discharge.



Figure 20.10 The implant was successfully restored 6 months later with a porcelain crown.

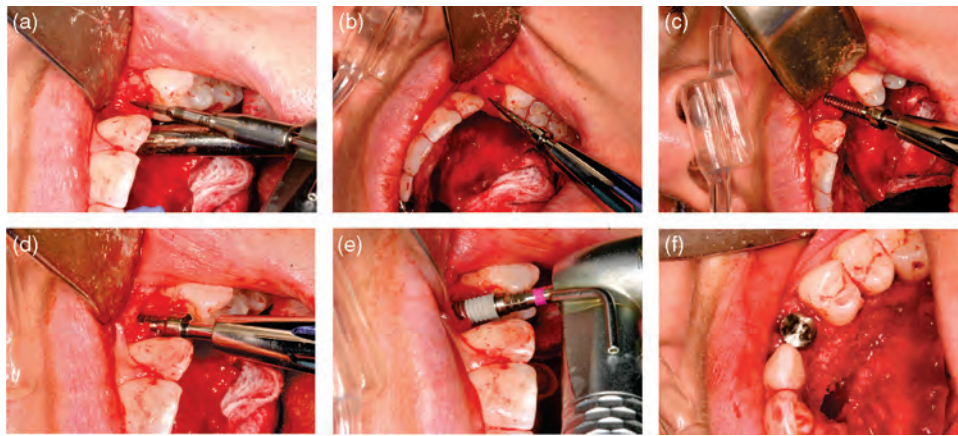


Figure 20.11 (a) Set of instruments that include expanding osteotomes that is offered by Salvin Dental Specialties, Inc. (Charlotte, NC, USA) for slow expansion of the thin ridge. (b) Progressive expanding osteotomes for expansion of the thin ridge, (c) progressive expanding osteotomes that are forming the tunnel osteotomy to the predetermined depth prior to implant insertion, (d) progressive expanding osteotomes that are forming the tunnel osteotomy to the predetermined depth prior to implant insertion, (e) insertion of the implant into the expanded ridge, and (f) insertion of the healing abutment.

Many companies offer convenient sets for the ridge-split procedure. Salvin Dental Specialties, Inc. (Charlotte, NC, USA) offers a set of expanding osteotomes for osteotome-driven ridge expansion with simultaneous implant placement (Figure 20.11).

In all cases, when ridge widening (expansion) is combined with an immediate implant insertion, one fundamental rule is important to follow for a successful implant osseointegration: engagement of the “periapical” bone beyond the split and graft has to be achieved. A principle of primary implant stability is important to follow. In these advanced RSP cases, it is imperative to engage implants “vertically” by creating an implant osteotomy deeper than the confines of the split. Therefore, it is important to drill the implant osteotomy of a suitable length beyond the split for placement of an implant fixture that can engage the native alveolar bone. This usually leads to a selection of implants with a length of about 11 mm or more. An apical portion of the implant is then engaged with the solid native bone beyond the split and graft and is responsible for primary implant stability, while a coronal part of the fixture is inside the split and is usually surrounded by bone graft material. In the mandible, the position of the inferior alveolar nerve and mental foramen in these longer osteotomies has to be respected. Another reason for improvement of primary implant stability is related to the condensing effect (lateral and apical bone condensation) of many ridge-widening instruments. Additional surgical procedures, such as sinus lift, can also be done simultaneously with the ridge-split, with or without implant insertion (Figure 20.12).

Some other modifications of the RSP (basic and advanced) have been suggested in the literature. A. Scipioni et al. [3] proposed a graftless “morphogenic bone splitting” technique done through the partial thickness flap when the bone–mucosa–gingival complex is displaced laterally in its entirety to eliminate the facially inclined hinge displacement often seen with a traditional RSP. Coatoam and Mariotti [4] proposed a modification of a traditional segmental ridge-split procedure with the use of a lyophilized bone allograft. Implants were placed simultaneously and cortical plates were braced with a ligature wire. An induced osteogenesis by periosteal distraction or guided bone regeneration by dynamic periosteal elevation are other modifications of the alveolar ridge widening

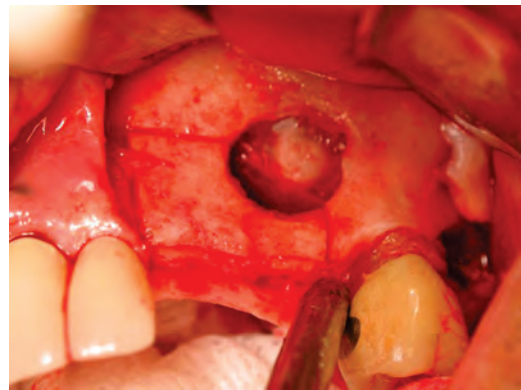


Figure 20.12 Ridge-split procedure can be done simultaneously with other surgical procedures, such as the lateral sinus lift shown in this clinical photograph (Stage 1 of the RSP plus the lateral approach to subantral augmentation). (Source: Dr. Bruce Hicke. Reproduced with permission from Dr. Bruce Hicke.)

(described in this book in Chapters 25 and 26). Here, the actual split is not done but the periosteum is tented to promote bone regeneration and widening [5,6]. Distraction osteogenesis principles can also be used for horizontal ridge widening employing titanium mesh [7] or crest widening/horizontal distraction devices [8] (described in this book in Chapters 24, 25, and 27).

A staged surgical approach with a postponed placement of implants after completion of bone augmentation appears to be a more predictable technique that produces fewer complications.

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CHAPTER 21

Comparison of Ridge-Split and Block Grafting Techniques for Width-Deficient Alveolar Ridges

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

There are few similarities and many differences between autogenous block graft and ridge-split/bone graft techniques. Both procedures require a skilled surgical practitioner equipped with knowledge of regional anatomy and vascularization, as well being prepared for risks and complications of the procedure. Both RSP and block grafting are used mainly in cases of width-deficient alveolar ridges for a two-dimensional horizontal alveolar ridge augmentation

(alveolar ridge widening) (Figures 21.1 and 21.2), although alveolar height gain can be achieved with both techniques (especially with block grafts, like J-blocks).

Autogenous intraoral block grafts (from chin, ramus, zygomatic buttress, maxillary tuberosity) demonstrate high osteogenic potential and are especially effective in segmental severe horizontal alveolar bone loss in the anterior maxilla and, occasionally, in



Figure 21.1 (a) Single edentulous alveolar ridge in the posterior mandible demonstrating moderate horizontal ridge deficiency; this case is suitable for the ridge-split procedure. (b) Single edentulous alveolar ridge in the posterior mandible showing advanced horizontal ridge deficiency; this case is suitable for the ridge-split procedure. (c) single edentulous alveolar ridge in the anterior maxilla (esthetic zone) demonstrating advanced horizontal ridge deficiency and preserved vertical bone height; this case is suitable for the ridge-split procedure.

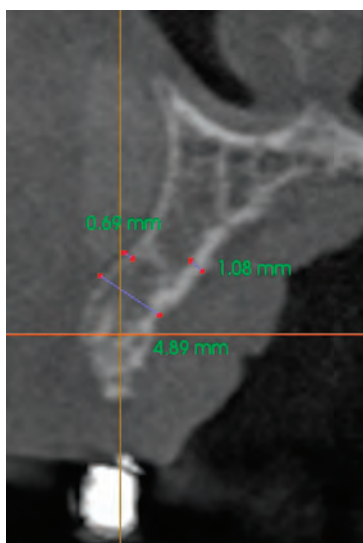


Figure 21.2 CBCT sagittal slice demonstrating a horizontal alveolar bone deficiency. RSP is best for ridges with a bone width of 3–5 mm.

the anterior mandible [1–3]. It is more difficult and less successful to correct width deficiency by block grafts in posterior regions of the jaws (such as the posterior mandible). The most common onlay block grafts utilized in implant dentistry to widen the ridge are the chin (symphyseal) and the ramus (posterior mandible). Please read the detailed description of extraoral and intraoral block grafting techniques in the Section III of this book.

Two main disadvantages of autogenous block or veneer grafts are donor site morbidity and late-term graft resorption [4]. Autogenous block bone resorption has been reported to have up to 5% early bone loss of the entire graft and up to 40% late-term loss of the graft volume due to remodeling and inadequate consolidation [5]. Ridge augmentation with mineralized block allografts offers an alternative to autogenous block bone by eliminating donor site morbidity (Chapter 15) [6]. Donor site morbidity, in addition to pain and swelling associated with the site of grafting (donor site), includes complications that are specific for each location. For example, complications from the symphyseal (chin) graft include lower anterior teeth paresthesia (“wooden” sensation), infection and slow healing, as well as ptotic or “witch’s” chin [7]. Patients’ acceptance of the symphyseal (chin) grafts is traditionally low [8]. Ramus grafts are usually tolerated better [9] and complications are less common but include lower lip and chin anesthesia due to the inferior alveolar nerve (IAN) injury, trismus, and mandible fracture. Table 21.1 demonstrates a 10-point side-by-side comparison of the ridge-split/widening/expansion technique with a veneer (onlay) autogenous intraoral block graft.

In the majority of cases, an operator will choose the technique he/she feels comfortable with based on previous (successful) experience and training. It is an ideal situation when a practitioner is comfortable with both techniques. Table 21.1 helps to define limitations of each technique and guides towards a proper treatment plan. The case below is a good example of when block graft and ridge-split can be selected for the same patient. Correct diagnosis should lead to a proper treatment decision.

Table 21.1 A 10-point comparison of the ridge-split and block bone graft techniques.

Comparison	Monocortical block grafting (intraoral)	Ridge-split procedure
1 Type of grafting	Onlay: external, “cortex-to-cortex”; donor cortical graft is added to the recipient cortical bone, resulting in a grafted bone that has cortical environment on one side and periosteum on the other	Inlay: internal (interpositional); cortical envelope is expanded and a particulate grafting is done “from within” resulting in a bilateral proximity of the grafted bone to both cortices (similar to a 4-wall defect of extraction socket)
2 Graft resorption	Free (devascularized) graft; the grafted bone may contain a substantial amount of non-vital bone that did not survive detachment, devascularization, and transportation. Slow and incomplete neo-vascularization rate [10]; an increased risk of post-operative graft resorption [5]	Vascular bone flap (osteoperiosteal flap); vascularization is preserved at all times. “Cancellous bone grafts are more rapidly and completely revascularized than cortical grafts” [11]. Decreased risk of post-operative graft resorption [12]
3 Donor site morbidity	Yes: pain, swelling, IAN injury (posterior mandible, ramus), “wooden” teeth sensation (chin), sinus perforation (zygomatic buttress), others	No
4 Recipient site morbidity	Soft tissue dehiscence and graft exposure, loose fixation screws and graft mobility; graft loss	Soft tissue dehiscence and graft exposure, buccal plate malfracture; inadequate split
5 Wound closure (recipient site)	Primary wound closure is mandatory	Closure by secondary intention is preferred
6 Buccal soft tissue flap	Buccal flap is lifted and often stretched. Tension-free primary closure is important and can be challenging	At the time of actual split, buccal flap is partially reflected and largely left attached to bone, not compromised, preserved as a source of blood supply
7 Wound healing	By plasmatic imbibition from the host (recipient) tissue	Internal “coagulum” is easily converted into the woven bone due to protection and excellent vascularization from both cortices throughout the whole process
8 Immediate implant insertion	Traditionally not done	Can be done in some cases
9 Delayed implant insertion	Implants are placed into cortical bone interface 4–6 months later	Implants are placed into cancellous bone interface 4–6 months later
10 Environmental factors and long-term stability of a graft	More subject to a post-op injury (“external” grafting). Less long-term stability and more long-term resorption [10]	Less subject to a post-op injury during mastication; more protected (“internal” or interpositional grafting). Less long-term resorption and more long-term stability [13,14]

Case report

A 60-year-old healthy patient is missing the right maxillary premolars and lateral incisor (Figure 21.3a). The patient had a bicycle accident and lost his lateral incisor more than 40 years ago and antenatally lost both premolars due to caries 5 years ago. The general practitioner plans to remove an old porcelain-fused-to-metal bridge between the central incisor and canine. The patient is interested in implant placement in all three edentulous areas: the lateral incisor and two premolars. A panoramic radiograph is inconclusive in terms of the alveolar width in both anterior and posterior maxillary regions (Figure 21.3a). The CBCT scan (Figure 21.3b, c, and d) demonstrates the alveolar width in both regions clearly and is a guide towards the treatment plan. The bone in the premolar region on the CBCT sagittal slice (Figure 21.3c) shows a good base and narrows down to about 3.4 mm in width closer to the alveolar crest. There are cortical and trabecular layers, and the trabecular layer has an appropriate width (about 3 mm) to be used for the split of the ridge. This is a good area for the ridge-split procedure. The alveolar ridge in the lateral incisor region on the sagittal slice of the CBCT (Figure 21.3d) is extremely thin and fragile in width and height, with ridge resorption and labial cortical bone collapse to about 1.8 mm in width at the alveolar crest. It will be exceedingly difficult to split this thin and curved (fragile) ridge along the thin trabecular layer of bone, even by an experienced operator. This ridge can be more responsive to an “external treatment” by guided bone regeneration (GBR) with a particulate graft or onlay (veneer) block bone graft (posterior mandible/ramus as a donor site could be a good option in this case). The grafting procedures for both regions can be done in sequence or at the same time, with a goal to widen both ridges to about 7–8 mm or more to accommodate implant fixtures of about 4 mm in diameter at a later time.

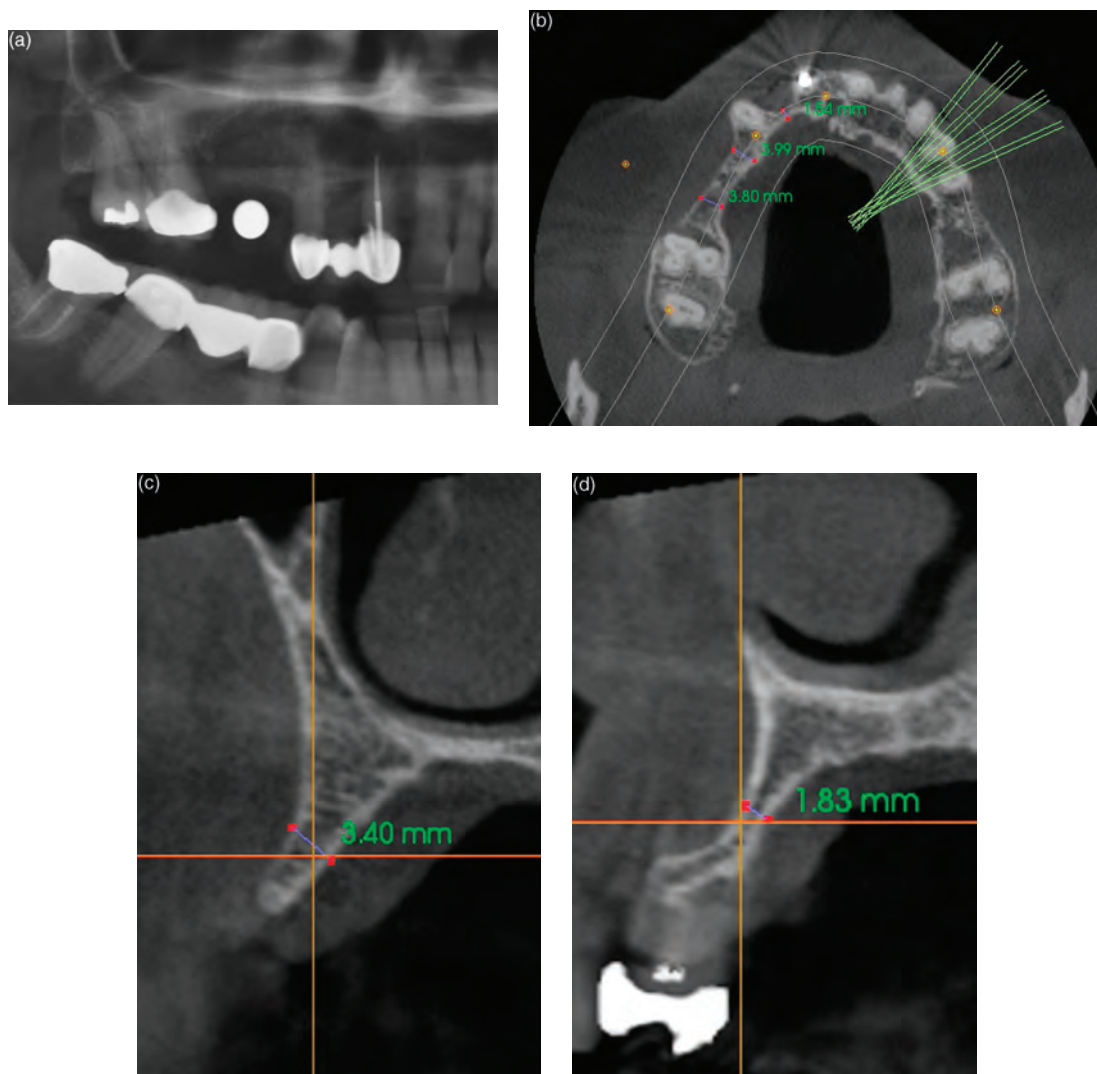


Figure 21.3 (a) Targeted panoramic radiograph of the patient with a traumatic tooth loss after the bicycle accident demonstrating moderate horizontal alveolar bone loss in the posterior maxilla and more advanced bone loss in the anterior maxilla (under the bridge); vertical bone is preserved in both areas. A decision can be made to use either the block graft or ridge-split procedure. (b) CBCT axial slice showing moderate horizontal alveolar bone loss in the posterior maxilla (about 4 mm of bone width remaining) that could be successfully treated with a ridge-split procedure and severe bone width loss in the anterior maxilla (about 1.5 mm of bone width remaining) that could be effectively treated with an onlay block bone graft. (Source: Tolstunov 2014 [15]) (c) CBCT coronal (cross-sectional) slice demonstrating moderate alveolar bone loss in the posterior maxilla (about 4 mm of bone width remaining) that could be successfully treated with a ridge-split procedure. (d) CBCT coronal (cross-sectional) slice showing severe horizontal bone loss in the anterior maxilla (less than 2 mm of bone width remaining) that could be successfully treated with an onlay block bone graft.

Conclusion

One of the key concepts in bone augmentation is a long-term stability that depends on the rate of post-operative resorption or “subtraction remodeling” [16]. In 1989, Whitaker introduced the concept of the *biological boundary* [17], arguing that the soft tissue envelope has a predetermined shape. A forceful change of this envelope by the surgical procedure may violate the natural biologic boundary. The onlay (block) grafts appear to violate this biologic envelope, according to this theory. Hypothetically, that is why they resorb faster than inlay grafts (such as the interpositional or “sandwich” grafting of the ridge-split procedures). This hypothesis still needs to be proven.

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CHAPTER 22

Alveolar Crest Spreading System for Horizontal Bone Augmentation in Implant Dentistry

Bruno Ella-Nguema

Department of Anatomy and Physiology, Faculty of Dental Sciences, Bordeaux University, Bordeaux, France

Introduction

Inadequate bone width in the alveolar ridge is a common limitation for dental rehabilitation in oral implant therapy. As a dental implant has to be surrounded by at least 1 mm of cortical bone on both sides, if the ridge is less than 5 mm wide, it is difficult to insert an implant directly to replace a missing tooth [1,2].

Horizontal bone expansion has been used since the 1980s to create sufficient width in narrow ridges with or without simultaneous implant placement [3]. This technique has continued to evolve, and new protocols have been developed, sometimes including grafting of bone into the expanded gap between cortical plates [4–6].

Although autogenous bone graft is considered to be a gold standard, donor site morbidity, graft resorption and local bone deficiency at the donor site often imply other methods of bone grafting [7,8]. In order to treat narrow alveolar ridges, alternative approaches to bone grafting have been developed. One of them consists of splitting the alveolar ridge cortical tables [9,10] and further open the space with Summers osteotomes [11]. Splitting is classically performed with a chisel and mallet [12–14] or rotating or oscillating saws [15,16].

In general, this technique allows the bone crest to expand and sometimes to insert an implant at the same time. The buccal wall is often the site of bone collapse. The protocol is therefore to reconstruct this side of the ridge. This procedure is mainly indicated in cases with sufficient bone height but inadequate thickness. At least 3 mm of initial crestal width is required to perform this technique [17].

Some important criteria have to be evaluated prior to performing the technique by clinical examination and additional tests (CT scan or CBCT). They include:

- Ensure that the patient is able to receive the protocol. The patient must be healthy and any contraindication for surgery must be examined.
- Evaluate the thickness, height, and morphology of the alveolar ridge.
- Evaluate the available bone height relative to the anatomical elements to be respected (for example, the inferior alveolar nerve (IAN) and mental foramen in the mandible). This helps to take into account the length of implants to be inserted.
- Ensure that there is a minimum amount of spongy (trabecular) bone between two cortical walls (at least 2 mm) for the technique to be successful. This layer of bone is essential to achieve bone expansion.

Description of techniques

There are techniques used only for maxilla and others used for the mandible. Here we briefly describe the existing techniques for narrow ridge expansion that can be used for both jaws. We present the example of the Crest-Control Bone Splitting System (Meisinger, Neuss, Germany) that has been developed to expand narrow ridges in the mandible and maxilla [18,19].

Osteotomy technique

There are different types of osteotomes: cylindrical osteotomes, cylindroconical osteotomes, and flat osteotomes. In general, these instruments are graduated and have progressive diameters to allow a continuous expansion of the bone crest.

- Alveolar osteotomy. This technique was developed by Summers to increase the height and width of the maxillary ridge [1]. It requires a minimum alveolar ridge thickness of 3 mm and utilizes cylindrical or cylindroconical osteotomes to condense the adjacent bone and to move it vertically and horizontally. This leads to an increase in the height and width of the alveolar ridge. The progressive use of different osteotomes is done using small mallets. Insertion of the implant can be performed immediately after preparation of the implant bed [1].
- Alveolar corticotomy. As described by Lalo et al. (2008) [20], this technique uses flat and thin osteotomes with a double bevel (2–5 mm) that have a progressive graduated diameter of 2 to 5 mm and a surgical mallet [20]. In the protocol, two vertical corticotomies are first carefully performed through the cortical layer of bone to the cancellous (spongy) bone layer using drills or saws. These bone cuts will limit the area to be expanded and eventually implanted. Vertical corticotomies are performed about 2 mm on either side of the mesial and distal edge of the future implant. This stage of bone expansion will test the strength and, more importantly, the plasticity of the bone. Then the horizontal crestal corticotomy is performed connecting vertical corticotomies together. A directed fracture is caused along the lines of osteotomy with a flat osteotome and soft and progressive movements. The dislocation of an alveolar bone flap is thus obtained. This maneuver of external expansion selects an axis for a favorable implantation. The implant can be inserted at the same time. The intercortical space (gap) is filled with a bone substitute or autogenous bone [20].

Bone spreading technique

Nishioka et al. (2009) [4] described the technique that uses a series of six screw spreaders with increasing diameters, which are gently introduced to expand the osteotomy site. With insertion of a larger screw spreader, the bone is pushed laterally. A control system allows for substance-saving compression of the medullary bone to a sufficient horizontal dimension. The implant should be slightly larger in diameter than the site created by the last screw spreader. The objectives of this technique are to conserve all bone in the surgical site and to selectively displace the bone laterally. Trauma and invasiveness are reduced with instrumentation through the ridge crest [4].

Split-crest technique

As described by Blus et al. (2006) [3] in their case series study, the ultra-sonic bone surgery (USBS) technique using the piezo-surgery (PS) device (Mectron, Genova, Italy) and the USBS device (Italia Medica, Milano, Italy) has been introduced to perform precise bone surgery [3,21–23]. It represents an alternative to the autogenous bone block graft. This technique uses piezo-electrical transducers because the generated movements are more energetic.

The surgical procedure starts with a basal longitudinal discharge notch, in addition to the vertical and longitudinal bone cuts. This longitudinal notch increases the bone resilience and eases mobilization of the vestibular bone flap. To widen the space between the tables and create the implant bed, conical screws of increasing diameter (Bone Management System, Meisinger, Neuss, Germany) are used. This technique can use a ridge expander when bone is particularly dense. Implants are inserted simultaneously [3]. This technique is similar to the edentulous ridge expansion (ERE) technique. It utilizes a Piezotome (Satelec Actéon, Mérignac, France).

These two techniques (ERE and USBS) can be followed by simultaneous implant placement in order to maintain the created space [24]. This space can be filled with an autogenous, allogeneic, or xenogeneic graft, with biomaterials or leaving a blood clot stabilized by a membrane, with or without the application of platelet concentrates such as PRP or PRF that seem to accelerate the healing of hard and soft tissues [25–27].

Split-Control® technique

This technique utilizes instruments shaped as screws for bone spreading. According to Coatoam and Mariotti [12], a greenstick fracture is first performed (with traditional corticotomies) and then the site is prepared with drills. The larger the diameter of the drill the more a bone expansion is accomplished, with a buccal cortical bone plate being displaced laterally rather than being cut. The implants are simultaneously inserted if they are stable and aligned [12].

Extension Crest® technique

This technique allows a gradual and controlled increase in the thickness of the ridge.

According to Chiapasco et al. (2006) [28], the Extension Crest technique consists of two surgical steel arms hinged apically and a transversal screw, which allows a progressive activation of the device. Every complete screw turn corresponds to an activation of 0.5 mm. The maximum expansion obtainable with Extension Crest is 5 mm. The rate of activation is correlated to surgical needs, whereas the rhythm of activation is connected to the local bone density. Mandibular bone, which generally presents a higher

density, may need a slower activation to avoid a fracture of the buccal plate. Once ridge expansion is completed, Extension Crest devices are removed and implant sites are prepared following a standard implant procedure. The wedge-shaped space obtained makes root-shaped implants very suitable to this procedure.

This technique is close to the Meisinger Crest-Control® technique, except that the device described by Chiapasco et al. (2009) [29] creates a conically widening crest.

Crest-Control® technique

This is the horizontal bone spreading system that allows for the predetermined and minimally invasive horizontal widening of the alveolar ridge, especially suitable for the distal portion of the mandible. With the well-proven horizontal spreader, the alveolar ridge can be expanded up to a maximum of 5 mm. Subsequently, an implant of any current implant system can be inserted. This system consists of two surgical steel arms (horizontal spreaders) hinged apically and a transversal screw (adaptor) that allows the device to be progressively activated. Once ridge expansion is completed, the expanding devices are removed and implants are placed following standard procedures. According to some authors, an implant(s) may be placed after alveolar bone expansion without the need to fill the residual defects around implants [30], while others reported crestal resorption after this approach [12].

This technique is indicated for patients in need of implant therapy of the mandibular and edentulous ridge. It is useful for bone densities of D1 to D3. The crestal bone should have a minimum width of 3 mm, which should include at least 1 mm of the cancellous layer of bone. The ridge should have a minimum height of 11 mm between the top of the ridge and IAN or mental foramen. Patients with systemic conditions contraindicating oral surgery, heavy smokers, and alcohol or drug abusers, and those with advanced periodontal disease and poor oral hygiene should be excluded.

Surgical protocol

To illustrate this technique, we present here clinical cases performed on mandibular and maxillary anterior and posterior regions [19]. The edentulous area corresponds to, on average, replacement of two-to-three teeth. Cases presented here include simultaneous ridge expansion and implant placement.

Materials used in this study

- A Crest-Control kit contains three spreaders, five burs, three saw discs, two thumb drivers, one ratchet.
- Bone substitute: type SBS 60/40® biphasic calcium phosphate (MBCP, Expanscience, France) [31], but it is possible to use other bone substitute materials.
- Absorbable membrane: type Bio-Gide® (Geistlich, Switzerland). Other absorbable membranes can also be used.
- Implants used are Speedy Groovy®, diameter 3.3–4 mm (Nobel Biocare, Sweden).

Before surgery, we would like to make sure at the clinical examination that the mouth opening is sufficient to insert our instruments. The crest of alveolar bone has to be assessed as deficient in width and equal approximately to 3–5 mm. This assessment is a combination of clinical and radiographic (often, CBCT) examination (Figures 22.1 and 22.2). Under local anesthesia, a crestal incision is performed and a full thickness flap is raised to obtain adequate visibility of the crestal bone followed by a partial thickness flap apical to the crest. In this part, the

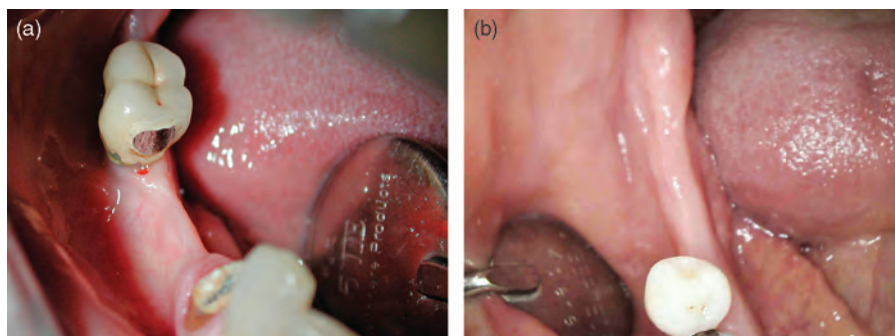


Figure 22.1 (a) View of the narrow ridges prior to surgery, demonstrating adequate vertical height and severely deficient alveolar width (b) View of the narrow ridge prior to surgery.

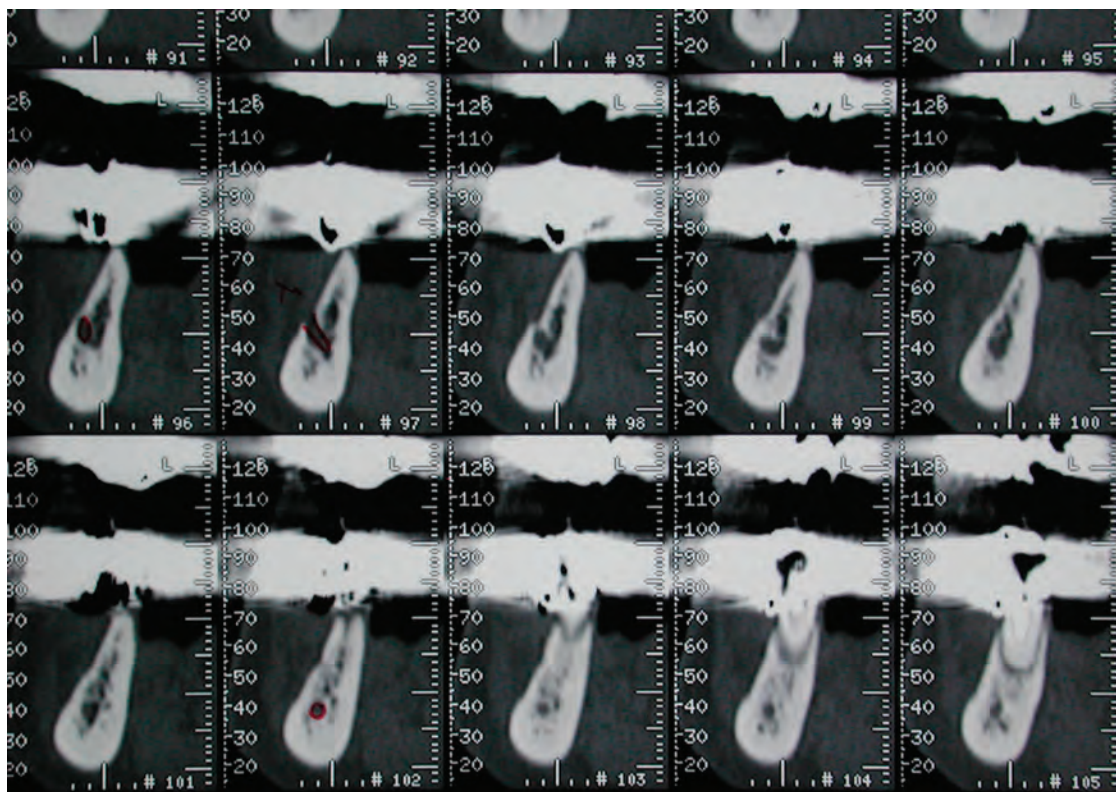


Figure 22.2 View of the pre-operative cone beam CT (CBCT) scan demonstrating a narrow alveolar ridge.

periosteum is dissected to ensure flexibility of the flap when covering the surgery site.

The initial osteotomy is performed on mid-crestal bone, using a diamond headed bur (802L) followed by a rotating micro-saw (diamond coated saw 231DC, 070) to separate the buccal cortical plate from the lingual plate, paying attention to stay 1 mm off the adjacent teeth (Figure 22.3). Two vertical osteotomies are performed at the end of the mesial and distal limits of the crestal osteotomy (Figure 22.4). The surgical bur (HM33IL and 859L) is then used over the entire length of the bone trough to prepare the site for insertion of horizontal distractors.

The Crest-Control Bone Splitting System (VCD50) is used through the crestal osteotomy (Figure 22.5). To replace two teeth, one distractor (horizontal spreader) may suffice. For more than two teeth, two or more may be used simultaneously. At this stage, the Crest-Control Bone Splitting System consists of two surgical steel arms hinged apically and a transversal screw, which allows the

device to be progressively activated intraoperatively to obtain ridge expansion of 6–8 mm. Once ridge expansion is completed, depending on the width of the implant that needs to be inserted, the expanding device(s) is removed, and implants can be placed following standard implant preparation procedure (Figure 22.6).

The spaces between implants are filled with a bone substitute of your choice (Figure 22.7). The surgical site (bone graft) is covered with a membrane of your choice (Figure 22.8) and closed due to mobility of the buccal mucoperiosteal flap (Figure 22.9). If the surgical site cannot be fully closed (primarily), it is especially important to cover it with a collagen absorbable membrane prior to suturing of the flaps [12,32]. The flaps are sutured without tension. A post-operative radiograph is taken after the procedure. Implants can then be restored after the osseointegration process takes place in about 4–6 months (Figure 22.10).

A typical case report that utilizes the technique of ridge widening with a Crest-Control Bone Splitting System is demonstrated in

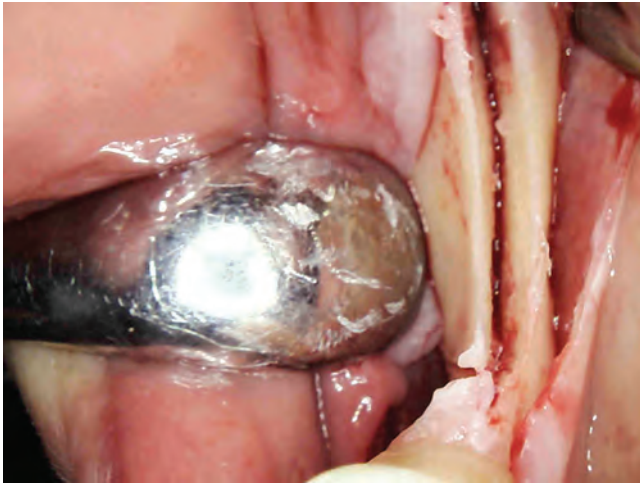


Figure 22.3 View of developing alveolar ridge-split (done with thin burs and a micro-saw).

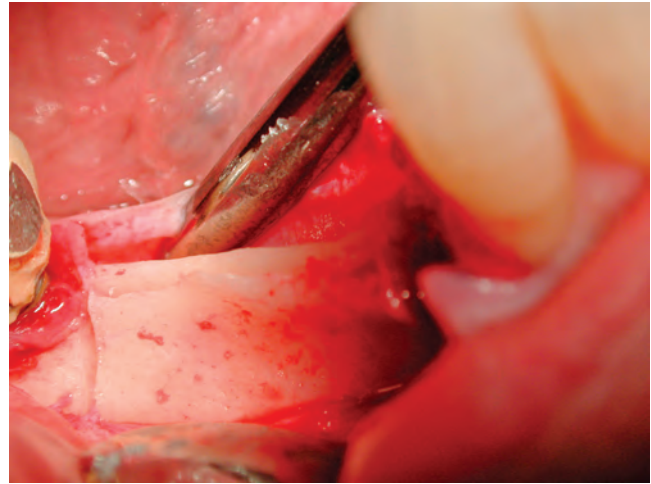


Figure 22.4 View of vertical mesial and distal corticotomies (in addition to mid-crestal osteotomy) and enlarging opening of the split accomplished with osteotomes.



Figure 22.5 Views of the crest-control bone splitting device inserted into the crestal osteotomy and being activated: (a) a single bone distractor is positioned and (b) two bone distractors are positioned.

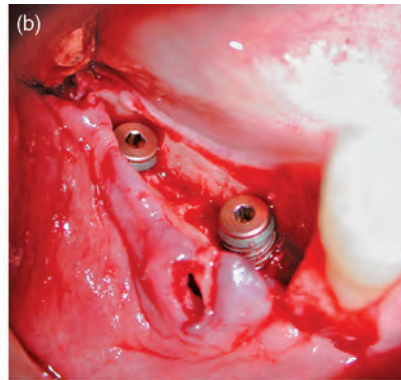


Figure 22.6 (a) View of immediate implant insertion into the expanded ridge. (b) Two implants placed immediately into the expanded ridge.

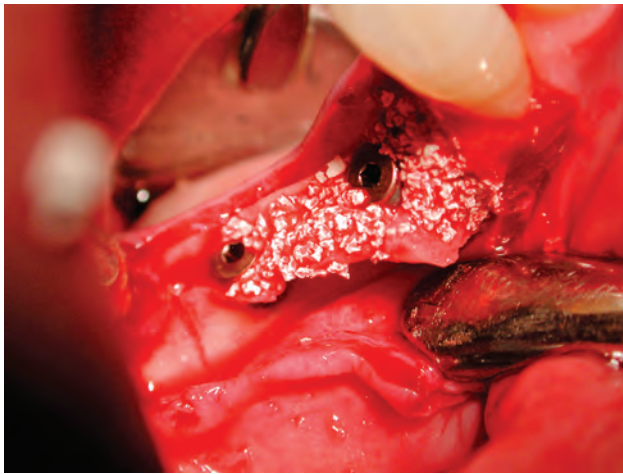


Figure 22.7 View of bone graft substitute placed into the created gap (interpositional or internal grafting).



Figure 22.8 View of the GTR or collagen membrane placed on top of the graft for its isolation and protection



Figure 22.9 View of primary closure of the wound at the end of surgery.

Figures 22.11 to 22.16. The patient had an extreme 2D alveolar ridge resorption with a loss of bone width to a remaining 3.5 mm in the area of the mandibular second premolar and first molar (Figure 22.11). The osteotomies, made with a thin diamond bur and micro-saw, consisted of mid-crestal and two vertical ones to separate the buccal cortical plate from the lingual plate (Figure 22.12).

Horizontal distractors were inserted and activated to widen the ridge to the predetermined dimension (Figure 22.13). A mini-screw was placed horizontally at the completion of the activation (ridge expansion) due to the buccal cortical wall instability. This improved its control in the expanded new position. After the ridge expansion of about 10 mm, two implants were inserted, engaging the bone beyond the split to achieve primary stability, and the bone grafting material was packed all around both implants to eliminate empty spaces inside the split (Figures 22.14 and 22.15). After a healing period of about five months, both implants were restored with two crowns connected as a bridge to an appropriate occlusal function to the patient's satisfaction (Figure 22.16).

According to Jensen et al. (2009) and based on results of his clinical study of relatively early osseous remodeling, full-thickness mucoperiosteal flaps should not be fully reflected when an alveolar split is done [17].

It is recommended to start the patient on antibiotics (Amoxicillin 2 g per day) the day before surgery and continue for 6 days, an analgesic as needed (Acetaminophen, for example), and Chlorhexidine 0.12% mouthwash twice a day for the first 3 weeks. The patient should stay on a soft diet and have good oral hygiene. Follow-up visits are checked and non-absorbable sutures are removed 15 days after surgery.

Benefits, risks and complications

The Crest-Control Bone Splitting System has a single surgical site, while the autogenous block bone graft requires a donor site as a

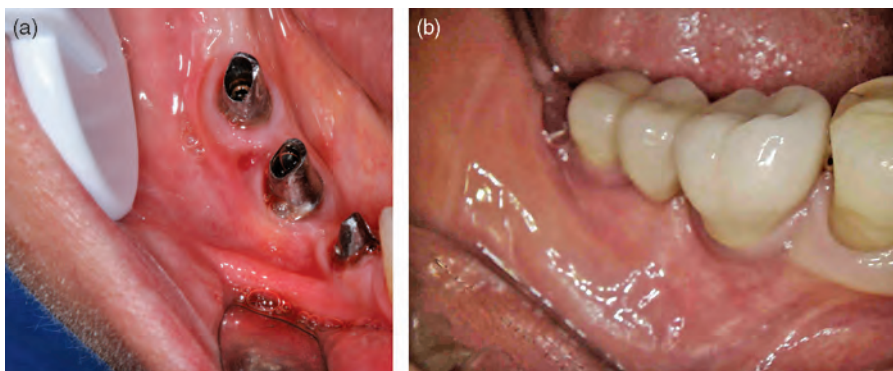


Figure 22.10 View of the implant restorative stage 4–6 months later: (a) abutment stage and (b) final crowns.



Figure 22.11 View of a segmental atrophic alveolar ridge with severe width deficiency.

second surgical site. Furthermore, the implants are usually inserted at the time of ridge expansion, while with a block bone grafting insertion of the implants is delayed for 3–4 months. As with any surgical technique, complications may occur. They can be divided into intra-operative and post-operative complications.

- Intra-operative complications. Complete buccal cortical fracture (separation of bone fragment) at the time of reflection of the full-thickness flap may occur during traumatic or forceful expansion of the ridge. Usually, this can happen when there is a minimum of cancellous bone (1 mm) between the cortical walls. Bone screws have to be placed in this case to fix the fragment and come back to the original technique in 3–4 months.

Intervention on the anterior or posterior area has no effect on fracture risk. It has been shown that the risk of fracture is greater when the ridge is narrowest [19]. It is recommended, especially in cases of narrow ridges (about 3 mm), to maintain ridge expansion using a bone substitute [19]. We still have to see in future research whether the horizontal ridge expansion technique is reproducible and if filling with bone substitutes is necessary to maintain the bone expansion.

- Post-operative complications. If the hygiene conditions and protection of the surgical site have been met (host factors), the healing is usually adequate until the prosthetic stage. Otherwise, an infection of the surgical site can cause bone resorption.

After the healing period (six months), the implant restorative stage follows. It helps to assess bone volume on the expanded site at this point. Bone loss due to its resorption can occur over a period of time. It appears that the location of the procedure does not have an affect on bone resorption at the surgical site, but whether the internal grafting was done after the ridge expansion does. Bone preservation (lack of relapse) is likely in cases of grafting [19].

Bone resorption may also occur around implants. In that case, guided bone regeneration (GBR) must be performed using the same or other bone substitute material [33,34].

A study conducted by Ella et al. (2014) [19] showed that the filling of the space between the walls avoids bone resorption when an expansion of narrow ridges is performed. The bone substitute had a significant positive effect to avoid bone resorption of 3 mm width ridges (5%) and 4 mm width ridges (5%) ($\alpha=0.02$).

Advantages and disadvantages

Atrophic edentulous jaws can represent a significant challenge in implant dentistry. Although ridge augmentation can help to restore

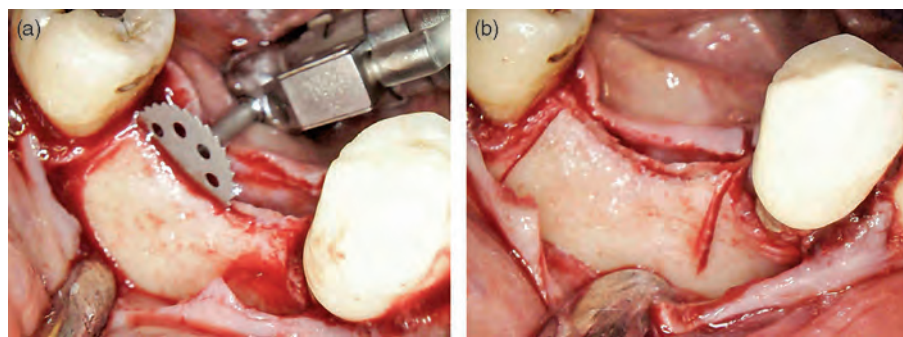


Figure 22.12 Intraoperative views of a micro-saw used to make corticotomies: (a) mid-crestal and (b) two vertical ones.

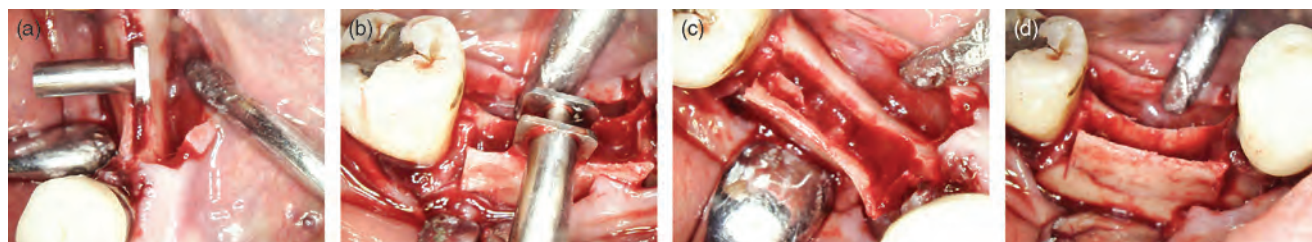


Figure 22.13 Intraoperative view of a crest-control bone-splitting system in function with placement and activation of horizontal distractors to achieve planned ridge expansion: (a) occlusal view, not activated, and (b) lateral view, activated. Intraoperative view of a crest-control bone-splitting system in function: (c) occlusal view, planned ridge expansion is achieved, and (d) lateral view, planned ridge expansion is achieved.

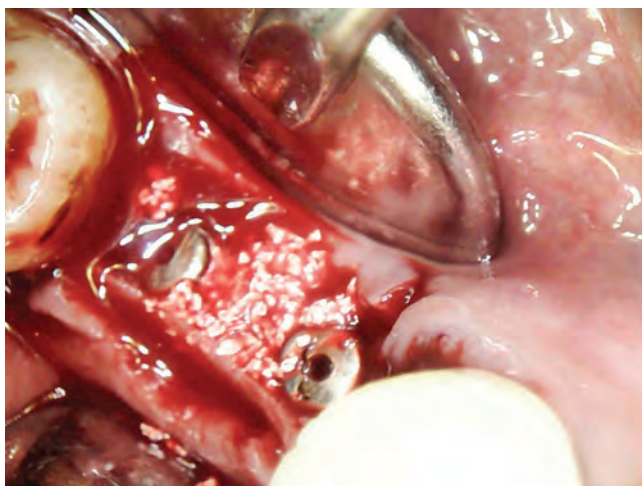


Figure 22.14 View of two implants inserted into the site with a bone grafting material packed around them.



Figure 22.15 Immediate post-operative radiograph of two implants placed into the site as well as a fixation screw placed to stabilize the buccal cortical wall to the lingual wall.

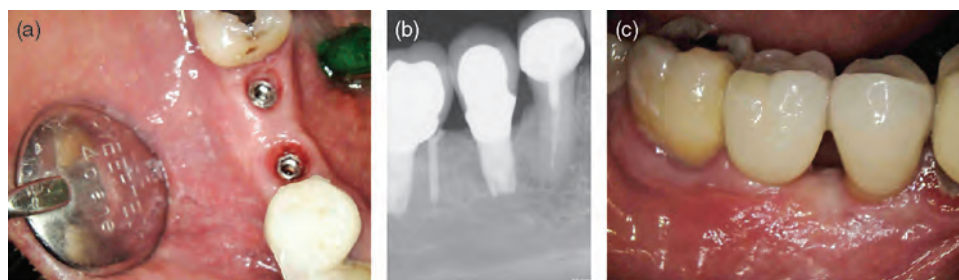


Figure 22.16 (a) Completion of a restorative stage where implants are exposed for placement of prosthetic components (intraoral photograph). Completion of a restorative stage with placement of two crowns connected as a bridge to full function: (b) periapical radiograph and (c) intraoral photograph.

ridge volume, some autogenous grafting procedures (block grafts) can significantly increase patient morbidity and treatment time [35,36]. Autogenous bone is traditionally considered to be a gold standard, although some intraoral donor sites do not always have enough bone [7,8,37]. The autogenous block bone graft approach presents several drawbacks: invasiveness of the surgery with an increased risk of morbidity, the risk of bone graft and/or membrane exposure and infection, increased number of surgical procedures reducing patients' comfort, and lengthening the treatment time [38–41].

From our study [19], we should note that the main advantage of the crest-expanding technique is that it is a less invasive procedure. During the procedure, the facial (buccal) wall expands with the medullary layer of bone being compressed against the cortical walls. As demonstrated by Ella et al. (2014) [19], horizontal expansion using the Meisinger Crest-Control® device, similar to other expansion techniques of narrow ridges, is reproducible and a good alternative to block bone grafting in narrow ridges [14,29,42]. However, the alveolar ridge should have a minimum width of 3 mm including a minimum layer of spongy bone of 1 mm between

cortical walls to avoid the risk of fracture during surgery and the likely risk of post-operative resorption during the healing stage.

The use of the proposed technique provides a progressive and controlled widening of the atrophied ridge. This technique is easily reproducible and avoids donor site morbidity and is comparable with the techniques of the osteoperiosteal flap [19].

According to Cakir-Ozkan et al. (2010) [43], stereologic evaluation of bone in the sheep model demonstrated significantly greater osteoblast density in bone formed through transport distraction osteogenesis when compared with bone grafting and the control. In terms of bone healing, the implant osseointegration is accelerated in the expanded bone due to local growth factors. Also, Scipioni et al. [30] demonstrated that a new bone in the expanded ridge forms from osteocytes and osteoblasts of the local cancellous bone. During the mineralization phase, bone healing and osseointegration appear to accelerate in the widened bone segment around dental implants with the help of growth factors of the forming callus.

Within the limits of this study [19] and according to other studies, the extension crest technique appeared to be reliable and a simple technique, with reduction of morbidity and times of dental

rehabilitation as compared with other techniques such as autogenous bone grafts and guided bone regeneration. Survival and success rates of implants placed in the treated areas are consistent with those placed in native bone [43].

The Extension Crest Technique also has the advantage of being less traumatic, whereas the Summers Osteotome Technique, due to use of the mallet and chisels, can lead, on occasion, to benign positional paroxysmal vertigo (BPPV) [44]. That surgical complication has been described as induced by percussion (tapping) with a surgical mallet along with the hyperextension of the neck during the operation. BPPV may occur due to the intraoperative displacement of otoliths [45].

Segmental ridge-split with USBS is rendered safe, less technique sensitive, and comfortable, without risk of soft tissue injury [3]. The limitations of this technique are the possibility to treat only horizontal defects and the necessity of cancellous bone within the edentulous ridge.

The Extension Crest Technique is not indicated for narrow ridges with cortical plates (buccal and lingual/palatal) directly connected. These defects are better treated with GBR or onlay grafts [28].

Conclusion

Today, a wide range of surgical procedures is available. It is difficult to demonstrate that any one of these techniques can offer better outcomes than another. Every surgical procedure presents advantages and disadvantages and priority should be given to those that are simpler and less invasive with less risks and complications [19,28]. Each technique requires specific indications. Clinical and radiographic criteria for selection of patients must be respected.

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Management of Complications of Ridge-Split Procedure and Conclusion (10 Commandments of Success with Ridge-Split Procedure)

Len Tolstunov

Private Practice, Oral and Maxillofacial Surgery, San Francisco, California, USA

Department of Oral and Maxillofacial Surgery, UCSF and UOP Schools of Dentistry, San Francisco, California, USA

Introduction

The most common traumatic event in the oral cavity is a tooth loss. This often leads to a pathologic remodeling of surrounding bone resulting in the volumetric collapse of the alveolar ridge that precludes implant placement. An alveolar bone deficiency often demonstrates a significant horizontal component of the bone loss. A width-deficient ridge in many cases consists of a severely resorbed trabecular (spongy or medullary) layer of bone with a buccal cortical plate collapse resulting from lack of masticatory function (lack of functional load). This leads to a narrowed alveolar ridge (Figure 23.1).

The ridge-split procedure (RSP) utilizes a surgical technique that is centered on the repositioning of the buccal cortical plate back to its original (pre-traumatic) position by expanding the ridge's trabecular layer. A particulate inlay bone grafting is often placed in these cases to improve long-term bone stability and prevent relapse [1]. Thus, the ridge-split procedure is a type of alveolar inlay osteoplasty. An endosseous dental implant, if inserted at the time of the split, is placed into a vastly vascularized medullary bone surrounded on both sides by dense cortical bone.

Among complications of the ridge-split procedure using the single- or two-stage approach, a "mistreatment" of the buccal cortical plate is one of the most common. First, a fracture of a thin and often fragile buccal plate can spread during the split and lateral expansion. As a result, only part of the buccal cortical bone (the occlusal or crestal portion) may expand buccally. The other *apical* portion of bone may still be attached to the remaining basal bone. A surgeon may not realize this complication in a closed flap environment and progress to the next stage of bone grafting. The *internally* placed cancellous bone graft that follows can be misplaced and become exposed to the buccal (vestibular) soft tissue. This can compromise the results of bone grafting and implant treatment (Figure 23.2). In 1994, Scipioni et al. [2] discussed the need to maintain an adequate thickness of about 1.5+ mm of the buccal cortical bone during the split. The whole buccal plate (that was subfractured) has to be evenly moved or repositioned during the procedure. The thicker the buccal plate (the layer to be mobilized), the easier this can be accomplished without complications. Staying parallel and close to the palatal (or lingual) cortical plate as well as use of piezoelectric instrumentation

during the split helps to keep buccal cortex integrity. Dual finger guidance (holding the expanding alveolar crest on both sides with a thumb and second finger) helps to "mold" and properly position the buccal fragment of bone. If the buccal plate appears too loose at the time of the split or an immediate implant placement, a horizontal fixation screw can be placed to brace both plates together. An interpositional bone graft, if considered, should be placed internally, into the gap, between the cortical plates.

The second common complication is a complete exposure of the buccal surface of bone at the time of the split (developing a full-thickness flap instead of a partial thickness or limited FT flap). If a split is carried out in this case in an immediate (single-stage) fashion, there is a high probability of a complete fracture of the buccal bone with the formation of a detached devascularized buccal bone fragment [3,4] (Figure 23.3a). A free buccal bone fragment then needs to be fixated to the alveolar ridge with osteosynthesis screws (Figure 23.3b). If it is not done, the fragment is likely to become necrotic and will need to be debrided/removed (Figure 23.4). After a waiting period of 4–6 months, the procedure has to be repeated. A lingual (palatal) plate fracture is rare and can be prevented by positioning chisel osteotomes parallel and not angled to the lingual plate.

Soft tissue complications can happen at the time of flap reflection and include tears of the buccal flap mucosa and periosteal perforation or dehiscence. Atraumatic surgery and attention to detail should hopefully help to reduce these issues. Also in many cases, soft tissue is not fully reflected but is raised together with a buccal portion of bone as an osteoperiosteal vascularized flap.

Using mallet and chisel osteotomes in the craniofacial region has to be gentle and controlled. Ridge-splitting and expansion utilizing these instruments might be unpleasant to patients. Panarrocha et al. [5] described benign (paroxysmal) positional vertigo (BPV or BPPV) as a complication of osteotome expansion of the maxillary alveolar ridge for implant placement. Saker and Ogle [6] presented a case of BPV subsequent to indirect (crestal) sinus lift as a complication of interventions with osteotome and mallet. Symptoms of BPV (BPPV) include a feeling of spinning or tilting (vertigo) during head movement, resulting from inner ear "stones" dislocation. If the



Figure 23.1 (a) Clinical photograph showing typical width-deficient alveolar ridge (posterior mandible) that can be suitable for the ridge-split procedure. (b) Clinical photograph showing characteristic width-deficient alveolar ridge (anterior maxilla) that often derives from the resorbed trabecular (spongy) layer of the bone and buccal cortical plate collapse. (c) CBCT image showing typical width-deficient alveolar ridge that consists of a severely resorbed trabecular layer of bone and buccal cortical plate collapse.

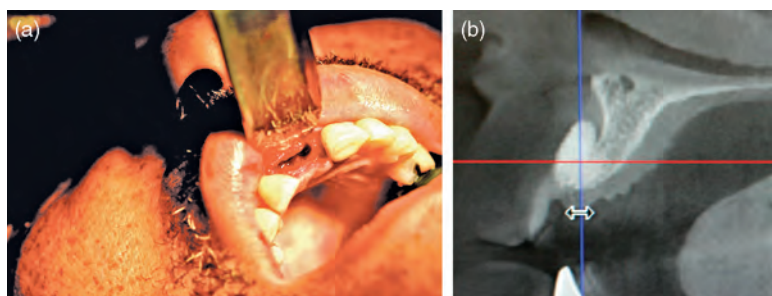


Figure 23.2 (a) Clinical photograph demonstrating complication of the ridge-split procedure that resulted from the accidental fracture of the coronal portion of the buccal cortical plate during the ridge expansion and inadvertent bone grafting into the subperiosteal labial soft tissue space in front of the buccal plate (instead staying between the cortical plates). (b) CBCT radiograph demonstrating complication of the ridge-split procedure that resulted from the accidental fracture of the coronal portion of the buccal plate during the ridge expansion and inadvertent bone grafting of the labial soft tissue space in front of the buccal plate. Source: Tolstunov 2013 [7].

condition does not improve, the ENT doctor might need to perform an Epley maneuver (head exercises) to “reposition” the stones.

The position of the mental foramen and IAN has to be determined pre-operatively on panoramic (taking into account a 20–25% magnification factor) and CBCT radiographs and monitored intra-operatively to prevent neurosensory complications during the mandibular RSP in the premolar region. Other complications, like post-operative infection and extensive bleeding, are rare and, if they happen, can be managed with debridement and antibiotics and local hemostatic agents, respectively.

Implant-related complications are also possible. If an immediate implant is placed incorrectly or with poor primary implant stability, or if a delayed implant is placed too early (less than 3 months) after Stage 1 of the RSP, an implant has a higher risk of non-integration and failure. An implant diameter has to correspond to the expanded ridge (in an immediate or delayed

approach). It seems that a root-form endosseous implant has to have at least 1.5 mm of bone on both buccal and palatal (lingual) sides for a long-term implant success (lasting osseointegration). Tapered implants tend to do better in a ridge-split environment. If an implant is too wide at the time of split and immediate implantation, the ridge expansion can be limited; an implant(s) may “dehiscence” through the buccal plate eventually during the healing period and become exposed to the buccal soft tissue (Figure 23.5). The same can happen if the buccal plate is too thin at the time of the split (Figure 23.6). This may go unnoticed if the buccal flap is not reflected or the post-operative CT scans are not ordered. When diagnosed, secondary grafting with GBR is needed to attempt regeneration of the buccal bone on top of exposed implant threads (Figure 23.7). A staged approach to the RSP seems to reduce the risk of the buccal ridge dehiscence, as well as crestal bone loss, soft tissue recession, and other complications [8].

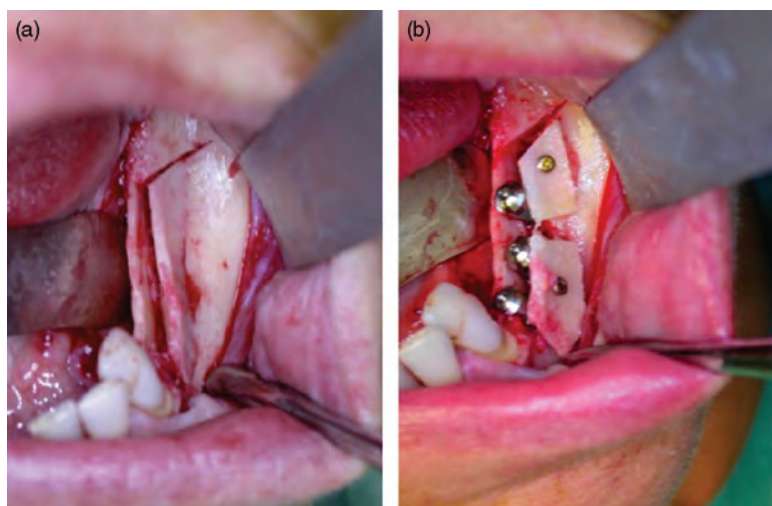


Figure 23.3 (a) Intraoperative photograph of complications of the ridge-split procedure when the whole buccal cortical plate was first fully stripped off the buccal soft tissue and then was fractured off, becoming a non-vascularized piece of bone (“free graft”). (b) Intraoperative photographs of complications of the ridge-split procedure; the fractures and denuded buccal cortex, which was fixated back with miniscrews and implants, were still inserted at the same time (not recommended by the author). Reproduced from References [3] and [4] with permission from Elsevier.



Figure 23.4 Complication of the RSP when the detached buccal cortical plate is completely separated from the soft tissue and eventually became necrotic (bone sequester). Reproduced from Reference [3] and [4] by permission of Elsevier.

Immediate implants should always be longer than the depth of the split to engage the *apical* bone and achieve primary implant stability intraoperatively. In many cases, it is beneficial to use an objective way to measure implant stability. An initial implant torque of 30–35 N cm appears to be a good indicator of implant stability in cases of immediate implants placed simultaneously with the RSP. An Osstell ISQ instrument (Osstell USA, Linthicum, MD) is one of the instruments that can also test the implant stability. Its function is based on the resonance frequency analysis (RFA) as a method of measurement of initial implant stability at the time of implant placement as well as before the restorative stage and functional loading. An implant stability quotient (ISQ) of 65 plus is considered an indication of a well-osseointegrated implant at the time of the restorative stage.

Conclusion: “10 commandments” to become successful in the ridge-split/ridge-expansion procedures

A learning curve has to be considered for a novice surgeon interested in mastering the ridge-split technique. A surgical



Figure 23.6 Intraoperative photograph of a post-operative complication of the RSP demonstrating placement of implants into a deficient ridge with a very thin (less than 1 mm) buccal cortical layer of bone that inevitably would result in protrusion of implant bodies (threads) into the buccal soft tissue months later. (Source: Tolstunov 2014 [9])

practitioner, skilled in a variety of hard tissue augmentation techniques, may have a faster and accelerated learning of the technique described. Many surgeons skilled in an open full-thickness (FT) flap approach for the block grafting technique might have some difficulties with semi-closed full-thickness or split-thickness (ST) flaps specific for the RSP at the initial stage of learning.

The author would like to conclude this part of the book with “10 commandments” that derived from the author’s experience as well as literature on the subject (4, 8–17). These surgical-restorative and patient-related considerations are the following:

- 1 Smokers have a higher rate of failure in both bone augmentation (including the RSP) and implant osseointegration.
- 2 Posterior maxilla due to poor bone quality is the least successful region for the RSP and implant osseointegration;
- 3 Secondary wound closure is standard in the RSP; primary wound closure is the exception.
- 4 Endosseous dental implants have to have at least 1.5 mm of bone on both buccal and palatal (lingual) sides for a long-term implant success (lasting osseointegration).
- 5 The most appropriate timing for delayed implant placement after alveolar bone augmentation (such as the RSP) is 4-to-6 months.

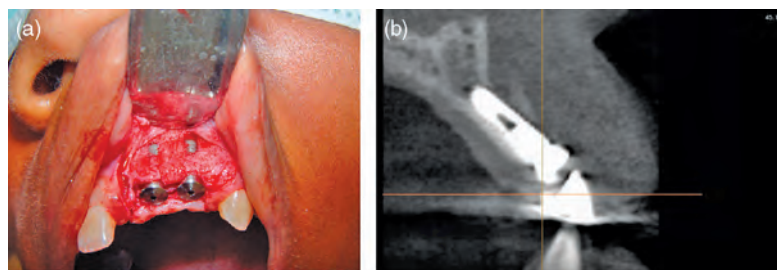


Figure 23.5 (a) Intraoperative photograph of post-operative complication of the RSP showing placement of inappropriately wide diameter implants into a thin ridge resulting in protrusion of implant bodies (threads) into the buccal soft tissue months later. (Source: Dr. Albert Zickmann. Reproduced with permission from A Zickmann.) (b) CBCT image of post-operative complication of the RSP demonstrating placement of an inappropriately wide diameter implant into a thin ridge, resulting in implant perforation into the buccal soft tissue months later.



Figure 23.7 Treatment of a complication of implant thread exposure by delayed secondary bone grafting with the guided bone (GBR) and tissue (GTR) regeneration approach. (Source: Dr. Albert Zickmann. Reproduced with permission from A Zickmann.)

- 6 Tapered implants placed simultaneously with the RSP tend to accommodate better to the expanded ridge than parallel-wall (straight) implants and have less risk of apical perforations.
 - 7 The ideal diameter and length for an endosseous implant immediately placed into the ridge divided and expanded by the RSP is 3.5–4.5 mm in diameter and 11.5–15 mm in length. Implants that are too wide will require more expansion and lead to a more buccal bone resorption. Implants that are too short may not have enough length beyond the split for primary implant stability. A delayed implant placement should follow standard recommendations for an implant choice.
 - 8 A staged approach to any alveolar ridge expansion technique (ridge-split and implants done at separate times) seems to improve surgical control and reduce the complication rate related to both sufficiency of the split as well as the quality of prosthetically driven implant treatment.
 - 9 The presence of an adequate keratinized (or attached) tissue on the buccal/labial gingiva and appropriate depth of the vestibule helps passive soft tissue coverage of an augmented bone/implant site and improves a long-term maintenance and hygiene of the area;
 - 10 It appears that bone augmentation through the RSP is long-lasting. If an implant fails, stability of the expanded ridge usually remains and it is possible to replace an implant in the same area at a later time with often no additional bone grafting required.
- Mobilization of a bone fragment surgically separated from its base can happen in two distinctive ways: static and dynamic. The static way of bone mobilization is described in this section of the

book. It is the basis of the ridge-split procedure. The static method is when surgical bone displacement is accomplished in a single move. The dynamic method is typical for the distraction osteogenesis (DO) procedure when *incremental* bone movement is emphasized. During a DO procedure, the bony segment moves slowly (about 1 mm a day), driven by a rotating mechanism. Distraction osteogenesis and its advantages are described in Section V of this book.

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SECTION V

Alveolar Distraction Osteogenesis for Horizontal Ridge Augmentation in Implant Dentistry

CHAPTER 24

Horizontal Alveolar Distraction Osteogenesis: Diagnosis and Treatment Planning

Sami A. Nizam II and Shahid Aziz

Department of Oral and Maxillofacial Surgery, Rutgers School of Dental Medicine, Newark, New Jersey, USA

History

The concepts of distraction osteogenesis were borne out of the orthopedic literature in Russia in the early 1960s by Ilizarov. It soon found its way to the Western world in the 1980s [1]. By the early 1990s it was successfully being applied to the maxillofacial region [2]. It was shortly after in 1996 that the first reports of alveolar distraction for implant site development were made by Chin and Toth [3]. Aparicio and Jensen were the first to publish on horizontal DO in 2001 [4]. However, since this time a majority of literature and device development has focused on vertical versus horizontal augmentation [5]. It is the goal of this chapter to provide an evidence-based guide to enable correct diagnosing and treatment planning of applicable cases for this underutilized technique.

Molecular biology

To accomplish this, one must first understand the complex cascade of cellular events that take place during distraction. After the initial bony cuts and application of the distractor (discussed in the following chapter) a *period of latency*, typically lasting 5–7 days, is observed to allow the formation of fibrovascular callus [6]. A hematoma is formed at the osteotomy site, as well as the release of inflammatory cytokines interleukin 1 and 6. Bone morphogenetic protein (BMP) 2 and 6 levels begin to rise, recruiting mesenchymal stem cells from the adjacent medullary bone and periosteum. By day 3 the initial clot becomes increasingly fibrous due to collagen and neovascularization, forming a pro-callus [7]. *Ossification* then begins to propagate due to increases in BMP 6 and transforming growth factor beta (TGF- β) [8].

Up to this point, healing is similar to that of a bony fracture. However, once distraction starts, mechanotransduction takes place as bone cells “sense” forces and transform these into biochemical signals capable of inducing intramembranous neo-ossification [7]. Movements of 0.5–1 mm per day are typically undertaken [6]. A central fibrous interzone forms and spindle fibroblasts, present in the callus, begin secreting type I collagen parallel to the direction of distraction. BMP-2,4,6, transforming growth factor *beta* (TGF β), insulin growth factor-1 (IGF-1), and basic fibroblastic growth factor (BFGF) peak during this phase. The receptor activator of nuclear factor kappa-B (RANK) to osteoprotegerin (OPG) levels rise, resulting in resorption of mineralized substrate formed in the initial

callus during the latency phase. Vascular endothelial growth factor (VEGF), as well as angiopieten-1 and -2 induce increasing neovascularization [8]. Of note, a positive correlation between vascularity and quality of bone exists [9].

The third or *consolidation phase* takes place at the conclusion of distraction. The device is then left in place to act as a rigid fixator. This phase typically lasts 8–12 weeks [6]. Levels of all BMPs begin to taper and the remodeling of the newly formed bone is initiated by tumor necrosis factor alpha TNF- α [8]. It is these events that allow supraphysiologic bone responses and shortening of treatment times that will be further elucidated in this chapter.

Diagnosis

Diagnosis begins with a standard implant work-up. A medical history and physical examination are performed. The edentulous site is examined closely, as factors effecting tissue vascularity, bone turnover, and producing scar tissue may adversely affect outcomes [9]. The site is then clinically inspected for morphology, neighboring occlusal scheme, and gross size. If advanced imaging such as computed tomography (CT) is not planned at this time, bone sounding can be undertaken to further appreciate 3D anatomy. Full upper and lower models should be taken. From these the final restoration is planned in conjunction with the restoring dentist. This allows identification of the precise augmentation needed and a guide for future implant placement [10]. Figure 24.1a demonstrates such a case where implant-supported restorations are planned at lower first molar sites bilaterally. An initial examination revealed uneven occlusal planes, as well as ridges that were horizontally deficient. Temporary restorations were milled with the help of computer-assisted design/computer-assisted manufacture (CAD/CAM) after wax-up of ideal occlusal relationships (Figure 24.1b).

Imaging is then undertaken. This could be in a variety of plain films or cone beam computed tomography (CBCT) imaging. The authors prefer CT imaging as it allows a thorough understanding of underlying bone morphology, surrounding structures, as well as the ability to estimate needed distraction distances. The final planned restoration can be simultaneously imaged to provide an even more accurate definition of augmentation needs (Figure 24.1c). If 3D imaging is not available, a radiographic marker should be used to

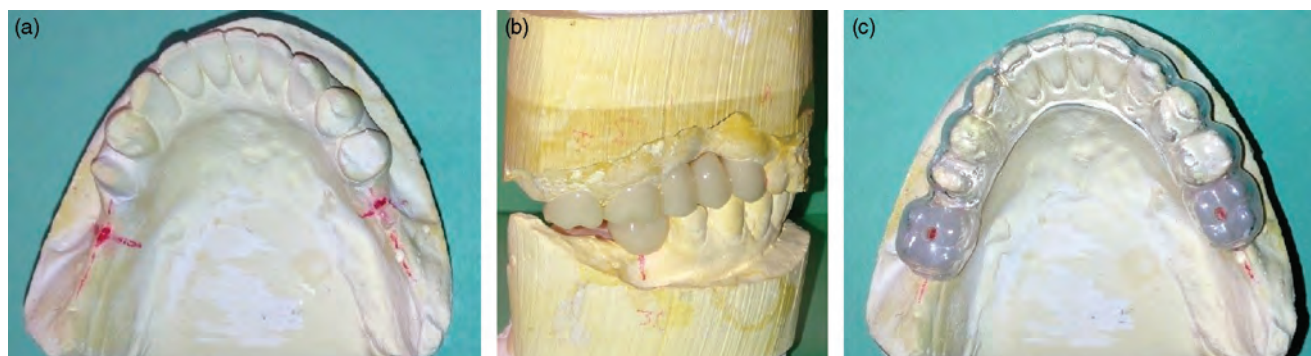


Figure 24.1 (a) Horizontally deficient ridges at bilateral first molar sites, (b) proposed occlusal scheme with computer-aided design/computer-aided manufacture (CAD/CAM) milled temporary restorations, and (c) barium impregnated guides constructed from proposed final occlusal scheme.

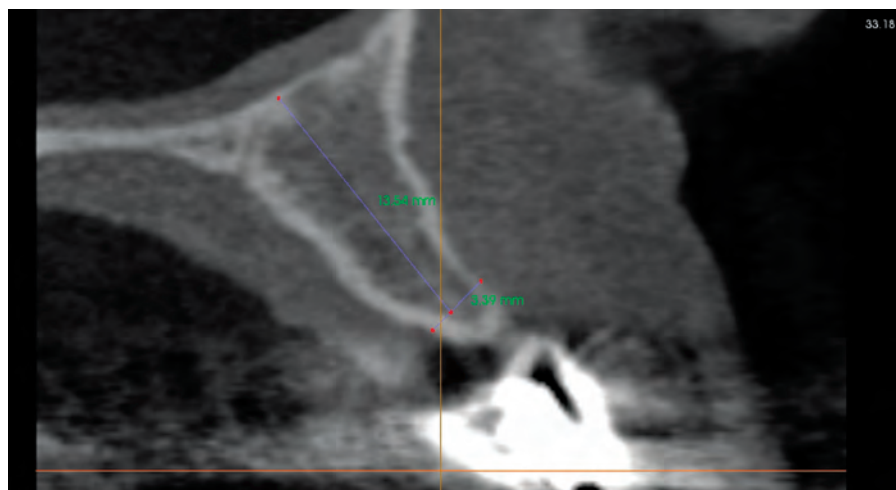


Figure 24.2 Cone beam CT scan of the patient in Figure 24.1 demonstrating the narrow ridge and, more importantly, the lack of bone stock at the proposed implant location.

estimate distortion on plain film and more accurately delineate distances from vital structures such as the mandibular canal. In addition to performing horizontal distraction osteogenesis (HDO), the site must include an adequate vertical height. This information can be obtained from using either of the two techniques above. Figure 24.2 demonstrates the cone beam CT (CBCT) obtained from the patient's anterior maxillary site. Less than four millimeters of bone width is available with an adequate vertical height. Due to bone width deficiency and occlusal relationships, the ideal planned implant site would place a narrow implant platform buccally to the available bone stock. Horizontal bone augmentation is needed in this case to place a regular diameter implant into a restoratively and occlusally driven position.

Classification systems frequently help guide treatment planning. L. Tolstunov recently published his implant driven classification of alveolar ridges based on CBCT imaging determined width and morphology. It consists of Categories I through VII [11]. Although he did not include horizontal DO as a technique in his original article, it can easily be applied to guide the practitioner in appropriate case selection. Horizontal distraction is applicable in class III (4–6 mm) and class IV (2–4 mm) ridges. The minimum ridge width appears to be dependent on the width of the cutting instrument used and risk mitigation. Three millimeters has been used as a cutoff point due to the increasing chance of segment fracture with

narrower ridges [12]. Additionally, any of the classes with the exception of class V can be distracted horizontally if the prosthetic work-up reveals inadequate bone at the planned site of implantation.

Treatment planning

Once the defect has been defined and an appropriate case selected, one must ascertain what advantages horizontal DO has over other techniques that can be used in similar situations. These other techniques, namely guided bone regeneration (GBR), ridge-split, and block grafting, all suffer from disadvantages. These include, but are not limited to, morbidity at the donor site, membrane infection, lack of soft tissue, variable amounts of bone resorption, and lengthy treatment times.

It is for this reason that Funaki and his group in 2009 compared HDO to a ridge-splitting in a dog model [13]. Specifically, they distracted 4 mm with implantation 2 months later versus a ridge split of 4 mm with grafting and immediate implant placement. They found sufficient bone formation compared with a conventional ridge-split, significant increases in keratinized soft tissue, and fully osseointegrated implants at 3 months when placed 8 weeks after the initial distraction. They used a 7-day latency phase and rate of 0.4 mm of distraction a day. Of note, the average bone gain at the

Table 24.1 Distraction osteogenesis versus traditional grafting techniques.

	Traditional techniques (GBR, block, ridge-split)	Distraction
Pros		
Cost	More material cost if allogeneic bone used	Cost of device
Graft resorption	Highly variable – depending on technique and patient factors	Reliable – 20% of distraction distance or transport segment
Time to implantation	4–6 months	Can be as short as 1 month depending on protocol
Keratinized tissue gain	None	Width of distraction
Morbidity	Graft site as well as donor site if autogenous	Less painful than traditional techniques
Cons		
Skill level	Less operator dependent	More operator dependent
Patient cooperation	Minimal	Multiple follow-ups and need for daily activation
Complication rate	Variable	Higher complication rates although majority are minor

end of the study was 2.7 mm in the distracted group versus 1.7 mm in the ridge-split group. Both sides showed marked resorption from the original 4 mm of gain, which they attributed to devascularization of the buccal segment in both cases during flap elevation.

In a recent long-term human study published by Yamauchi and his group in 2013 [5], a mesh distraction device was applied in a similar fashion, with total stripping of the transport segment, as was used in the animal study above. Their average latency time was 9 days. The average distraction was 5.6 mm with an average bone gain after consolidation being 3.6 mm. Implants were implanted in bone at an average of 13 weeks of consolidation and subsequently had 100% survival and 94.2% success rate at a median 5.4 years out. Of note, they experienced a 58% complication rate, although these were all minor complications that did not hinder final implant placement, a majority of which were distractor dehiscence.

Watzak and his colleagues in 2005 published a simplified technique using one or two 1.2 mm bone screws [12]. They used a consolidation period of 7 days, distraction of 0.5 mm per day, and consolidation of 12 weeks prior to placement of 12 implants with 100% osseointegration and functionality at 1 year. They also opted to fully elevate a mucoperiosteal flap of the transport segment. They gained an average of 3 mm, but made no comment on transport segment width resorption. They reported a complication rate of 10%, which was due to the loosening of one microscrew. It was replaced with a 2 mm rescue screw and distraction continued without complications.

Laster et al. published a series of nine patients using a different distractor (Laster Crest Widener, MIS implants, Pretoria, South Africa) [14] that obviates the need for total devascularization of the transport segment during device application. Implants were placed after a short consolidation time of 7–10 days and 20 of 21 implants survived after 12 months of follow-up. An average bone gain of 4–6 mm was observed. This early implantation protocol was based on earlier work by Nasaka, who showed successful early implantation into the regenerate of horizontally distracted bone as long as primary stability was obtained [15]. Of note, one case had crestal resorption late after implant placement and this was the only case with a mucoperiosteal flap elevated. Additionally, no post consolidation measurements were quoted so a comparison cannot be drawn on the effect of devascularization of the transport segment [14].

As eluded to in the diagnostic section, if inadequate bone stock is available to place implants in a prosthetically favorable position, horizontal DO can be used to buccally displace a large alveolar segment. Gaggl and his colleagues demonstrated this when they distracted six narrow anterior maxillary alveolar ridges buccally (six patients). They used the Callus Spreader (SIS-Trade Inc., Klagenfurt, Austria) with a latency of 7 days, distraction of 0.5 mm a day, and a consolidation of 12 weeks with implant placement at that time. They placed a total of 56 implants in six patients' maxillas (some of which had sinus lifting). They recorded seven implant failures: four in the sinus lifted bone and three in the distracted bone. They successfully replaced the failed implants in distracted bone after 3 months of further healing and re-implantation [16].

Although the above case series used different devices and techniques, they all resulted in successful implantation of functional osseointegrated implants with success rates approaching 100%.

For the HDO, the literature has established the following: (1) reliable gain in bone that is amenable to implantation with implants; (2) gain in keratinized soft tissue; (3) shortening of treatment times when compared to traditional techniques; and (4) minimal pain and no need for a separate donor site.

However, drawbacks include being more labor intensive to patient and surgeon, as well as higher complication rates, although these are typically minor and result in no difference in treatment outcomes. Therefore, treatment planning of an alveolar HDO case involves identifying cases that would benefit from these advantages over traditional techniques and selection of the appropriate technique and device for an individual situation (Table 24.1). What follows is a literature-based discussion of how to select these factors.

Distractors

Despite the scarcity of literature, multiple distractors are available or can be fabricated specifically for HDO. As vertical alveolar distractors are commonly classified into extraosseous or intraosseous, so too can horizontal alveolar distractors.

Extraosseous

The most commonly quoted in the literature is the Alveo-Wider (Okada Medical Supply, Tokyo, Japan). This is a mesh-style distractor that commonly requires total de-gloving of the transport

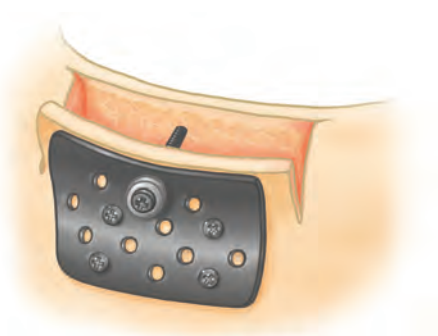


Figure 24.3 Alveo-Wider (Okada Medical Supply, Tokyo, Japan).

segment for application. It is affixed to basal bone apically and the transport segment coronally with 1.2 microscrews. A 2 mm width distraction screw is placed centrally in the mesh, which provides a horizontal distraction force against the lingual bone as it is incrementally activated [17]. The device is shown in Figure 24.3. Advantages of this device include good control of the transport segment and ability to fixate the transport segment in multiple locations if fracture of a thin ridge occurs during splitting. As it is the most published, it has a proven track record of success. Disadvantages include a tipping direction of distraction as the screw becomes activated, the need to strip large areas of periosteum off the transport segment, rendering it avascular, dehiscence of the tissue covering the distractor leading to inflammation, the need to remove the device, thus requiring large areas of stripping, and the cost [5].

Although in a sense an intra- and extraosseous distractor, the Laster Crest Widener (MIS implants, Pretoria, South Africa), is presented here for simplicity (Figure 24.4), it is also available for commercial purchase. It consists of 4 arms. These arms are seated at the crest with the arms placed between the buccal and lingual cortex. Each of the two arms move in opposite directions with screw activation moving the buccal cortex laterally [18]. Advantages of this device include the ability to place without stripping of the periosteum, the ability to place implants with little or no consolidation phase, and easier troubleshooting since the device is visible throughout the distraction. Disadvantages are cost, its exposed position, which can cause problems with temporary restorations, and easy disturbance of the device. Additionally, the device cannot be left in place for a full consolidation period, as it would become hard to retrieve once the regenerate has solidified.

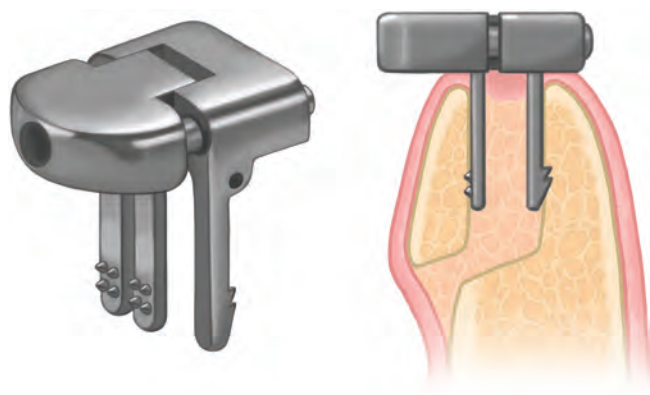


Figure 24.4 Laster Crest Widener (MIS, Pretoria, South Africa).

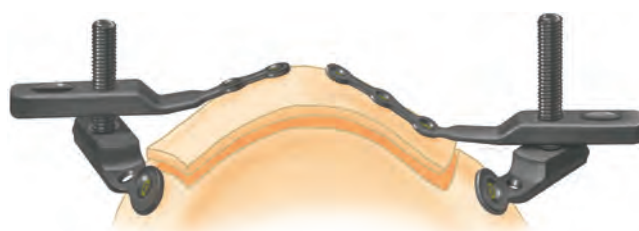


Figure 24.5 The Callus Spreader (SIS-Trade Inc., Klagenfurt, Austria).

The Callus Spreader (SIS-Trade Inc., Klagenfurt, Austria) is a device that consists of two mini plates. One is secured to the transport segment and one is secured to solid bone to act as a base plate. A 12-mm screw fits and spins freely in the base plate and engages a thread on the transport plate [16]. Figure 24.5 depicts the device. Advantages of this device include sturdy construction, good vector control, and literature backing greater than >10 mm distractions. Disadvantages include price and bulkiness of the device, which limits its usability to anterior alveolar segments.

Intraosseous

The LEAD distraction system (Stryker, Kalamazoo, MI) was designed as an intra-alveolar vertical distractor. It has been used in the literature with slight modification, which involves not placing its footplate into the distraction site. Instead, the transport portion is merely attached to the buccal aspect with miniscrews and the distraction screw engages the lingual cortex (Figure 24.6). Advantages include easy temporization and the ability to add a vertical component to the distraction, depending on device angulation. Disadvantages include unpredictable vector control due to slippage of the distraction screw against the lingual plate, device cost, and the need to strip the transport segment for application as well as retrieval, although to a lesser extent than mesh-type distractors [19].

Although not frequently cited in the literature a device is available through KLS Martin (Tuttlingen, Germany) that consists of a distraction screw available in multiple lengths, transport segment fixation plates, and fixation screws [20]. It can be viewed in Figure 24.7. This device is almost identical to the LEAD system (Stryker, Kalamazoo, MI) when used as modified above. Intuitively it carries the same advantage and disadvantages. However, the distraction screw has a pointed, non-threaded end that rests on

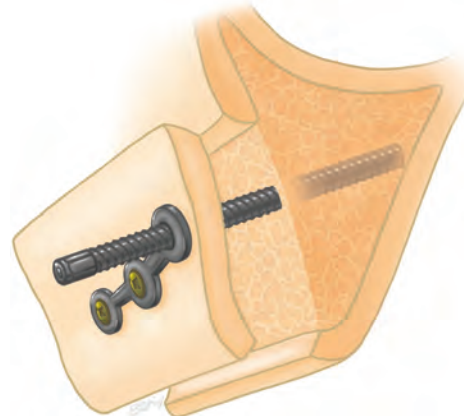


Figure 24.6 Modified LEAD (Stryker, Kalamazoo, MI).

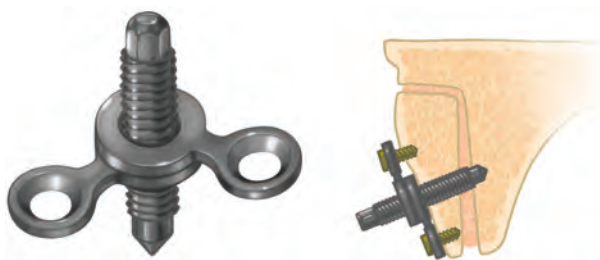


Figure 24.7 KLS Martin (Tuttlingen, Germany).

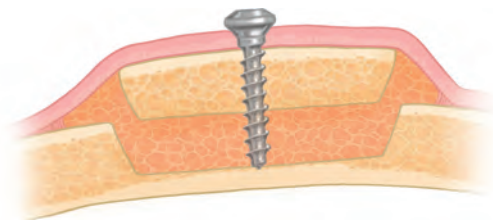


Figure 24.8 Microscrews.

the lingual plate, which theoretically may avoid slippage and loss of vector control upon distraction.

One of the simplest devices cited in the literature uses titanium microscrews (Figure 24.8). Watzak and his group published this technique in 2005, as described above. The screws engage the bone of the transport segment and rest against the lingual cortex, similar to the commercial systems above. Multiple screws can be placed to improve stability and vector control. Advantages include price, simplicity, and the ability to place and remove with minimal tissue stripping. Disadvantages include stability issues and possible screw loosening [12].

One can see how choosing the appropriate device for a given defect could yield superior results. If one encountered an extremely narrow mandibular ridge with dense cortices, a higher chance of an unfavorable split with multiple fragments would be possible. The Alveo-Wider (Okada Medical Supply, Tokyo, Japan) would be a good choice due to its mesh design allowing multiple fixation points for possible fragmented segments. If site development had to be kept to an absolute minimum cost, a single microscrew could be used. If treatment time was to be kept to a minimum, the Lester Crest Expander (Surgi-Tech, Belgium) could be used.

Technique selection

Unlike alveolarvertical distraction osteogenesis (VDO) where the transport segment remains pedicled to the transport segment, a majority of cases in the literature of alveolar HDO describe complete stripping of the mucoperiosteum to allow access for osteotomy and device application. This point was brought up in an article by Garcia-Garcia in 2005 [21]. He described the technique of transporting the devascularized transport segment as dynamic guided bone regeneration and not traditional distraction osteogenesis. This concept is similar to what we now call periosteal distraction, which is described elsewhere in this book. His modified technique described using osteotomes with two incisions, a crestal and small vestibular. Through these, mesial and distal vertical tunnels are created. The standard four osteotomies are then completed and a modified LEAD system (Stryker, Kalamazoo, MI) is then placed. He felt using this technique obviated the resorption of the transport

segment, as is commonly seen when complete stripping is undertaken.

However, since this time, researchers have distracted completely avascular transport segments in dog mandibles with success [22]. They theorize that vascularity of the transport segment may not be as important as once thought and demonstrated that mature bone had replaced the transport segment at 12 weeks. In fact, they noted that the avascular block underwent similar histologic change, as did the regenerate. Although they cite the need for further research, they felt this phenomenon was in part due to the complex up-regulation of genes and production of growth factors that mechanical tension places on all peri distraction tissues.

Due to scarcity of the literature, no scientific comparison can be made in regards to the matter. Until then, sound biologic principles should be adhered to and pedicles should be maintained whenever possible. As noted earlier, some devices inherently allow this, such as the Lester Crest Expander (Surgi-Tech, Belgium). Others, such as a single microscrew, decrease the need for exposure for application. However, if a larger segment is being distracted, even a larger mesh-type distractor can be applied using the technique described by Aikawa [23].

Selection of distraction protocol

What follows below is a discussion on selection of the protocol to be used. While reading each section, Table 24.2 can be referenced to provide a prospective to currently cited protocols in the literature.

Latency

Latency periods in the currently published literature for horizontal DO are remarkably similar to most protocols calling for a period of 7 days. The range is from 5 to 9 days. However, Moore et al. published a randomized controlled trial in dogs transporting alveolar segments comparing no consolidation with the 5-day period. They found no statistically significant differences in regenerate formed. Of note, though, is the fact that their transport segment remained pedicled to the lingual, and they found poorer regenerate on the buccal site where their segment was stripped [24]. Incision design also plays a role, as Takahashi noted dehiscence at the crest using a 7-day consolidation period [17]; however, Watzky noted no such problem when using a buccal vestibular incision [12]. Additionally, Garcia-Garcia used a 5-day latency period with a crestal and buccal vestibular incision and experienced no dehiscence [21]. At this time, 7 days appears to provide a good compromise between minimal complications, maximal gain, and time saving.

Rate

A majority of the studies available at this time use rates of approximately 0.5 mm a day with a range from 0.4 to 1 mm. Spencer and his group also looked at the optimal rate of alveolar distraction using the same dog model above. They found no difference between rates of 1 and 2 mm a day. However, as noted above, he was transporting alveolar segments with lingual pedicles [25]. Again, if the buccal segment remains pedicled, a rate close to 1 mm can be chosen, but if the segment is stripped during device placement it may be wiser to apply 0.5 mm of distraction a day as this has been found effective in the literature.

Rhythm

A majority of papers available on horizontal DO use a bi-daily distraction rhythm where the total daily rate is split into two, usually in the morning and the evening by the patient. Al Ruhaimi found

Table 24.2 Horizontal alveolar DO protocols.

Lead author	Year	Latency period	Distraction rhythm and rate per day	Consolidation period	Implant loading after placement	Device
Nosaka	2002	7 days	1 mm	12 days		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Takahashi	2004	7 days	2 × 0.225 mm	8 weeks	16 weeks	Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Nosaka	2005	7 days	1 mm	12 days		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Aikawa	2008	7 days	2 × 0.225 mm	20 weeks		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Funaki	2009	7 days	0.4 mm	8 weeks		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Sun	2009	9 days	2 × 0.25 mm	8 weeks		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Yamauchi	2013	9 days	2 × 0.2–0.4 mm	13 weeks		Alveo-Wider (Okada Medical Supply, Tokyo, Japan)
Bulut	2010	7 days	2 × 0.45 mm	12 weeks	12 weeks	Custom mesh-type distractor
Gaggl	2005	7 days	2 × 0.25 mm	12 weeks	16 weeks	The Callus Spreader (SIS-Trade Inc., Klagenfurt, Austria)
Laster	2005	7 days	2 × 0.2 mm	7–10 days	16 weeks	Laster Crest Widener (MIS, Pretoria, South Africa)
Garcia-Garcia	2004	5 days	0.5 mm	12 weeks		Modified LEAD (Stryker, Kalamazoo, MI)
Oda	2004	7 days	2 × 0.4 mm	8 weeks	16 weeks	Modified LEAD (Stryker, Kalamazoo, MI)
Watzak	2006	7 days	0.5 mm	12 weeks	16 weeks	Microscrews

there was no difference in using a bi-daily versus a single distraction of 1 mm per day using a rabbit mandible model [26]. Again, this may not apply if the blood supply is not maintained to the transport segment, but selecting a single distraction daily may lessen the burden on the patient. Either method seems to be effective in regards to HDO.

Amount of distraction

There is no question, relapse occurs during alveolar distraction. Nosaka's dog studies found almost complete resorption of the transport segment that he attributed to devascularization of the transport segment and flaws in the distraction device. His recommendation was to perform a large enough distraction to compensate for resorption of the transport segment [15,27]. Interestingly, this phenomenon occurs as well in vertical distraction, even when the blood supply is maintained to the transport segment. Most studies quote a 20–25% relapse. They attribute this to tilting of the segment due to active transport segment resorption and tilting of the distracted segment [28]. Therefore, when performing horizontal distraction, the segment should be over distracted enough to allow full resorption of the transport segment if it occurs.

Consolidation and implantation

Most of the currently cited protocols use a consolidation period of 12 weeks. However, Laster in 2005 and Nosaka in 2002 used periods of 1–2 weeks successfully after horizontal alveolar DO [14,15]. Nosaka noted no difference in bone healing of the distracted bone when implants were placed versus distracted bone without implants [15]. Faysal researched this question comparing a 6-week consolidation phase versus a 14-week consolidation phase while performing vertical alveolar DO. He found no statistically different outcomes. He theorized that this may be due to increased vascularity in the maxillofacial region and concluded that shorter consolidation times should be employed to shorten the overall treatment time [28]. Current data indicates that times from 2 to 12 weeks are effective and can be safely used.

Prosthetic loading

Of the studies cited in this chapter, six reported the time to loading of implants as 3–4 months, which is consistent with traditional implant loading times [29]. To date no studies have been published using earlier loading protocols. However, there is no reason to believe that implants placed in mature distracted bone would behave any differently than native bone, as noted by the histopathology studies by Chiapasco [30].

Putting it all together

Table 24.3 provides the authors' protocol based on current literature in the left column. The right column provides more aggressive protocols that have been used successfully for horizontal DO taking advantage of the unique metabolically active environment that distraction induces. The final column depicts total treatment times to prosthetic loading of integrated implants. This time is based on placement of a 4.3-mm wide implant into a 3-mm ridge. This requires distraction of bone to achieve 8 mm of width initially and allows total resorption of the transport segment if this occurs, giving a final width of 6.5 mm.

Table 24.3 Authors' protocol and shortened protocols cited in the literature.

	Authors' recommended time periods	Literature proven shortened periods
Latency	7 days	5 days [21]
Rate	0.5 mm daily	1 mm daily [27]
Rhythm	Once daily	Once daily [27]
Consolidation	8 weeks	1 week [14]
Prosthetic loading	16 weeks	12 weeks [31]
Total treatment time*	36 weeks	15 weeks

* Total treatment time calculated for placing a 4.3-mm implant into a 3-mm ridge. This requires distraction of bone to achieve 8 mm of width initially and allows total resorption of the transport segment if this occurs, giving a final width of 6.5 mm.

Consultation

The patient consultation is perhaps the most important step in treatment planning of any case. HDO chapters in this section, including complications, provide a framework to undertake an educated discussion with the patient, paying specific attention to their role in the process. One must make the patient aware that small allogeneic grafts may be required at the time of implant insertion to provide an optimal prosthetic implant placement.

Patient acceptance of alveolar distraction has been studied and reported to be 8.1/10 at the end of treatment (0 being completely dissatisfied and 10 being completely satisfied) [32]. Pain is another factor that patients often inquire about, as slowly turning a screw in one's jaw daily evokes feelings of discomfort. This was also studied by Allias and his group, who compared patient's pain with distraction osteogenesis and autogenous grafting, where 70% stated that the autogenous grafting was more painful [33].

Conclusion

Horizontal DO is an underutilized technique at this time that produces predictable results in a timely fashion with high rates of patient acceptance. Success is dependent on selecting appropriate cases such as Tolstunov class III and IV ridges with adequate vertical bone height after full prosthetically driven diagnostic work-up. As distraction osteogenesis is more labor intensive than traditional techniques, Table 24.1 should be used as a guide to select DO over traditional techniques.

The correct device should be selected, as each provides distinct advantages in different clinical situations. As mentioned earlier, the blood supply should be maintained to the transport segment, if possible. A protocol must then be selected and Table 24.3 can help to provide guidance in selection. Once treatment planning is complete and the surgeon and patient have discussed all risks and benefits, the surgical treatment can commence, which is detailed in the following chapter.

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Horizontal Alveolar Distraction and Periosteal Expansion Osteogenesis

Kensuke Yamauchi and Tetsu Takahashi

Department of Oral and Maxillofacial Surgery, Tohoku University Graduate School of Dentistry, Sendai, Japan

Introduction

Following tooth loss, deficiencies in alveolar ridge bone height and width limit the use of dental implants. Clinically, the greatest loss of the alveolar ridge is usually in the horizontal dimension [1]. Recently, ridge augmentation has been adopted for both functional and aesthetic implant-supported restoration of the atrophic, narrow alveolar process. Bone grafting with an autogenous block bone graft, guided bone regeneration (GBR), and ridge-split expansion techniques have been used for this purpose [2–4]. However, these procedures have disadvantages, such as the need for surgical intervention and harvesting bone, unpredictable bone resorption, and difficulty with soft tissue coverage that have a risk for following wound dehiscence.

Ilizarov established the concept of distraction osteogenesis (DO) for orthopaedic surgery in the early 1950s [5]. Subsequently, McCarthy et al. introduced the technique to oral and maxillofacial surgery [6]. In 1996, alveolar DO was introduced as an effective new technique for ridge augmentation [7] and the vertical alveolar DO technique is now applied widely to correct alveolar ridge defects or atrophy. The advantages of DO over bone grafts or GBR include the lack of the need for a donor site and simultaneous lengthening of the surrounding soft tissues. Horizontal DO for correcting narrow alveolar ridges has also been reported [8–10].

This chapter presents a horizontal DO using a titanium mesh device, developed based on animal research and clinical application, and a further technique of grafted bone DO, periosteal expansion osteogenesis using a β -TCP block and a shape memory alloy mesh device for minimum invasive treatment.

Horizontal alveolar distraction osteogenesis

Device

The horizontal distraction device consisted of a 0.3-mm-wide commercially pure (CP) titanium mesh plate and a pure titanium distraction screw 2 mm in diameter and 12 mm in length (Alveo-Wider®, Okada Medical Instrument Supply, Tokyo, Japan) (Figure 25.1). As most of the transport segment in the horizontal distraction is thin, the segment can be difficult to fix with the distraction device. The mesh-type device used a 1.2-mm-diameter titanium microscrew placed in the transport segment and stabilized

to the remaining mandible. The mesh structure has many holes for inserting microscrews, which is an advantage, especially when the transport segment is fractured. The device moves 0.4 mm with one turn.

Surgical procedure

The DO procedure was performed under local anesthesia with/without intravenous sedation. A crestal incision was made, which extended vertically on the mesial and distal sides. The mucoperiosteum was reflected, exposing the labial surface of the bone. First, a vertical osteotomy was performed using a reciprocating bone saw. This was followed by a horizontal osteotomy to the depth of the buccal plate using an oscillating saw. Finally, a splitting osteotomy was completed using a reciprocating bone saw and a thin-bladed osteotome, and the transport bone was then displaced labially by making a horizontal greenstick fracture apically (Figure 25.2). The horizontal distraction device was set on the transport bone and fixed to the segment using 1.2-mm-diameter titanium microscrews (Figure 25.3). The hole was made in the transport segment allowing the distraction screw to touch the lingual cortex. An activation trial

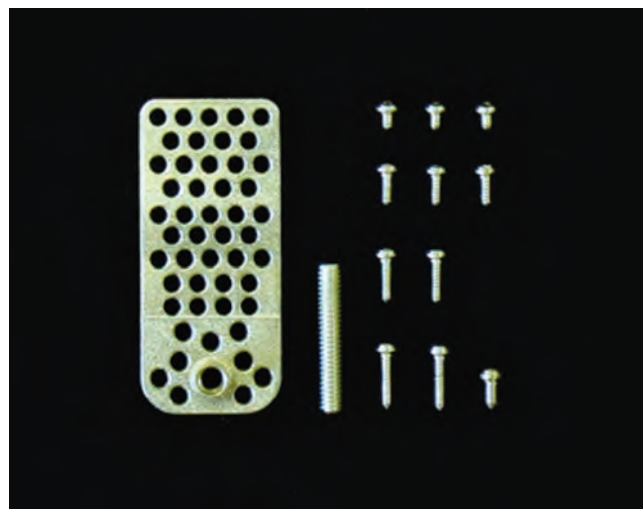


Figure 25.1 Horizontal alveolar distraction device; Alveo-wider®.

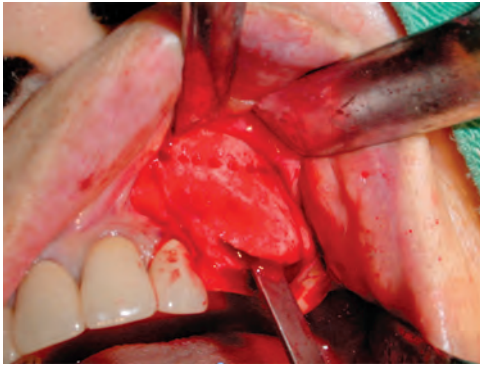


Figure 25.2 Greenstick fracture using a chisel.

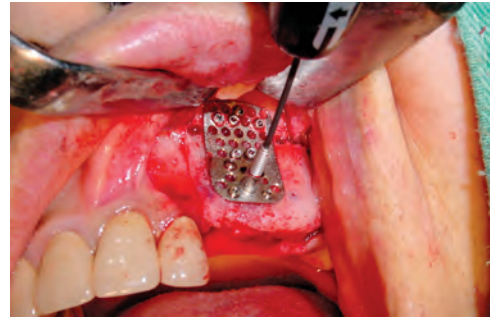


Figure 25.4 Trial distraction was done by turning the activation screw.

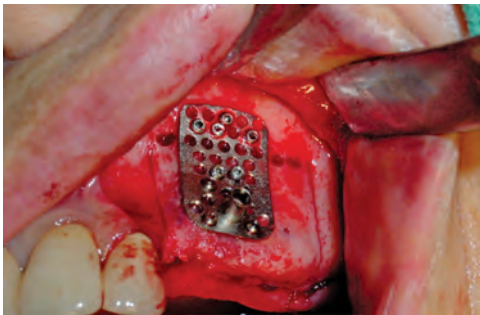


Figure 25.3 Setting a distraction device. Mesh device was fixed with screws.

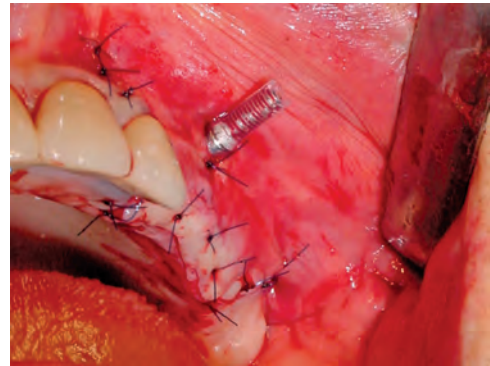


Figure 25.5 The flap was closed and the activation screw was penetrating from the flap.

was performed to confirm the mobility of the transport segment (Figure 25.4). The distraction screw was returned to the initial position following wound closure using nylon sutures with the distraction screws protruding from the flaps (Figure 25.5).

Post-operative protocol

After a latent period to allow periosteal healing and early revascularization, the distraction devices were activated by turning the distraction screws 0.2–0.4 mm twice a day. Activation of the distraction device was continued until the target amount was achieved. No provisional/removal prostheses, except for the incisor region, were used in the distraction area due to the technical difficulties caused by the presence of the distraction device and in order to avoid interfering with the healing phase. After the

consolidation period, the devices were removed and implants were placed in the distracted areas using a prefabricated surgical template (Figure 25.6).

Compared with vertical DO, there are some technical difficulties with horizontal DO. First, a splitting osteotomy is necessary and a splitting osteotomy for a thin alveolar ridge can be extremely difficult with the risk of cracking or fracturing the transport segment, even when the osteotomy is successful. Second, the transport segment must be freed from the periosteum, because the splitting osteotomy must be completed in addition to the horizontal osteotomy. A titanium mesh plate was used to stabilize the transport segment. The advantages of using a titanium mesh plate for this purpose are as follows. First, titanium mesh is strong enough for stabilizing the transport segment, even if the transport

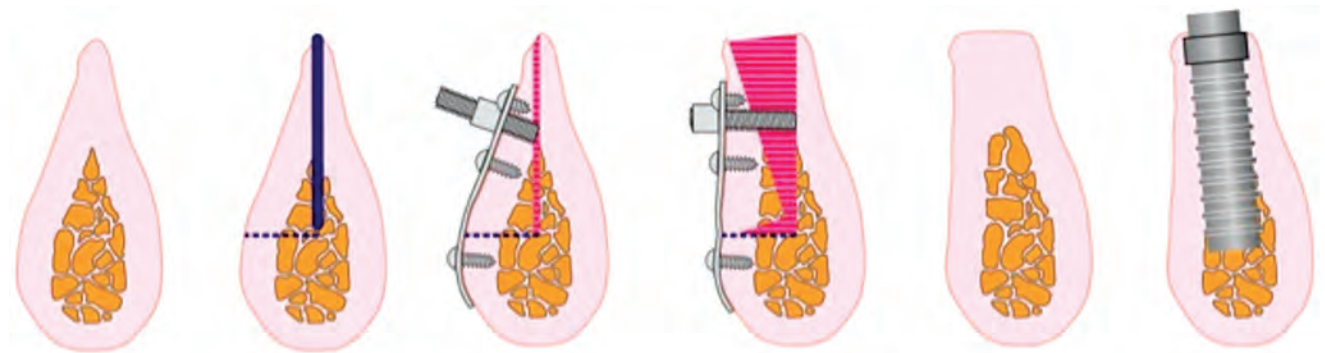


Figure 25.6 Schematic images of horizontal alveolar distraction osteogenesis using Alveo-wider®.

Case report

A healthy 51-year-old female presented with a chief complaint of masticatory dysfunction. She had been using removable partial dentures for the maxilla and mandible and had been suffering from instability of the mandibular denture because of advanced periodontitis involving the abutment teeth (right mandibular lateral incisor and canine). After these teeth were extracted, she insisted on having an implant-supported prosthesis instead of a removable denture. Computed tomography (Aquilion, Toshiba Medical, Co., Japan) revealed that her anterior alveolar ridge was extremely thin, being 2 mm wide at a level 3 mm from the apex of the alveolar crest (Figure 25.7). The initial plan was to perform bone grafting for implant placement. However, the patient refused to undergo bone grafting. Therefore, horizontal DO of the anterior mandibular ridge was chosen to augment the alveolar ridge after conventional implant placement in the posterior molar region bilaterally.

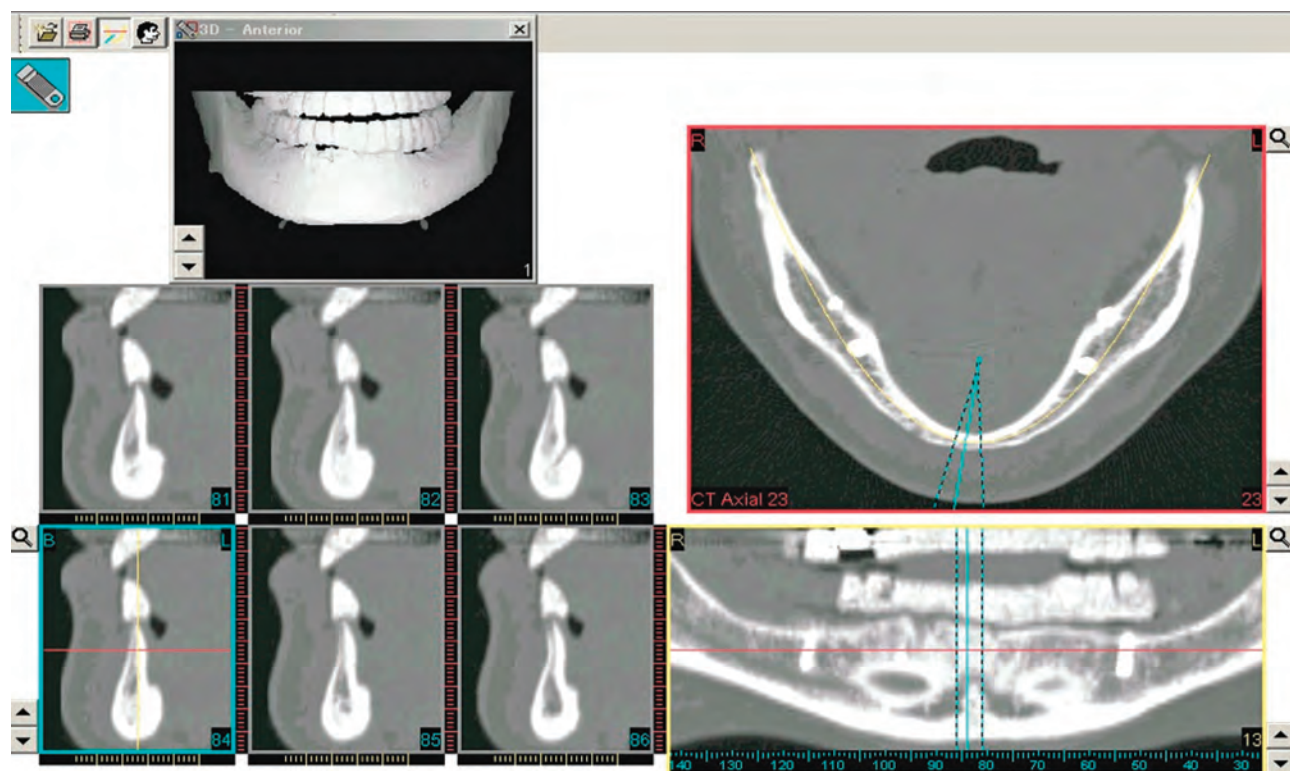


Figure 25.7 Preoperative CT images. Narrow alveolar process can be seen.

segment cracks or fractures after the splitting osteotomy. While there was a crack in the right transport segment in this operation, the crack had completely disappeared by the time the distraction device was removed. Second, a titanium mesh plate may prevent the transport segment from resorbing because of pressure transmitted via the labial soft tissue.

In the previous report, the keratinized tissue gain on the DO side was greater than on the bone splitting side in dog model [11]. In conventional bone grafting and vertical alveolar distraction, the elongation of the soft tissues involves mainly the movable mucous membrane. In contrast, with horizontal DO using this device, the elongation of the soft tissues involved the keratinized tissue, probably because a crestal incision was made within the keratinized tissue in our method, which resulted in a direct increase in the keratinized gingiva of the alveolar crest area. The elongation of the keratinized soft tissue seems to be a major advantage of horizontal DO that would avoid the need for surgery to acquire keratinized tissue for cosmetic purposes. In addition, the physical stress, costs, and treatment period could be reduced.

Surgical procedure

The patient was anesthetized with local anesthetic and intravenous sedation. A crestal incision was made and extended vertically mesial to the first molar region. The mucoperiosteum was reflected, exposing the labial surface of the mandible. First, a vertical osteotomy was performed using a reciprocating bone saw. This was followed by a horizontal osteotomy to the depth of the buccal plate using an oscillating saw (Figure 25.8). Finally, a splitting osteotomy was completed using a reciprocating bone saw and a thin-bladed osteotome and the transport bone was then displaced labially by a horizontal greenstick fracture apically (Figure 25.9). In this manner, a transport bone segment was made from the central to the canine region bilaterally. A horizontal distraction device consisting of a 0.3-mm-wide CP titanium mesh plate and a pure titanium distraction screw 2 mm in diameter and 12 mm in length (Alveo-Wider®, Okada Medical Instrument Supply Co. Ltd., Tokyo, Japan) was attached bilaterally using a titanium microscrew (1.2 mm in diameter) placed in each transport segment and stabilized to the remaining mandible (Figure 25.10). The wounds were closed with 4-0

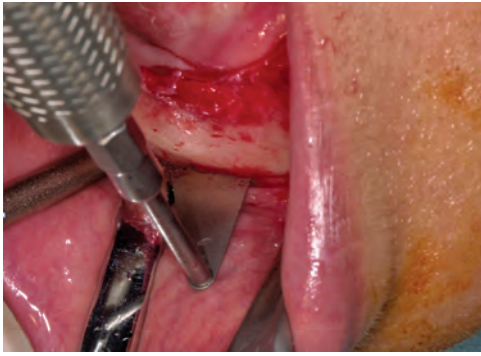


Figure 25.8 Transport segment was made by using a microsaw to cut the cortical bone.

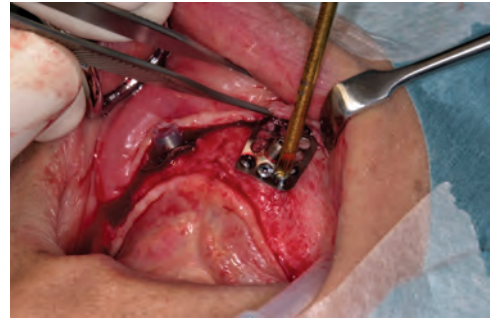


Figure 25.12 Intraoperative photograph at device removal. The distraction gap was filled with newly formed bone.

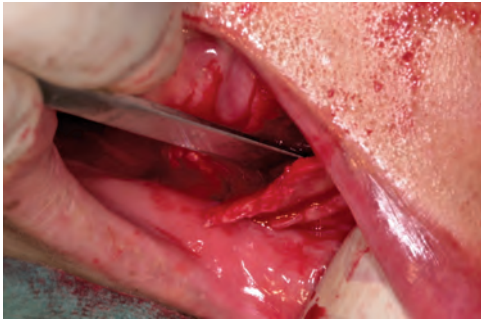


Figure 25.9 Greenstick fracture was done by a chisel inserted from the alveolar ridge.

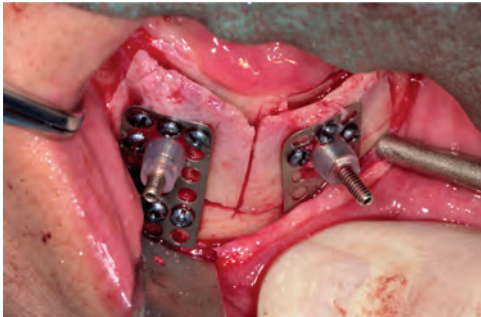


Figure 25.10 Alveo-wider® devices were set on the mandibular bone in the anterior region.



Figure 25.11 The flap was closed with sutures; activation screws were penetrating from the flap.

Gore-Tex® suture (Johnson & Johnson, Somerville, NJ) with the distraction screws penetrating from the flaps (Figure 25.11).

Post-operative protocol

After 7 days to allow for periosteal healing and early revascularization, the distraction devices were activated by turning the distraction screws 0.225 mm twice a day, for 14 consecutive days on the left side and for 12 days on the right side. In all, the alveolar process of the anterior mandibular region was widened to 6 mm at a level 3 mm from the apex of the alveolar crest on both sides. During distraction, there were no apparent problems except a small dehiscence was observed in the middle of the flap. The patient was instructed to rinse her mouth daily with chlorhexidine chloride solution. After consolidation for 3 months, the devices were removed and it was confirmed that the distracted areas were completely filled with newly formed bone (Figure 25.12). Post-distraction CT (Newtom, Italy) confirmed that the alveolar process had widened to 5.8~6 mm at 3 mm from the apex of the alveolar crest (Figure 25.13). Two months after distraction device removal, four 13-mm-long standard Astra Tech Implants (Astra Tech AB, Göteborg, Sweden), all 3.5 mm in diameter, were placed in the distracted areas with good initial stability (Figure 25.14).

Four months after implant placement, the implants were uncovered and abutments were connected (Figure 25.15). A bone-anchored fixed definitive prosthesis was then fabricated and put in place (Figure 25.16). No significant marginal bone resorption was seen around the implants 7 years after implant placement (Figure 25.17). The patient has been using this prosthesis with satisfactory function and great satisfaction.

Alveolar distraction osteogenesis using grafted bone (periosteal expansion)

In an experimental study of horizontal DO, woven bone was observed in the distraction gap at 12 weeks and new mature lamellar bone was observed at 24 weeks. In addition, most of the transport segment was absorbed [11,12]. They suggested that in a clinical setting, horizontal DO should not be performed until at least 5 mm of callus elongation is present, and the implant should be placed approximately 2 mm away from the transport segment. This resorption of the transport segment probably occurred because the periosteum was completely reflected from the transport segment and not pedicled. The possible mechanism of bone formation with this horizontal DO method seems to depend mainly on the

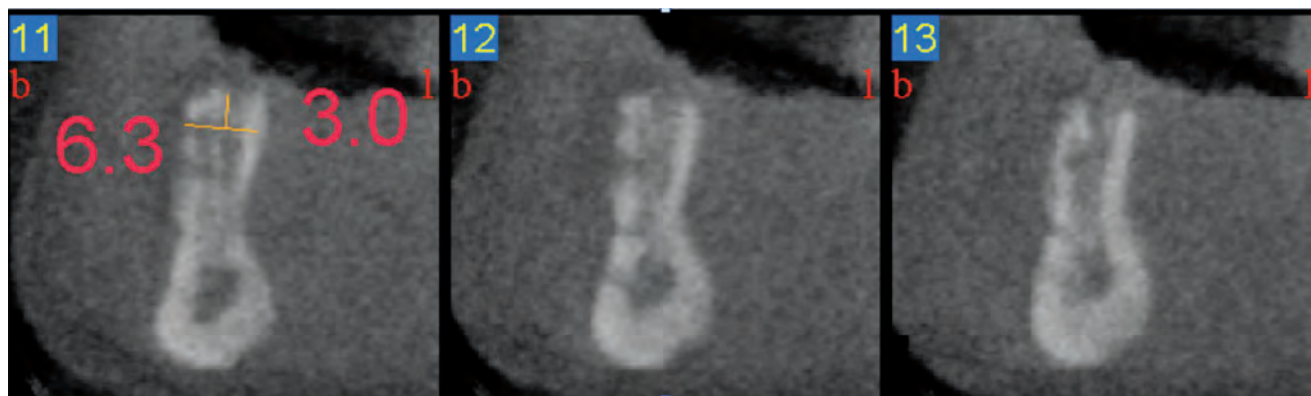


Figure 25.13 CT images at the consolidation period of 6 months.

periosteum. Therefore, this method is not conventional “bone distraction”, but is “periosteal expansion” [14,15]. As Garcia-Garcia and Somoza-Martin commented, this method is not true bone distraction, but instead *dynamic guided bone* regeneration [16]. The role of the transport segment seems to be as a continuously expanding space maker.

Based on this concept that “transport segment works as a space-maker under the periosteum”, it is not necessary to make the transport segment from the original bone surface but can be done using a block bone substitute from another region. Considering clinical situations, there are many cases with severe atrophic jawbone that do not have enough to make the transport segment

using saw or burs, especially in cases after marginal jawbone resection. The experimental study of the dog model also showed newly formed bone tissue in the gap between the grafted block bone and the original bone surface by making the space in the same manner as with horizontal alveolar DO (Figures 25.18 and 25.19). This result suggested the possibility that a severe atrophic jawbone could be augmented by the distraction protocol without any bone cutting at the original bone. It has also some advantages because this procedure acquires not only bony tissue but also soft tissue, so the risk of dehiscence and difficulty of initial closure after the bone augmentation might be decreased, especially for patients with a tight scar. However, there are disadvantages to this technique, such as device costs, the physical burden during the activation phase, local symptoms around the activation screw, and the need for a second operation to remove the device. According to this technique, the transport segment was detached from the periosteum completely; consequently, there was no vascularity to the segment, so post-operative resorption had to be estimated and overcorrection was needed to acquire the sufficient volume. The latency period is based on the mobility and size of the transport segment at the operation and might need a longer period compared with the original DO protocol. Consequently, the total period until the end of activation is about 1 month. Conventional techniques, such as veneer block bone grafts or GBR, usually involve fewer difficulties in terms of post-operative management.



Figure 25.14 Panoramic radiographic images after implant insertion.



Figure 25.15 Intraoral photograph after setting of healing abutments.



Figure 25.16 The final prosthesis was set.

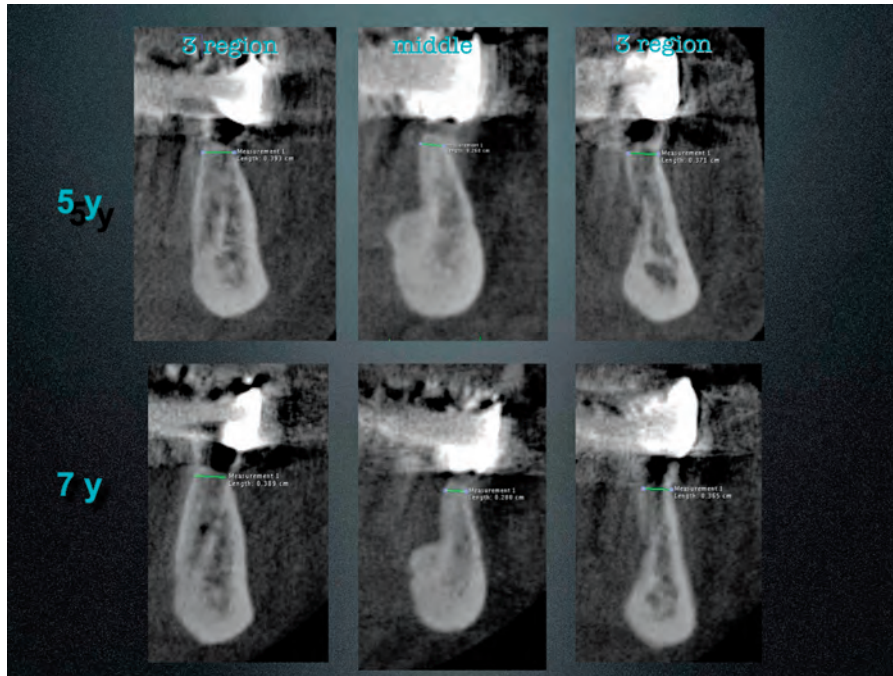


Figure 25.17 Computed tomography (CT) images at post-operative 5 and 7 years.

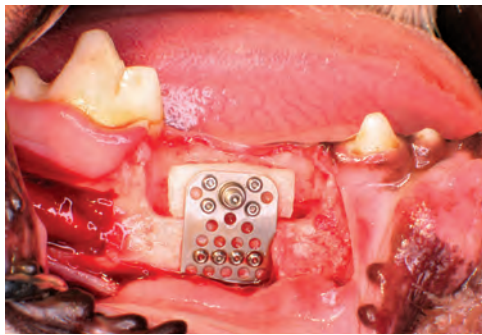


Figure 25.18 Animal experimental study of alveolar distraction osteogenesis using grafted bone. The bone block was taken from the posterior side of the distraction area.

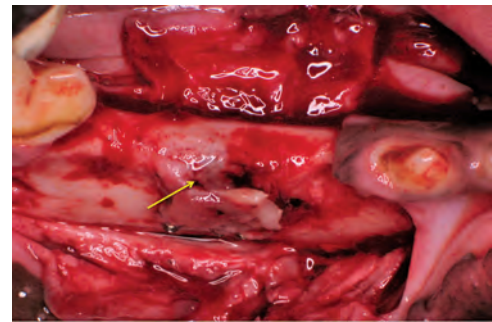


Figure 25.19 Newly formed bone was observed at the gap between the transport segment and the original bone surface (yellow arrow).

Case report

A healthy 23-year-old male presented with a well-circumscribed multilocular radiolucency on a routine radiograph. After a biopsy for the cystic region in the mandible, histological findings showed ameloblastoma. The unicystic ameloblastoma was treated by enucleation and some curettage for remaining bone tissue (Figure 25.20). There was no recurrence for more than 2 years and the patient did not want to use a conventional removable denture for the mandibular molar region but insisted on having an implant-supported prosthesis. A panoramic radiograph revealed that his molar region was lacking height for implant insertion (Figure 25.21). Furthermore, surrounding soft tissue on the defected area was very tight, lacking keratinized gingiva at this region. The initial plan was to perform bone grafting for implant placement. However, there was difficulty of soft tissue closure because of the scar, and there was not enough bone height to make the transport segment. Therefore, DO with grafted bone was chosen to augment the alveolar ridge after conventional implant placement in the posterior molar region.



Figure 25.20 Panoramic photograph after the tumor resection.



Figure 25.21 Panoramic photograph after a 2-year follow-up. Alveolar bone defect can be seen on the left side of the mandibular molar region.



Figure 25.22 After raising a mucoperiosteal flap. The mandibular bone surface was intact.

Surgical procedure

The patient was anesthetized with local anesthetic and intravenous sedation. A crestal incision was made and extended vertically mesial to the first molar region. The mucoperiosteum was reflected, exposing the labial surface of the mandible of the left side (Figure 25.22). The defected area was measured and we evaluated the condition of the surrounding soft tissue. First, veneer bone substitute was taken from the mandibular ramus area on the opposite side. A horizontal incision was made and the mucoperiosteum was reflected, exposing the bone surface of the lateral ramus and post-molar region. The block was designed from the required volume on the left side and then corticotomy was performed with an ultrasonic bone-cutting device (Variosurg, NSK, Japan) (Figure 25.23). The bone block was adapted to the bone surface on the defected area and trimmed to the ideal shape without any gap between the original bone surface and the block (Figure 25.24). The decortication was performed by penetrating the lateral cortex using a small fissure bur. In this case, there was an additional small defect at the mesial region, so the small block bone graft was added using one titanium screw. The main block bone graft was fixated with a distraction device, which was the same as cases with a horizontal DO (Figure 25.25). A horizontal distraction device, consisting of a 0.3-mm-wide CP titanium mesh plate and a pure titanium distraction screw 2 mm in diameter and 12 mm in length (Alveo-Wider®, Okada Medical Instrument Supply Co. Ltd., Tokyo, Japan), was attached using a titanium micro screw (1.2 mm in diameter) placed in the block graft and stabilized to the original mandible. An additional screw was used at the distal end to stabilize the block until the activation. Making a tension release incision, the wounds were closed with a 5-0 monocryl® suture with the distraction screws penetrating through the flap.



Figure 25.23 A bone block was taken from the mandibular ramus using an ultrasonic bone device (Variosurg®).



Figure 25.24 The block was trimmed to fit the defect area.



Figure 25.25 The block was fixed with a distraction device and a micro screw was used to fix and contact the original bone surface at the posterior part. A minor block bone graft was done at the anterior region.

Post-operative protocol

After 14 days to allow for periosteal healing and early revascularization, the stabilized screw was removed with a small incision and the distraction devices were activated by turning the distraction screws 0.225 mm twice a day, for 8 consecutive days. During distraction, there were no apparent problems such as dehiscence or minor infection around the activation rod. The patient was instructed to rinse her mouth daily with chlorhexidine solution. Post-distraction CT confirmed that the alveolar process had increased 2 mm in height and 5 mm in width from the original alveolar crest. After a consolidation period for 6 months, the devices were removed and it was confirmed that the distracted areas were filled with newly formed bone except for the top of the crestal region (Figure 25.26). Then the small bone graft was done and the wound



Figure 25.26 Intraoperative photograph of distraction device removal. A bone gap was still present at the top of the ridge, but anterior and posterior gaps were filled with newly formed bone.

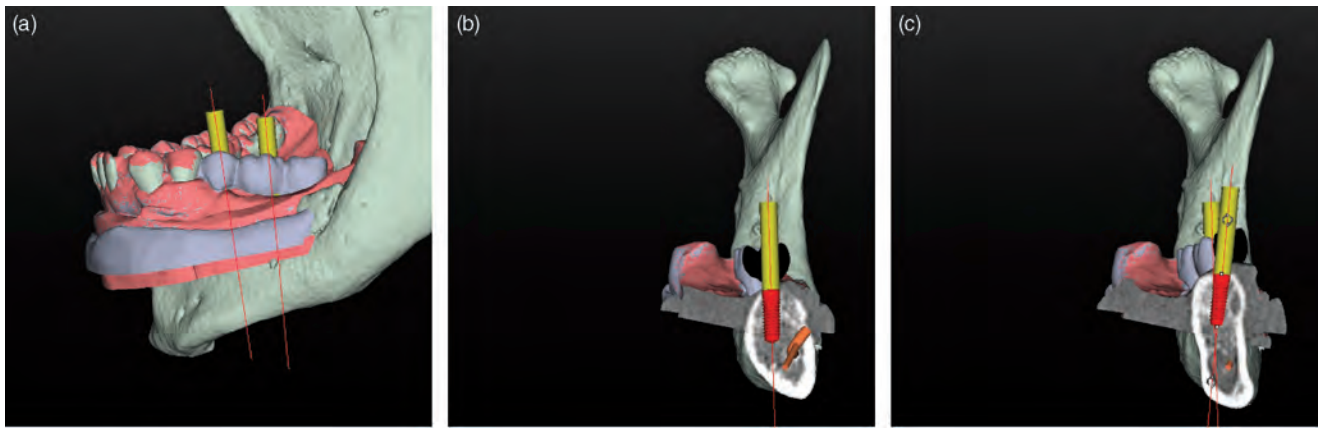


Figure 25.27 Implant simulation was done by Simplant® software. (a) 3D image combined with the bone image and scanned plaster model image, (b) section image for molar, (c) section image for premolar.

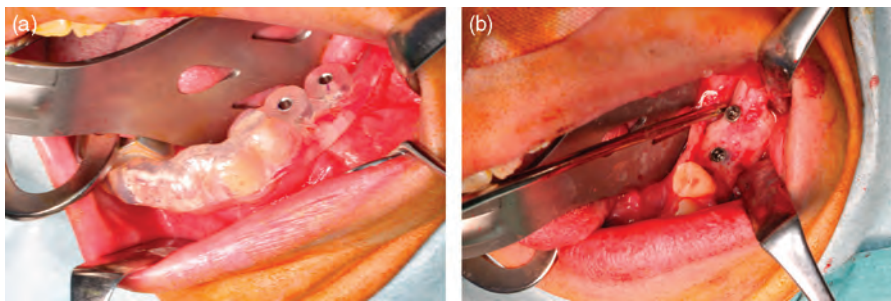


Figure 25.28 (a) Implants were inserted using a surgical guide based on simulation. (b) Implants were placed with sufficient initial stability.

was closed. Implant insertion was planned using simulation software (Simplant, Dentsply IH) (Figure 25.27a to c). Four month later, two 10-mm-long standard ITI implants (Straumann, Switzerland), 4.1 mm in diameter, were placed in the distracted areas with good initial stability (Figure 25.28a and b).

Periosteal expansion osteogenesis (PEO) using β -TCP block

DO is a biological process that leads to new bone formation between segments that are gradually separated and continues as long as the strained tissue is activated incrementally. However, it requires appropriate bone volume to make a transport segment or bone block by performing an osteotomy, which induces a greater burden on the patient.

The periosteum is thought to contain cells that have the potential to differentiate into osteoblasts [17]. DO is successful because, under appropriate levels of stimulation, periosteal mesenchymal stem cells differentiate into osteoblasts and produce early subperiosteal callus within the osteotomized gap. Tension on the periosteum alone can lead to the production of subperiosteal bone. Furthermore, the peripheral part of newly formed bone in DO is formed by subperiosteal mesenchymal stem cells [18].

Recently, bone-substitute materials have been advocated as alternatives to autografts and allografts. Highly purified β -tricalcium phosphate (β -TCP) has been manufactured and is attracting attention because of its biocompatibility and biodegradability. During the bone remodeling process, β -TCP is gradually degraded and finally replaced by mature new bone in animal experiments. This material has been shown to have good biocompatibility and osteoconductivity in clinical settings [19].

Furthermore, strain is thought to induce subperiosteal bone formation. Recent *in vivo* studies have shown that tensile strain acting on the periosteum, which causes tenting of the subperiosteal capsule, is sufficient to produce bone formation without corticotomy or local harvesting of the bone [20,21]. These studies indicate a new technical aspect of DO or tissue expansion with the controlled guided formation of new bone. With this background, we examined periosteal expansion osteogenesis (PEO), based on the concept of DO, using a highly purified β -TCP block instead of an original bone segment in a dog model.

Surgical protocol

A horizontal incision around the mucogingival junction was made and the mucoperiosteal flap was reflected, which exposed the lateral surface of the mandible. The β -TCP block was placed at the bone surface and two titanium screws were inserted at the inferior border of the block to avoid inferior displacement. Another two titanium screws (diameter, 2.0 mm; length, 12 mm) were inserted from the lingual aspect to push the block to the buccal side (Figure 25.29). The tips of those screws touched the medial surface of the block. After checking the movement of the block by trial activation, the screws were turned back to the initial position. The wound was closed by layers using 5-0 nylon. After a latency period of 8 days, during which primary wound healing occurred, the lingual screws were activated to push the β -TCP block laterally and expand the lateral soft tissue by 0.5 mm/day for 8 days (Figure 25.30a and b). The expansion areas were left untreated for 8 weeks (Figure 25.31). Then, mucoperiosteal flaps were raised, and the superior aspects of β -TCP and expanded areas were exposed (Figure 25.32). After the lingual screws were removed, implants were placed at the mid-point of the β -TCP block and osteotomies for one implant were drilled



Figure 25.29 Animal experimental study: a β -TCP block was placed on the lateral surface of the mandible.



Figure 25.31 The width of the alveolus was increased by activation.

according to the manufacturer's protocols. Implants were inserted such that the implant shoulder was located at the gap between the β -TCP block and the original alveolar bone (3.5 mm in diameter, 9 mm in length; Astra Tech, Mölndal, Sweden) (Figure 25.33). The flaps were sutured and the implants were left submerged with their cover screws in place for 8 weeks. Sutures were removed after 1 week.

Resonance frequency analysis (RFA) was conducted for all implants at the time of placement and at 8 weeks after placement using Osstell Mentor (Integration Diagnostics AB, Savadale, Sweden). Stability of the implants was measured based on detection of vibration with a resonance frequency measurement probe (Smart-Peg Type 5; Integration Diagnostics AB) (Figure 25.34). This probe has a magnetic material in the upper part of the instrument that forms a magnetic field with the Osstell Mentor used to detect the vibration (Figure 25.35). This probe was screwed into the implant body in accordance with the manufacturer's recommendations.

Neither complication related to the materials used at the sites of intervention before, during, or at the end of the experimental phase, and nor were infections observed within or around the β -TCP block. The alveolar form at the experimental region changed dramatically following lateral expansion with the β -TCP block and the amount of augmentation was significant. The RFA also showed the sufficient value to confirm implant stability during this experimental study.

Periosteal expansion osteogenesis using shape memory alloy mesh

We previously investigated the utility of periosteal expansion osteogenesis (PEO), which is the same concept as periosteal DO, using a highly purified β -tricalcium phosphate (β -TCP) block instead of titanium devices in a dog model. We found that newly formed bone at the gap between the original bone and β -TCP block, and the β -TCP block, acted as a space-maker under the periosteum. This suggests the possibility of inducing a newly formed bone with



Figure 25.32 After a consolidation period of 2 months, the gap was filled with newly formed bone.

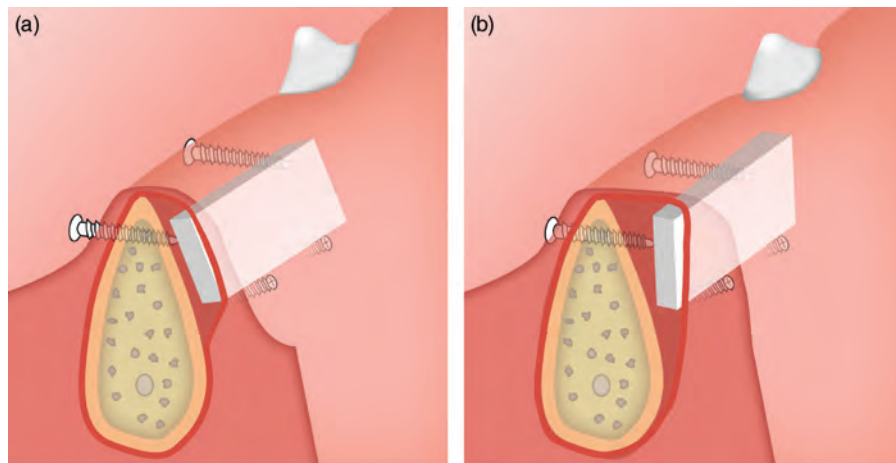


Figure 25.30 Schematic images of periosteal expansion osteogenesis using a β -TCP block: (a) before activation, (b) after activation; the block was pushed laterally with lingual screws.



Figure 25.33 Implant was inserted at the augmented area.

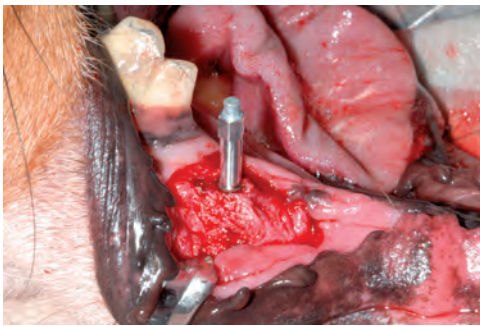


Figure 25.34 Smart-peg was set for evaluation of the RFA.

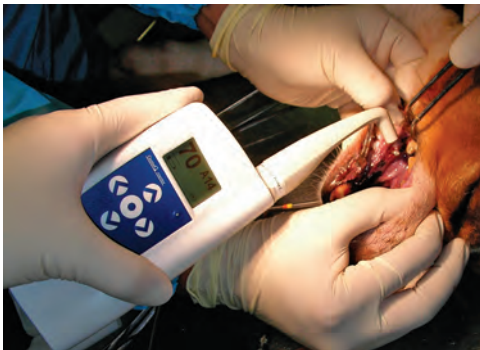


Figure 25.35 RFA showed sufficient initial stability.

no autogenous grafting or osteotomy. However, there is a need for mechanical activation, like in a DO protocol with a turning device penetrating the mucosa or skin. Such penetration of soft tissue around the augmented area can cause wound dehiscence or exposure of the device and subsequent infection. Considering the ideal conditions for acquiring sufficient bone, a complete capsule under the periosteum is required.

Many studies have been done to make novel distraction devices that expand automatically, for example, motor-driven, spring-mediated, and hydraulic devices [22]. However, most of those devices were too big for implantation. A clinical useful device that has an automated activity requires specific parameters: small size, ease of implantation, being fully buried, biocompatibility, sufficient force generation and good maintenance. NiTi implants have been used for cardiovascular and orthodontic treatments [23]. However, these materials are not used for bone augmentation, although a few animal studies have shown the possibility of using them for jaw elongation or alveolar bone augmentation with a DO technique. In those cases, they were used as spring devices, so it was difficult to control the activation rhythm and distraction or expansion vector. To create the ideal space with no manual activation, we developed a simple self-activated mesh device made of Ni-Ti shape-memory alloy (SMA) for periosteal expansion.

Device

The device consisted of Ni-Ti materials (Ni, 56.1; Ti, balance; Fe ≤ 0.05 ; O ≤ 0.05 ; C ≤ 0.03 ; N ≤ 0.02 wt%). The form of the mesh device was 5 mm width, 25 mm length, and 0.275 mm thickness. The pre-curved form was designed so that the middle point was 4 mm above the baseline (Figure 25.36a and b).

The deformation behavior of the SMA mesh plate was measured by a compressive test. The plate was fixed on an Instron-type testing machine (Model AG-I; Shimadzu Co., Japan) and compressive stress was applied perpendicularly to the plate at a cross-head speed of 1.0 mm/min. Compressive load and displacement were calculated when the plate became completely flat. The width of the center and the whole of the plate are 5 mm and 15 mm, respectively. If it is assumed that the former has the same size as the latter, the compressive load required for the same displacement as the latter is calculated as 2.7 N ($= 0.9 \div 5 \times 15$). This is lower than the measured compressive load of the whole plate. This is attributed to the fact that the center of the plate has a porous structure.

Surgical procedure

The operation was performed under standard sterile conditions. The forehead of the animal was shaved and disinfected with 1% iodine sodium. After U-shaped skin and V-shaped periosteal incisions were made in the forehead region, the frontal bone of the

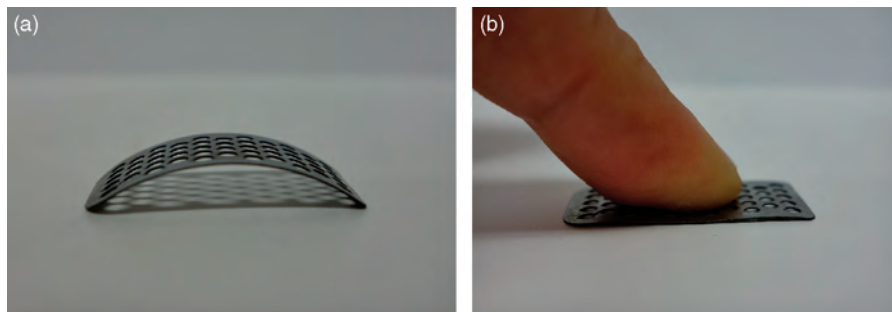


Figure 25.36 Shape memory alloy (SMA) mesh device. (a) Pre-curved style as dome shape. (b) The device was pushed to the baseline but preserved memory (elasticity).

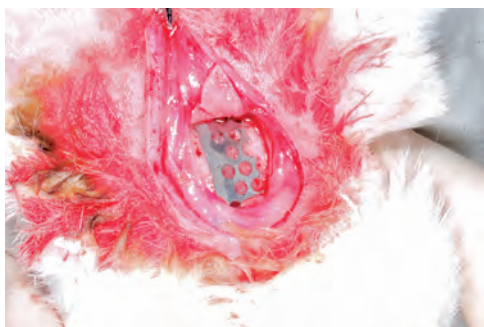


Figure 25.37 The SMA mesh device was inserted under the periosteum.

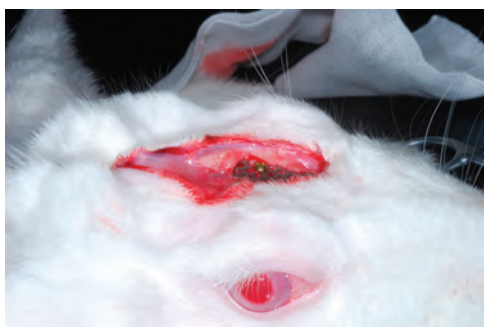


Figure 25.38 The SMA device was pushed to the surface of the cranial bone and fixed with a titanium screw.

animal was exposed following careful elevation of the periosteum. The device was inserted under the periosteum (Figure 25.37). In the experimental group, the device was pushed, bent, and attached to the bone surface and fixed with a titanium screw (diameter, 2.0 mm; length, 4 mm) (Figure 25.38). In control group animals, the device was only inserted under the periosteum. After irrigation with saline, the periosteum was positioned back in its original place and stabilized by suturing with 5-0 Vicryl (Figure 25.39). The skin was made using 4-0 Vicryl.

All rabbits were given water and normal rabbit food post-operatively. After 14 days a soft tissue incision 2 mm long was made over the screw and a driver was inserted for its removal in the experimental group. The wound was closed using 5-0 Vicryl after screw removal in the experimental group. Rabbits were sacrificed



Figure 25.39 Periosteum flap was closed over the SMA device.

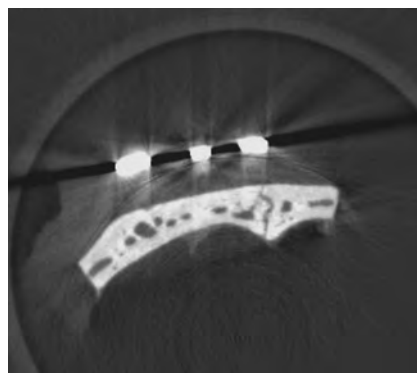


Figure 25.40 Micro CT image of the control group (without activation). There was some bone in the gap between the device and the original bone surface.

after a 3- and 6-week consolidation period with a lethal dose of thiopental sodium. In the control group, the timing of the sacrifice was the same as in the experimental group, so it was done at 5 and 8 weeks after the operation.

Results

No complications related to the materials used at the sites of intervention before, during, or at the end of the experimental phase and no infection within or around the device were observed in any animal. Upon screw removal, the device was activated to the original position immediately in two animals. They were concealed under the soft tissue during activation and the consolidation period until the time of sacrifice and no clinically active inflammation was observed around the SMA device.

Five and eight weeks after operation, soft focused CT images showed that the newly formed bone was less radiopaque than the original bone. Newly formed bone tissue was hardly observed in the control group at post-operative 5 weeks (Figure 25.40). The peak of newly formed bone was located under the center of the device. The dome-shaped bone was identified from the original bone in the experimental group (Figure 25.41). With an increasing bone consolidation period, the date was also relatively increased but there were no static differences between both time courses [24].

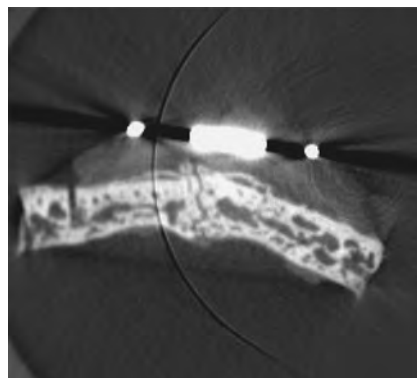


Figure 25.41 Micro CT image of the experimental group (with activation). Newly formed bone was observed from the original bone surface at the gap.



Figure 25.42 Decortication procedure to the original bone surface.

The effect of decortication for periosteal expansion osteogenesis using the SMA device

In our study, the measured volume of newly formed bone was ~30% of the area created under the periosteum by the SMA device. This was considered an insufficient volume of alveolar bone for implantation in the clinical environment [24]. Conventionally, block bone graft and guided bone regeneration (GBR) have been used to augment bone height and/or width for successful placement of a dental implant. Prior to bone graft placement, intentional drilling of holes through the cortical bone, known as decortication, was performed to enhance the healing process by promoting bleeding and allowing progenitor cells and blood vessels to reach the grafted site more readily. The surgical procedure and post-operative management were the same as in the described study. In the decortication group, the cortical bone was perforated by drilling through the SMA mesh with a round bur (Figure 25.42).

A decortication procedure was added to stimulate tissue regeneration from the original bone side, with the goal of creating sufficient new bone volume for clinical application. Using this method, the newly formed bone ratio was 60% after a 3-week consolidation period and 70% after a 6-week consolidation period, appearing sufficient for possible clinical applications (Figure 25.43).

The decortication procedure enhanced early bone regeneration from the original bone surface. This technique appears to be a promising clinical alternative for alveolar bone augmentation and introduces the new concept of “dynamic GBR” for atrophic alveolar bone.

Conclusion

The advantages of DO over bone grafts or GBR include the lack of the need for a donor site and simultaneous lengthening of the surrounding soft tissues (histiogenesis). Horizontal DO for correcting narrow alveolar ridges has also been reported [8–10].

This chapter described a successful use of a horizontal DO technique with a titanium mesh device developed based on animal research and clinical application, and an innovative technique of grafted bone DO, periosteal expansion osteogenesis using a β -TCP

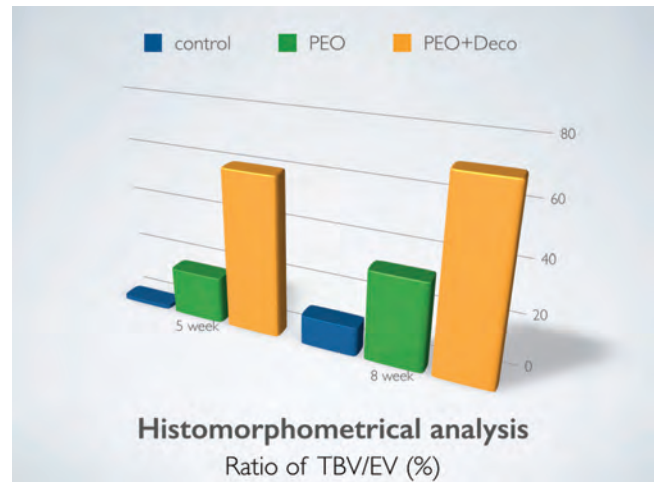


Figure 25.43 The diagram shows the histomorphometric analysis of control, PEO, and PEO combined with decortication.

block, and a shape memory alloy mesh device for the minimum invasive treatment of narrow alveolar ridges in implant dentistry.

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CHAPTER 26

Cortical Bone Repositioning Technique

Kensuke Yamauchi and Tetsu Takahashi

Department of Oral and Maxillofacial Surgery, Tohoku University, Sendai, Japan

Introduction

Previously, we showed both clinically and experimentally that the transport segment serves as a space-maker when the distraction osteogenesis (DO) technique is employed; it is most important to maintain a secure space under the periosteal point to allow successful bone regeneration [1–3]. Lethaus et al. found no significant difference between static and dynamic activation when guided bone regeneration was underway in a pig model [4]. Several static bone augmentation methods for dental implant therapy have been developed. The “split crest” is the most popular method; the crestal bone is split to create a width sufficient for implantation [5,6]. This method can be used to correct horizontal defects in the crestal region; fixation of the split bone is not usually necessary. Sometimes, the crestal bone is resorbed at the edge of the split area. Another static method is the “shell technique” that creates a space under the periosteum using an autogenous bone block or a bio-material [7,8]. In this chapter, we describe our novel procedure, which maintains a secure space under the periosteum by replacement of the lateral cortex via fixation, employing titanium screws. This cortical bone repositioning (CBR) technique avoids donor site morbidity, is a single operation (thus without any postoperative activation phase), and uses a minimal amount of materials to encourage regeneration of a horizontal alveolar bone defect (Figure 26.1a and b).

Screw fixation

Osteosynthesis is a standard method in oral and maxillofacial surgery, especially for open reduction with internal fixation (ORIF), orthognathic surgery, and jaw reconstructive surgery [9,10]. Screw fixation must be rigid to afford adequate strength and stability for mastication; the technique has been widely used for many years. Two forms of screw fixation are available, lag screw and position screw fixation (Figure 26.2a and b). If the bony contact between the original bony surface and the bone segment is good, the lag screw technique is ideal. Here, the screw hole in the outer cortex or bone segment is reamed to a diameter slightly greater than the outer diameter of the screw, whereas the hole in the inner cortex or original bone is smaller. This difference in diameter creates compression and stability; the outer segment is pushed inward by the screw head. In the bone graft technique, the shape of the bone block is adapted to that of the original bony surface, and bone remodeling may then progress safely because the contact between the segment

and original bone is ideal; no space is available for soft tissue insertion. The position screw technique affords adequate fixation without compression. The bone segment and the original bone must be held in alignment as the pilot screw hole, and subsequently the screw itself, engages both bone substitutes. The interbone gap can be maintained and the length of the gap can be controlled during the screwing procedure.

Indications

With either technique, a diagnostic stent is made and used to plan the fixed dental prosthesis prior to data collection via conventional radiography and computed tomography (CT). A horizontal alveolar bone defect was observed in our present case: the vertical height was adequate for implant insertion and the buccal and lingual/palatal cortices were clearly observed. Thus, these structures contained thin cancellous bony areas that are evident on CT images.

Surgical technique (Figure 26.3a to i)

Generally, mid-crestal incisions are followed by sulcular incisions with/without vertical incisions on the neighboring teeth. Full-thickness flaps are raised and the defect areas are exposed to an extent that allows insertion of surgical instruments. Next, slits are made in the periosteum below the flap to allow tension-free closure.

Bone blocks (minimum height 6 mm) are designed for placement in the defects and an ultrasonic bone-cutting device or a small-fissure burr is used to cut the lateral cortex (only). Prior to block mobilization, a pilot hole for screw insertion is drilled, but only in the lateral cortex. A self-tapping mini-screw is inserted and advanced until it touches the lingual/palatal cortex. The screw is removed and the lingual cortex drilled out to a diameter identical to that of the lateral hole. After the pilot hole is made in the lingual cortex, the lateral bone block is freed from the original bony surface. The screw is re-inserted into the lateral cortical bone block and the block is placed laterally, to allow fixation upon further screw insertion into the lingual/palatal cortex. After checking that the block is adequately stable, a small amount of particulate bone is placed at the step (thus not in the gap) between the block and the original surface. In some patients with big steps, or when problems are encountered with the blocks, a resorbable membrane is placed over the block area. The flap is closed after creation of periosteal, releasing incisions to ensure tension-free closure.

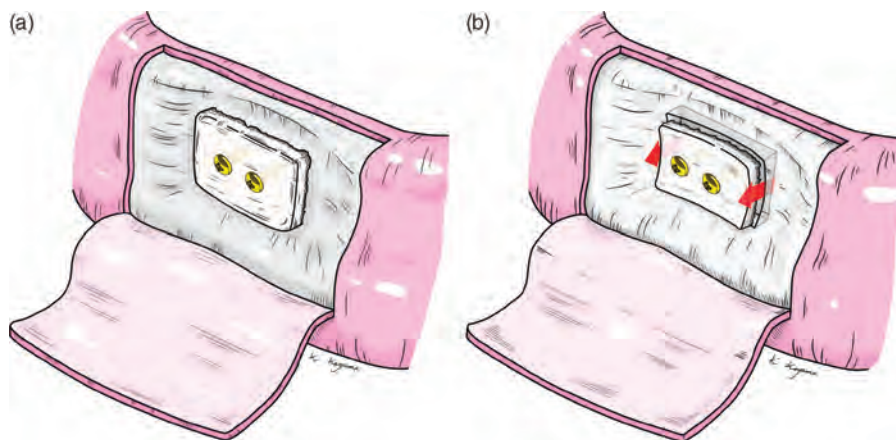


Figure 26.1 (a) Block bone graft, (b) cortical bone repositioning (CBR).

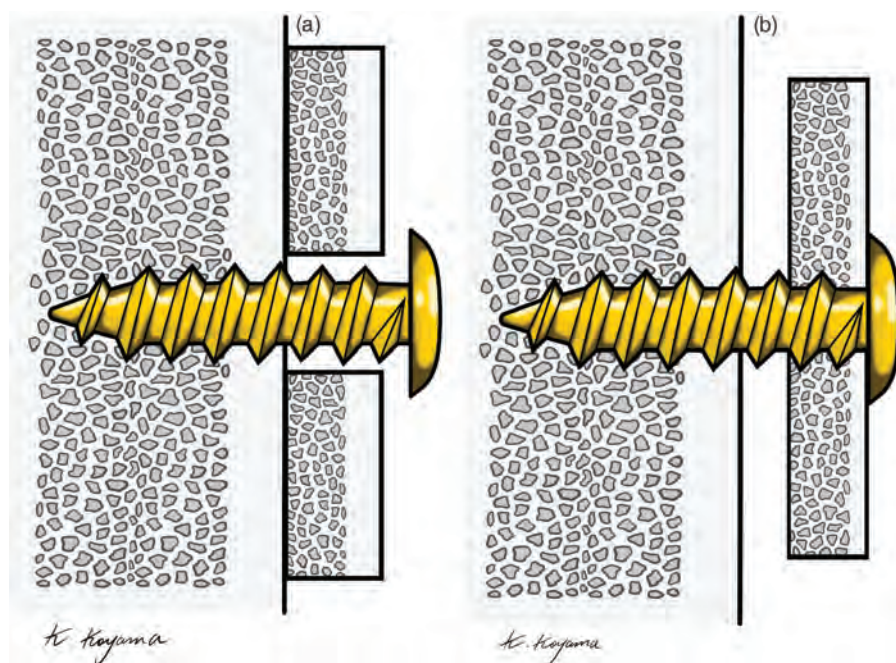


Figure 26.2 Type of screw fixation: (a) lag screw fixation with compression, (b) position screw fixation without compression.

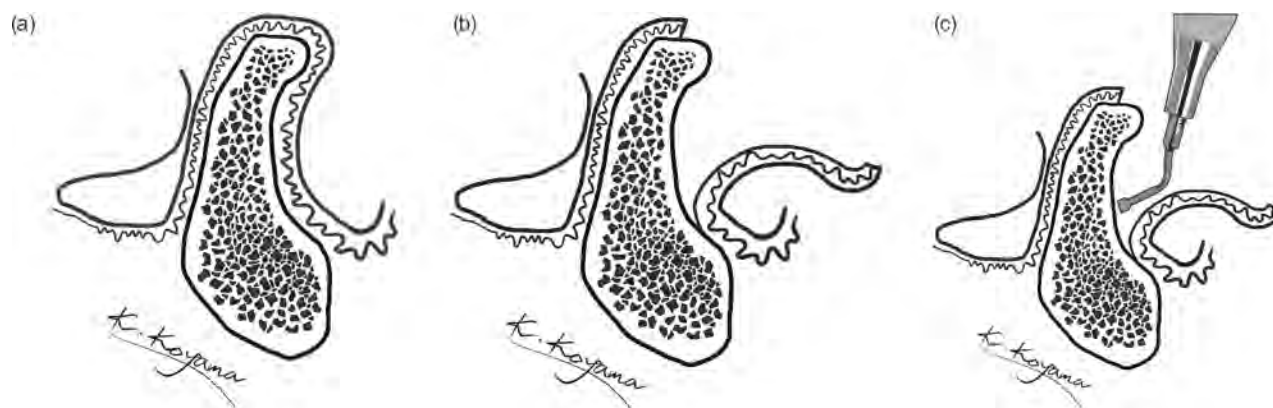


Figure 26.3 Surgical technique of CBR: (a) pre-operative condition, (b) making a crestal incision and raising flap, (c) single corticotomy using an ultrasonic bone-cutting device, (d) screw insertion and mobilization of the lateral cortical bone block, (e) screw removal and drilling to the lingual cortex, (f) lateral repositioning of the cortical bone block, (g) flap closure after periosteal releasing incisions, (h) after a consolidation period, (i) screw removal and implant insertion.

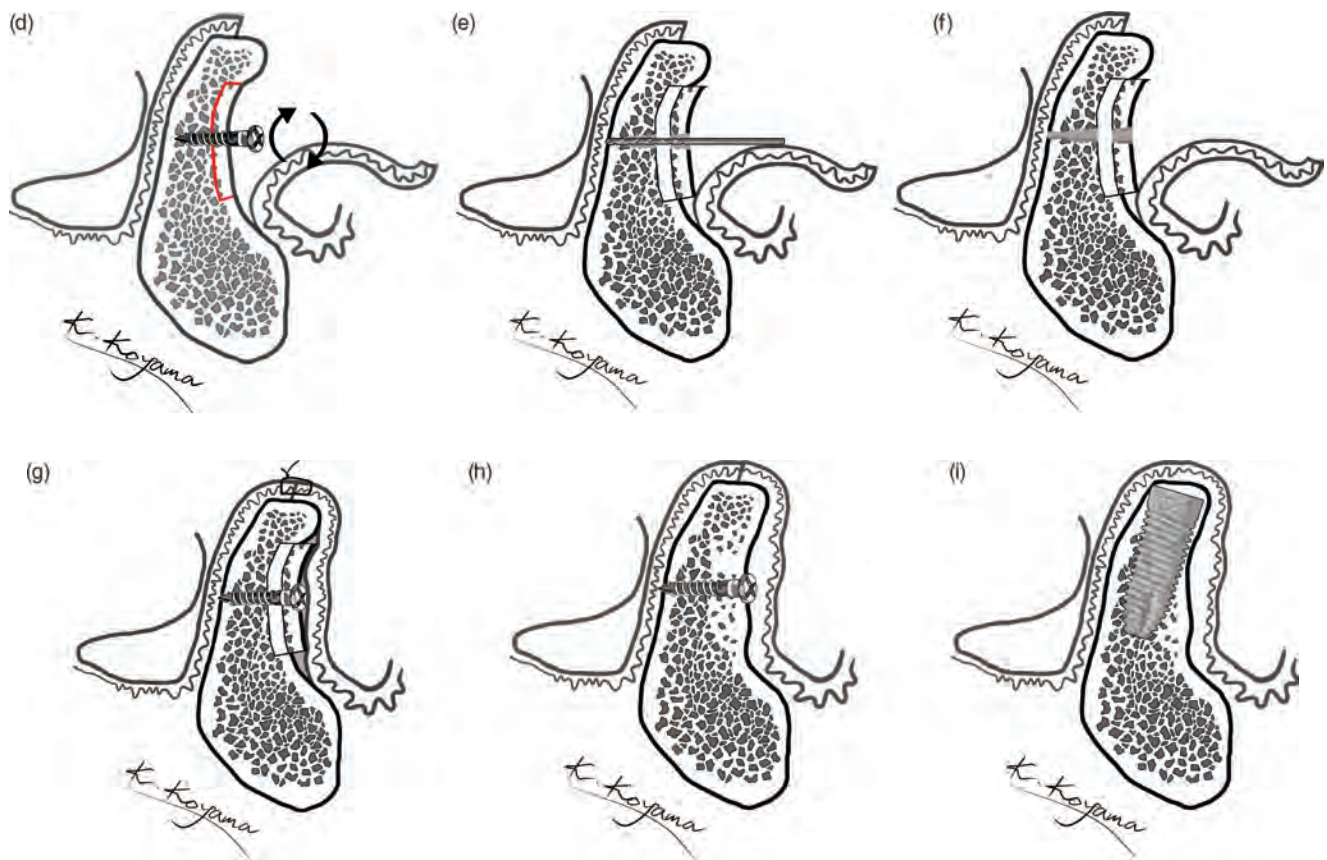


Figure 26.3 (Continued)

Case report 1 (Figure 26.4a to s)

A 52-year-old systemically healthy female was referred to the Dental Implant Center of Tohoku University Hospital for a fixed prosthetic rehabilitation from the first incisor to the canine of her left mandible. A pre-operative panoramic radiograph and a cone-beam computed tomography (CBCT) scan were performed to plan implant positioning and to evaluate alveolar residual bone anatomy. The horizontal defect of the middle portion was observed from CBCT images and has the risk for exposure of the implant surface using the standard procedure.

The pre-operative mean residual bone height of the canine region was 32 mm, the width of the crestal region was 5.7 mm and that of middle portion was 3.6 mm.

From these radiographic and dental cast evaluations, lateral a "cortical bone repositioning (CBR)" procedure was chosen to allow placement of two implants. The patient did not allow use of any biomaterial, especially made from an animal, so we planned to use only autogenous bone. The patient gave written informed consent to the treatment.

The CBR procedure was performed under local anaesthesia. A crestal incision was made, which extended vertically on the mesial and distal sides. The mucoperiosteum was reflected, exposing the labial surface of the bone. The block bone was designed at the atrophic area and then a monocortical osteotomy was performed using a 701 fissure bur and an ultrasonic bone-cutting device (Variosurg, NSK, Japan). The hole made in the center of the block allowed the screw to touch the lingual cortex. This was followed by insertion of a 1.7-mm-diameter self-tapping titanium screw (length 8 mm, Stryker) to the depth of the lingual cortex using a hand driver. Finally, the screwing procedure was continued to make the block bone pull out from the surrounding bone and the block was then displaced labially with the assistance of a thin-bladed osteotome. After confirming the lateral mobility of the block, the screw was removed and the drill was reinserted in the same hole of the lateral cortex to make a hole in the lingual cortex. The screw was inserted to fix the bone block at the lateral position as a positioning screw technique. Some bone taken by the bone scraper at the same surgical field was placed in the gap between the block and the original bone surface. Two implants (OsseoSpeed TX 4.0 S; length 11 mm, Dentsply Implant Company) were then inserted in a standard manner. Some bone chips taken from the surrounding area by the bone scraper were placed around the cortical bone block. After making periosteal releasing incisions to obtain a tension-free closure, the flap was closed by 5-0 Softretch (GC, Tokyo, Japan).

Antibiotics were given: 300 mg of Cefdinir (Astellas, Tokyo, Japan) orally for 4 days together with a non-steroidal anti-inflammatory medication Loxoprofen (Daiichi-Sankyo, Tokyo, Japan). The post-surgical instructions included a soft diet and 0.12% Chlorhexidine mouth rinses for oral hygiene. Panoramic radiograph were performed immediately after surgery. The patient was examined clinically 1 and 2 weeks and 1, 2, and 3 months after surgery. CBCT was taken 2 months after surgery and panoramic radiographs was taken 3 months after surgery. No complications were observed during the follow-up.

A secondary operation to set the healing caps was performed 6 months after the first surgery. The screw remained in the same position and most of the gap was filled with newly formed bone. The implants were stable without vertical bone resorption and movement. The final prosthesis was fixed 9 months after the first surgery.

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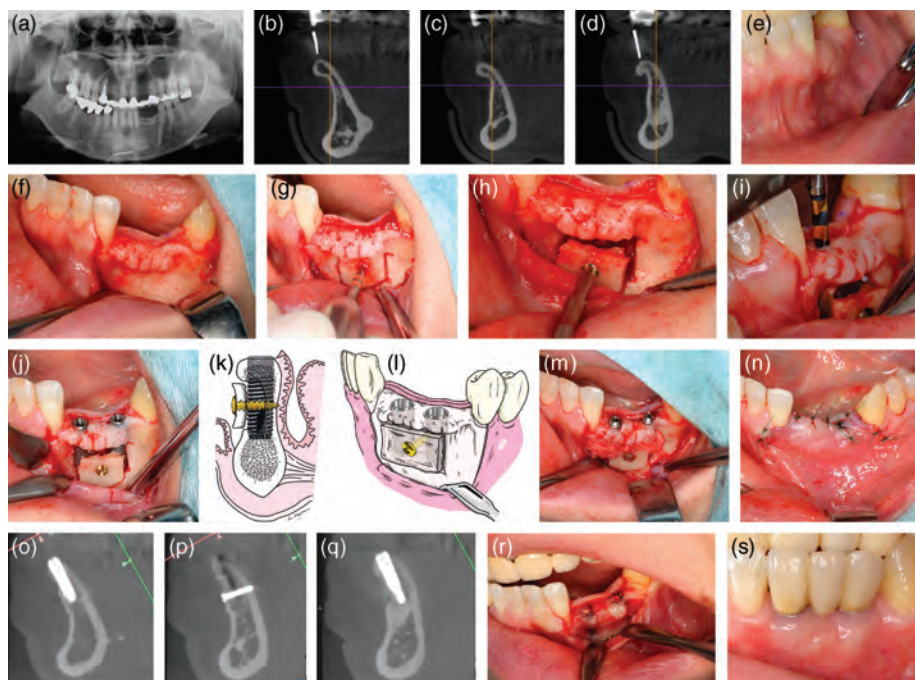


Figure 26.4 (a) Preoperative panoramic radiograph. (b) CBCT cross-sectional images. Two implants were planned at the medial and distal parts of the missing tooth area. The middle part of alveolar crest was dented, so the alveolar bone was observed as gourd-shaped in the sectional images: mesial section. (c) Middle section (center). (d) Distal section. (e) Preoperative clinical situation revealing a horizontal defect under the top of alveolar crest. (f) Crestal incision with additional buccal vertical incision of the adjacent tooth. (g) Making the bone block at the buccal cortex of the defect area; mono cortical drilling was performed to insert the titanium screw. (h) Self-tapping screw was inserted and touched to the lingual cortex and the screwing procedure was continued until the block was fully mobilized to the buccal area. (i) The block was fixed with a screw by re-drilling and re-insertion to the lingual cortical bone; then a standard drilling procedure for a dental implant was performed as usual. (j) Implants were placed with secure initial stability. (k) Cross-sectional image of this technique. (l) Schematic image of simultaneous CBR and implant insertion. (m) Implants were placed at a planned location and the block was fixed with one screw with autogenous bone chips. (n) The wound was closed by soft nylon following periosteal releasing incisions. (o) Post-operative 2-month CBCT images. The width of the middle part of the alveolar crest was gained using the CBR procedure. The cortical bone width was not changed at the middle section; mesial section. (p) Middle section (center). (q) Distal section. (r) Clinical situation at the secondary operation revealing newly formed bone at the gap between the block and original bone and no bone resorption around the screw head. (s) Intraoral photograph after the set of final prosthesis.

Case report 2 (Figure 26.5a to k)

A 72-year-old healthy female was referred for a fixed prosthetic rehabilitation from the right central incisor to the left lateral incisor of the maxilla. A pre-operative panoramic radiograph and a CBCT scan were obtained to plan implant positioning and evaluate the residual alveolar bone anatomy. A horizontal defect was evident on the CBCT image and the implant surface was at risk of exposure if the standard procedure were to be employed. The pre-operative mean residual bone height of the canine region was 18 mm, the width of the crestal region 2.5 mm, and the width of the middle portion 3.6 mm. After radiographic and dental cast evaluation, the lateral CBR procedure was chosen to allow placement of two implants. The patient gave written informed consent to this treatment.

The CBR procedure was performed under local anesthesia. A crestal incision was initially made; this extended vertically on both the mesial and distal sides. The mucoperiosteum was reflected, exposing the labial surface of the bone. A bone block was designed to fit the atrophic area and monocortical osteotomy was performed using an ultrasonic bone-cutting device. A hole drilled in the center of the block allowed the screw to touch the lingual cortex. Next, a 1.7-mm-diameter self-tapping titanium screw (length 8 mm, Stryker) was inserted to the depth of the lingual cortex, using a hand driver. However, during screw insertion, the block fractured into several pieces, commencing at the hole. The two largest fragments were located laterally and superiorly and were fixed with titanium screws. The other fragments were returned to their original sites and Cerasorb (Curasan Inc., USA) was packed around the pieces, which were covered with a resorbable membrane (Koken Tissue Guide; Olympus Terumo Biomaterials, Tokyo, Japan). After the creation of periosteal-releasing incisions to ensure tension-free closure, the flap was closed using 5-0 Softstretch (GC, Tokyo, Japan).

During healing over 5 months, no complication such as bone dehiscence or infection was noted. A secondary operation was performed 6 months after the initial operation; the bone volume was adequate and no resorption around screws was evident upon raising of the mucoperiosteum flap. Two titanium screws were removed using a hand driver and two implants (OsseoSpeed TX 3.5 S; length 11 mm, Dentsply Implants) were inserted in the standard manner.

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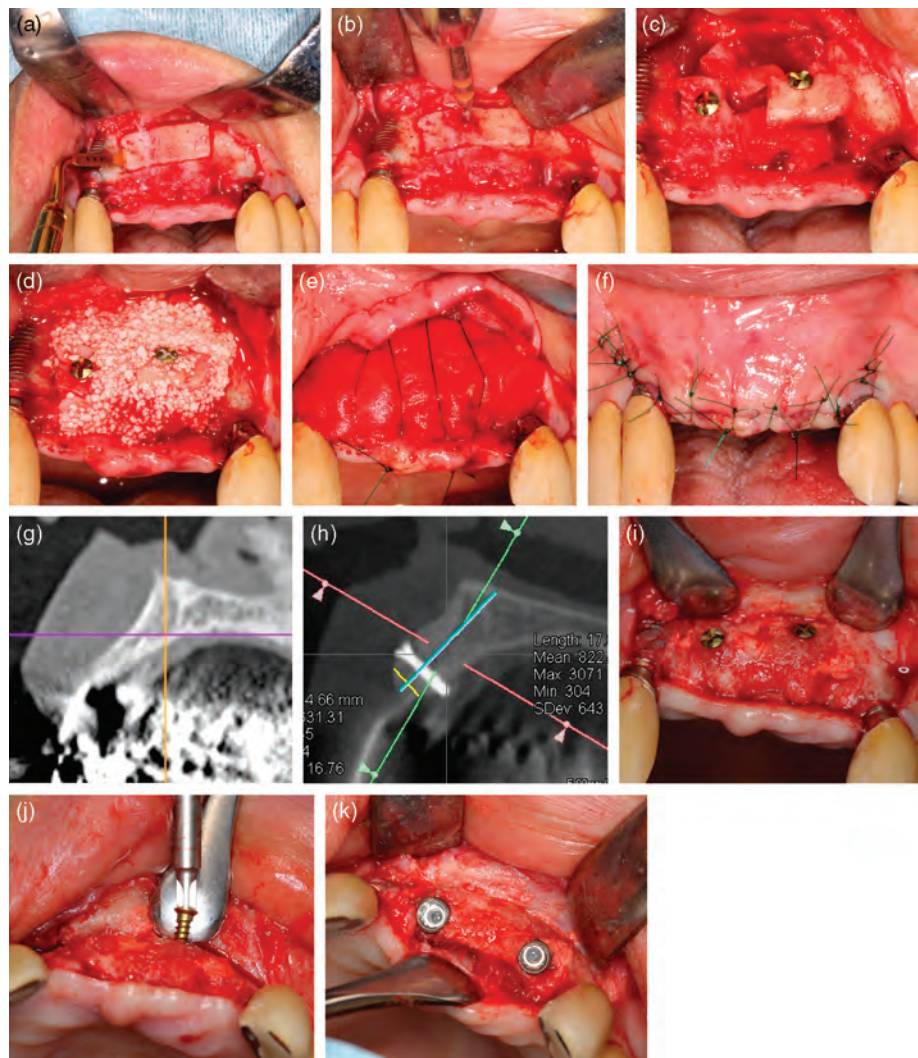


Figure 26.5 (a) Monocortical osteotomy was performed using an ultrasonic bone-cutting device. (b) Monocortical drilling was performed to insert the titanium screw. (c) Fracture happened to occur at mobilization of the mono cortical block. Two pieces of the fragments were fixed with the mini screws. (d) Bone chips and Cerasorb (Curasan Inc., USA) were placed around the pieces. (e) Augmented area was covered with a resorbable membrane (Koken Tissue Guide; Olympus Terumo Biomaterials, Tokyo, Japan). (f) After creation of periosteal-releasing incisions to ensure tension-free closure, the flap was closed. (g) CT cross-sectional image before surgery. (h) CT cross-sectional image after a consolidation period for 3 months. (i) Second operation for the screw removal and implant insertion. Bone volume was adequate and no resorption around screws was seen. (j) Mini screws were removed using a hand driver. (k) Two implants (OsseoSpeed TX 3.5 S; length 11 mm, DENTSPLY Implants) were inserted in the standard manner.

Discussion

Horizontal atrophy of the alveolar region may render implant placement difficult, compromising prosthetic rehabilitation. Various surgical techniques have been developed to solve this problem; these include autogenous or artificial bone grafts and the split crest technique. These conventional procedures have certain disadvantages, including donor site morbidity, unpredictable bone resorption, and difficulties with soft tissue coverage. DO is an innovative procedure used to avoid donor site morbidity, problems with soft tissue coverage, and limited augmentation [3]. Watzak et al. developed a horizontal DO technique using a micro bone screw [11]. This had all the advantages of DO and no volume limitation. However, disadvantages were also apparent, including the need

for daily manual activation, a requirement for a secondary operation to remove the device, limitation of the distraction vector, and the risk of infection from the activation rod. Our previous experimental studies showed that bone regeneration might occur in secure regions under the periosteum. Lethaus et al. found no difference in bone formation after performance of dynamic and static procedures in which space was created under the titanium mesh [4]. CBR is a static procedure: a secure space is created under the periosteum via lateral replacement of the buccal cortical bone block. CBT is a one-stage procedure (post-operative activation is not required) and allows full defect coverage with soft tissue, requires minimal materials, can be performed in a single surgical field, lacks donor site morbidity, and is rapid.

Bone regeneration after application of CBR appears to differ from that after bone grafting. In the grafted area, consolidation of augmentation material involves the formation of a graft-woven bone complex, which is remodeled into lamellar bone and can accept functional loading [12,13]. However, bone healing after DO occurs via callus formation, similar to the fracture-healing process, characterized by overlapping modeling exhibiting regional acceleration [14]. Regeneration after CBR is similar to bone healing after fracture; the osteotomized bone block is located laterally and does not overlap the cortical bone.

An extremely narrow alveolar bone with a small marrow space is at higher risk of cracking or fracturing of the cortical bone block at the point of separation from original bone. Thus, indications for CBR include cases with cancellous bony areas between the lateral and medial cortical bone. Furthermore, the initial stability of block bone is dependent on adequate screw fixation at the palatal or lingual cortex; poor cortex quality is associated with a risk of fixation failure. It is better to advise the patient to accept conventional grafting when block fixation is unstable.

CBR employs positioning screws used in osteosynthesis during oral and maxillofacial surgery. In our present case, we used a single self-tapping screw and drilling was performed prior to screw insertion. When a self-drilling screw is used, the tip of the screw must be narrow, compromising stability. Because the initial block stability is critical, we used a self-tapping screw. If stability remains inadequate, another screw can be placed or a screw of a wider diameter can be used.

Conventional grafting is associated with donor site morbidity; autologous bone is harvested from a remote area [15,16]. The use of allografts and xenografts has been advocated to avoid donor site morbidity. However, such grafts are associated with infections, resorption after grafting, and additional costs. Titanium screws have long been used in maxillofacial surgery, such as ORIF, and orthognathic and reconstructive surgery. The screws are safe, afford good mechanical strength, and are of lower cost than biomaterials and devices.

Conclusion

The advantage of the CBR technique compared to autogenous grafts is the lack of donor side morbidity (co-morbidity). This technique has the possibility to induce the patient's regenerative ability for bone healing. Further clinical and experimental studies are needed to prove the stability and healing process for the treatment of horizontal defects in the alveolar region.

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Horizontal Alveolar Distraction Osteogenesis: Complications and Their Management

Andrew Yampolsky and Shahid Aziz

Rutgers Oral and Maxillofacial Surgery, Rutgers – The State University, New Brunswick, New Jersey, USA

Introduction

Distraction osteogenesis (DO) has been applied to the area of alveolar reconstruction as a result of the lack of predictability in traditional alveolar bone grafting techniques [1,2]. In particular, alveolar distraction is thought to be beneficial in situations where the degree of hard and soft tissue loss is so great that traditional grafting techniques are unlikely to achieve a satisfactory result. While the benefits of distraction osteogenesis such as histiogenesis are theoretically able to overcome many of these difficulties, it is not without limitations [3]. Distraction osteogenesis often requires intricate hardware, careful treatment planning, prolonged treatment times, and delicate surgical techniques. As a result, there is ample opportunity for the development of surgical complications. Estimates of the probability of complications with DO vary greatly depending on the publication cited but may range between 36% and 100% [4].

Classification of complications

As distraction osteogenesis has a prolonged treatment phase it is prudent to classify any possible complications based on the point in treatment at which they occur [5]. Surgical complications may be divided into intraoperative and post-operative complications, and include complications that are a direct result of surgical errors as well as reasonably normal post-surgical sequelae. Next, the distraction phase is a period of time when the distractor is activated and thus puts a strain on both the patients' tissues and hardware, which may result in unexpected difficulties. Finally, the post-distraction phase may have undesirable results as well [4].

Surgical complications include entities commonly encountered in dentoalveolar surgery and speak to the anatomical hazards typically encountered in this operative site: paresthesias, bleeding, mandible fracture, infection, hematoma, suture dehiscence, as well as entities that speak to the complexity of DO such as fracture of the transport segment [6,7]. A review of the literature demonstrated that most of these complications were relatively minor, the most severe complication being profuse bleeding from the floor of the mouth, necessitating operative intervention under general anesthesia [8]. This, however, is a well-documented complication with surgery of the anterior mandible and may occur with more straightforward procedures such as implant placement. Most of

the paresthesias were transient in nature and thus treated as minor complications [9].

Perhaps unsurprisingly, the activation phase is a significant source of complications for distraction osteogenesis. A common problem cited both in alveolar distraction and traditional craniofacial distraction osteogenesis is difficulty in controlling the vector of the transport segment [10]. This can have consequences in terms of the subsequent implant restoration that is usually the goal of alveolar distraction. Mechanical complications such as device instability, malfunction, and inability to activate the device have also been cited and may be the result of incorrect surgical technique and device placement [7,11]. Some patients have reported pain and discomfort upon activation [12].

Complications following the distraction and consolidation phase of treatment typically revolve around a less than ideal final treatment outcome. Despite the notion that DO results in histiogenesis and creates concomitant expansion of the soft tissues, authors have cited soft tissue complications ranging from a lack of keratinized gingiva to inadequate vestibule [13]. Complications involving the regenerated alveolar bone complex are cited as well and range from overcorrection, to poor quality bone formation, to necrosis of the transport segment [14].

Avoiding and managing complications

A variety of techniques have been described in an attempt to avoid complications associated with DO. Reducing intraoperative complications involves a meticulous surgical technique and a thorough understanding of the anatomy of the surgical site. The use of properly sized instruments when performing the osteotomies will help prevent injury to the transport segment, basal bone, and the surrounding soft tissues [8]. Similarly, many surgeons feel that the use of ultrasonic instruments is useful in avoiding surgical complications. Trigeminal nerve injury, if it occurs, should be managed with serial neurosensory testing and with appropriate and timely microsurgical repair in the event that sensory function does not recover or dysesthesia develops [11].

Mandibular fracture is a potentially devastating complication and may occur either during the initial surgery or postoperatively during the distraction or consolidation phases [15]. Some authors have made recommendations regarding the residual mandibular bone

height. The residual bone height above the inferior alveolar nerve should be greater than 6–8 mm. A residual basal bone height of less than 10 mm is associated with an increased rate of fracture during the consolidation phase [13]. Much like the technique used when performing a marginal mandibular resection, the osteotomies should be gently curved, avoiding sharp angles, which may be points of stress in the post-operative period [8].

Meticulous pre-operative planning, including three-dimensional imaging and mounted study models, may help avoid complications during the activation and consolidation phases. Mounted study models can be used to help plan an appropriate distraction vector and ensure that the selected distraction device is capable of producing the appropriate vector and is able to be fit without imposing on adjacent anatomic structures [5]. Resistance to distraction may be the result of bony friction or incorrectly oriented osteotomies. The osteotomy must be designed in a gently divergent manner to ensure that the transport segment can be distracted without bony interferences [9]. The distractor must be activated intraoperatively to ensure that there are no interferences [9]. Vector deviation during activation may occur as a result of the pull of the lingual periosteum and the floor of mouth musculature and may be corrected by wiring the appliance to adjacent teeth [5]. Pain during distraction may be managed by increasing the frequency of distraction while maintaining the total daily rate unchanged [16].

The main complications in the post-distraction phase are the result of inadequate bone formation, a bone defect in the distracted bone, or soft tissue deficit. Some authors recommend taking into account a certain degree of relapse and hence intentionally over-distracting by approximately 25% over the required amount of bone [8,12]. Furthermore, post-distraction defects may also be augmented using traditional guided bone regeneration techniques. Any soft tissue defects present can be corrected with adjunctive soft tissue procedures.

Complications specific to horizontal alveolar distraction osteogenesis

As is the case with vertical DO, there exist both externally positioned devices, such as the Alveo-Wider (Okada Medical Supply, Tokyo, Japan), and internal devices, such as the modified LEAD distraction system (Stryker, Kalamazoo, MI). Unfortunately, regardless of the system used, placement of the distraction devices frequently requires wide stripping of the mucoperiosteum that provides vascularity to the transport segment [17,18]. As a result, avascular necrosis of the transport segment is much more common in the horizontal alveolar distraction [6]. This fact may contribute to some of the relapses seen in DO and highlights the importance of building in overcorrection while treatment planning such cases [8].

Conclusion

While the reported complication rate in alveolar distraction osteogenesis may at first glance appear to be unacceptably high, it is important to note that the majority of complications are relatively minor and do not affect the outcome of treatment. Furthermore, the rate of complications is considerably improved in experienced hands. Alveolar distraction osteogenesis is an important technique in the armamentarium of any implant surgeon.

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SECTION VI

Soft Tissue Grafting for Implant Site Development

Soft Tissue Grafting for Implant Site Development: Diagnosis and Treatment Planning, Esthetic Evaluation

Edgard El Chaar and Sarah Oshman

New York University, College of Dentistry, New York, USA

Introduction

The guiding force behind dentistry today is based on a trilogy of dental implants, esthetic dentistry, and periodontal health. Execution of this trilogy requires the use of challenging techniques in soft tissue augmentation, whose mastery requires a comprehensive understanding of vascularity, anatomy, wound healing, and tissue manipulation. Comprehension of the principles guiding soft tissue surgical techniques can help lead to successful outcomes and the long-term health of implemented esthetic augmentations. The next two chapters will focus on various techniques in surgical soft tissue manipulation that can be used in combination with implant dentistry to recreate an esthetic result that mimics the ideal natural dentition. The diagnosis of aberrations in soft tissue surrounding implants and achievement of the ideal mucogingival esthetics in implant dentistry comes from an awareness of mucogingival esthetics of the natural dentition. Therefore, time will be spent in this introductory chapter addressing the ideal mucogingival esthetics of natural teeth. The techniques for soft tissue manipulation around teeth will also be covered as well because the techniques used to augment and adjust soft tissue around implants stem from those developed to correct mucogingival deformities around natural dentition. While many techniques used on teeth can be translated to use around implants, the differences in surrounding tissue quality, anatomy, and vascularity around teeth and implants make these procedures even more challenging when used concomitantly with implant dentistry. An understanding and ability to achieve ideal results with soft tissue around implants begins with both the comprehension of the origins of these procedures around teeth and the differences in anatomy and vascularity between teeth and implants. Achieving an ideal result in any soft tissue procedure regardless of whether or not it is around implants or natural teeth requires proper diagnosis, identification of pathology, understanding of wound healing, comprehension of vascularity and anatomy, and understanding of esthetics. This chapter will provide the tools needed to understand the surgical techniques provided in both Chapters 29 and 30.

Historically a major goal of mucogingival therapy was to increase the zone of keratinized gingiva around natural teeth. In the 1950s through the early 1980s there was a belief that an inadequate zone of keratinized tissue led to unhealthy periodontal conditions such as increased attachment loss and inflammation [1–3]. It was believed

that an increased zone of keratinized tissue around teeth provided a barrier to plaque and inflammation, prevented recession, dissipated stress, improved patient comfort, and gave ease of hygiene [2,3,4–8]. More recent studies find that association between a wide band of attached gingiva and periodontal health is anecdotal. Hall, Lang, Loe, and Dorfman concluded that there is no minimum amount of attached gingiva necessary for health and no direct link between the amount of attached keratinized gingiva, periodontal health, and further recession [9–12]. These conclusions are widely accepted but note that these studies did not account for biotype or tissue thickness and did not consider the role of keratinized tissue around implants or prosthetics. While there is not currently a suggested minimum amount of keratinized tissue around natural teeth there is one surrounding prosthetics. In 1979, Maynard and Wilson mentioned that the outcome of restorative procedures are more predictable with the presence of at least 5.0 mm of keratinized tissue in areas of restorations and in 1987 Bissada found increased gingival inflammation around restored teeth with less than a 2.0 mm band of keratinized tissue [13].

The debate for the need of keratinized tissue once again arose with the advent of implant therapy as implants can either enter the oral cavity passing through alveolar mucosa or attached keratinized tissue. The tissue that surrounds an implant is dependent on what existed prior to implant placement and the clinician's handling of the hard and soft tissue during placement and uncover of the fixture. Due to the differences in the surface structure of implants and natural teeth, there are drastic differences in the surrounding oral mucosa as each emerges into the oral cavity. Natural teeth are coated with cementum that allows for direct insertion of collagen fibers while implant surfaces, either a rough-treated surface or the original polished titanium surface, will have the collagen fibers running parallel and inserting only in the crestal bone (Figure 28.1). In both dental implants and natural teeth the junctional epithelium attaches with hemidesmosomes coronal to the bony crest and a region of connective tissue [4]. In healthy teeth, the junctional epithelium terminates around the cemento-enamel junction while in implants the junctional epithelium ends at varying distances coronal to both the bony crest and the area of connective tissue, which is in direct contact with the implant surface [14]. As in teeth, the biologic width is found around implants and with implants this area will form during healing through crestal bone resorption if an

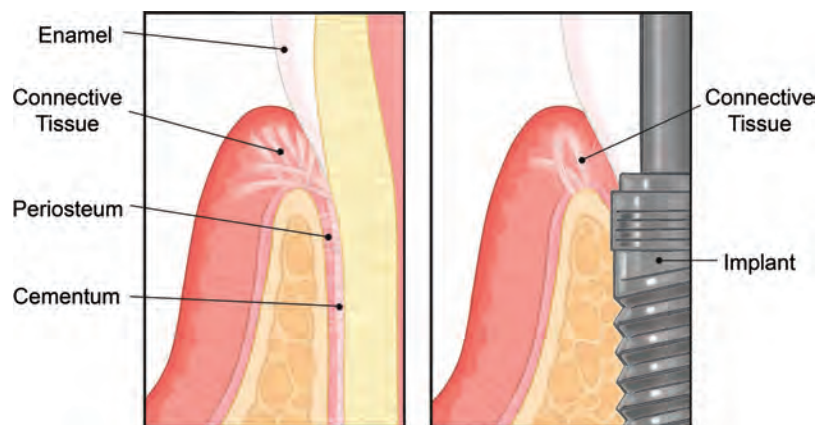


Figure 28.1 A side by side comparison of the periodontal attachment apparatus of a natural tooth to that of an implant.

adequate distance between the osseous crest and soft tissue does not exist at the time of placement. Abrahamsson in 1996 found the dimensions of the components of biologic width surrounding implants to be 1.2–2.0 mm for a junctional epithelium and 1.0–2.0 mm for connective tissue [15]. The same biologic width and mucosal attachment forms around implant fixtures whether or not the surgery is preformed in one or two stages [16,17]. Around teeth the area of connective tissue contains organized fiber groups including fibers that insert perpendicular to the root surface directly into the cementum (Figure 28.1). The connective tissue surrounding implants is highly collagenous and contains fibers that extend from the alveolar crest to the gingival margin, the majority of which run parallel to the surface of the implant [15]. Another marked difference between the connective tissue surrounding implants and teeth is a decreased vascularity surrounding implants due to the lack of a periodontal ligament (PDL) and the fibrous nature of the tissue. This lack of both vascularity and a firm direct attachment to the surface makes implants more susceptible to pathologic challenges than natural teeth [18]. The reduced vascularity surrounding implants and the fibrous nature of the tissue makes it more difficult to handle and manage surgically than those surrounding natural teeth [19]. While polished and rough surface implants have similar patterns of fibrous insertion and the characteristics of the connective tissue surrounding them is the same, there has been an increase in the prevalence of peri-implant mucositis and peri-implantitis with rough surface implants [20].

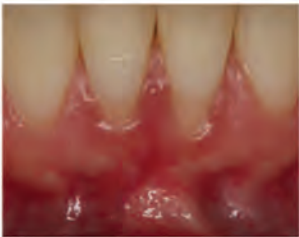
With the use of a rough surface over the implants and the increased susceptibility to gingival disease, the need for keratinized tissue around implants to aid in maintaining health became apparent. The importance of keratinized tissue around implants was demonstrated in a study of 200 implants, which revealed that an increased width of keratinized mucosa around implants is associated with less bone loss and improved soft tissue health [21]. The effect of soft tissue on implant health is seen again in another study, which found an increase in crestal resorption around implants lacking keratinized tissue as compared to those with adequate keratinized tissue in beagle dogs [22]. The importance of the presence of keratinized tissue is seen in its role maintaining health as well as its place in creating proper esthetics [23–25]. A decision to augment keratinized tissue surrounding implants is one to be made by the clinician based on the patient's ability to maintain the area, the health of the surrounding tissue, as well as the esthetics. The sections on surgical techniques will provide guidance on the management of soft tissue when uncovering implants to help ensure

adequate and esthetic soft tissue as well as ways to augment the soft tissue if deemed necessary.

Classification systems

Identification of aberrations in soft and hard tissue is the first step in diagnosis and treatment of mucogingival and ridge deformities. Many classification systems have been identified over the years to help with identification of defects, communication between clinicians, and even aid in the predictability of treatment success. Proper understanding of common classification systems and the prevalence of deformities is helpful in conducting patient examinations. There is currently no classification system for mucogingival deformities around implants, but as the goal of implant therapy is to mimic the form and function of natural dentition it is important that clinicians can recognize aberrations in the soft tissue of natural teeth and then use clinical judgment to assess those around their implant counterparts. The most widely accepted classification for ridge and mucogingival deformities are those presented by Siebert and Miller respectively. P.D. Miller developed a system of classification that is meant to aid in determining the success of root coverage in treating different types of gingival recession. He divided recession into four classes and listed the expected root coverage for Class I through IV successively as 100%, 100%, partial root coverage 50–70%, and less than 10% with no anticipated root coverage achieved [26]. His system of classification is presented in Table 28.1. Seibert classified the partial edentulous ridge in his papers regarding the reconstruction of tissue in edentulous spans using full thickness onlay grafts [27]. His classification can be seen in Table 28.2. Both systems of classification alluded to a common trait, which is the need of bony support for successful treatment outcomes. Favorable outcomes in soft tissue grafting are dependent on the vascularity provided through the underlying osseous structure, which is why a direct correlation between outcome predictability and bony support is seen in these classifications. As there is no classification for mucogingival deformities around implants, practitioners are left with their clinical judgment and the principles that guide esthetic ideals in natural teeth for recognition of defects. Because of the anatomical differences between implants and teeth, when assessing predictability of treatment outcome around implants one must use the concepts that guide these common classification systems, such as the amount of vascular supply and osseous support for tissue, rather than the systems themselves. Some clinical examples of mucogingival deformities around implants are depicted in Figure 28.2.

Table 28.1 Miller classification of root coverage.

Class I		Recession that does not extend beyond the mucogingival junction with no loss of interproximal bone
Class II		Recession that extends to or beyond the mucogingival junction with no loss of interproximal bone
Class III		Recession that extends to or beyond the mucogingival junction with some periodontal attachment loss or malpositioning of teeth
Class IV		Recession that extends to or beyond the mucogingival junction with severe periodontal attachment loss and/or severe malpositioning of teeth

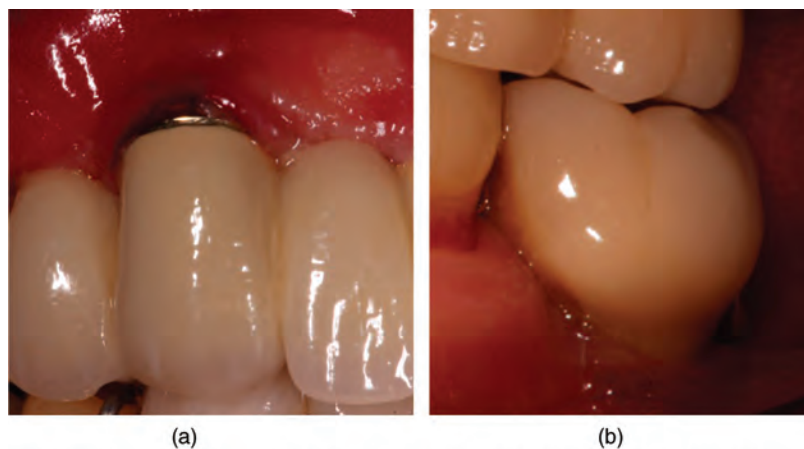
Esthetic considerations

Understanding of normal anatomy as well as the interdependence of patient's dentition, gingiva, and lip line in achieving esthetic harmony are necessary for successful management of soft tissue surrounding implants. The location and shape of the gingival margin is dependent on all parts of a patient's smile, which include

lip line, incisal edge, buccal corridor, tooth position, tooth shape, gingival margins, and biotype. One needs to look at all of the elements that make up a patient's smile before determining the ideal location shape and amounts of soft tissue. Evaluation of a patient's smile begins from outside in, starting with evaluation of the open smile and where the lips part relative to teeth. Then we can divide open smiles into three categories: high, average and low according to the amount of gingival display and relative position of the upper lip as seen in Table 28.3 [28]. It is important to note a patient's lip line prior to treatment planning as mucogingival esthetic considerations are of extreme importance in patients with high and average smile lines and chosen treatment should reflect this anatomy. An average smile line is considered the most ideal when reflecting a

Table 28.2 Siebert edentulous ridge classification.

Class I	Horizontal or buccal tissue loss with normal ridge height
Class II	Vertical tissue loss with normal ridge height
Class III	Combined horizontal and vertical bone loss



(a) Depicts an implant in the area of #6 with mid facial recession and a lack of keratinized tissue.
(b) Depicts an implant in position #19 with lack of keratinized tissue.

Figure 28.2 Clinical examples of mucogingival deformities around existing implants. (a) Note the thin mucosa and recession in the area of implant 6. (b) A lack of keratinized tissue in the area of implant 19.

harmonious relationship between the lips and the gingival structures [29]. A low smile line hides the gingiva and is not of great consideration for mucogingival esthetics and a high smile line can be reduced if necessary through elimination of gingiva via surgical means [30]. Once a patient's lip line has been noted the clinician can begin analysis of the dentogingival unit to determine the ideal location of the patient's gingival margins. Determination of the ideal location of the maxillary gingival margins begins with location of the ideal incisal edge of the maxillary anterior teeth. In a symmetrical smile the ideal incisal edge of the upper teeth follows the curvature of the lower lip. While the curvature of the lower lip determines the incisal edge position of the upper teeth in one dimension, the incisal limit of the maxillary anterior teeth is actually a three-dimensional point that is dependent on phonetics, function, and esthetics (Figure 28.3).

Table 28.3 Tjan open smile classification.

High smile	Reveals the total cervicoincisal length of the maxillary anterior teeth and a contiguous band of gingiva	
Average smile	Reveals 75% to 100% of the maxillary anterior teeth and the interproximal gingiva	
Low Smile	Low smile: Displays less than 75% of the anterior teeth	

The apical limit or gingival margin is dictated by the shape, length, and width of the teeth. Because the apical limit is not determined by function and phonetics like the incisal limit, the apical limit can be altered with mucogingival surgery, grafting, or crown lengthening in order to reflect teeth of ideal proportions. While the width of the teeth is often fixed and the ideal incisal limit is fixed, the ideal teeth proportions can be achieved through surgical alteration of the gingival margin. The ideal proportions for maxillary incisors, laterals, and canines are listed in Table 28.4 [31–33]. The height of a tooth is measured from the incisal edge to the gingival zenith, whose mesial distal location affects the appearance of harmony in the gingival margin. The margins of the teeth should be symmetrical with the height of the maxillary central and canine gingival margins in line. The gingival zenith of the maxillary lateral should be approximately 1.0 mm coronal to the height of the central teeth and canines [30]. The height of the gingival margin then moves evenly and apically as the arch progresses posteriorly [34,35]. The gingival zenith of the maxillary central incisor is located about 1.0 mm distal to the long axis of the tooth and the zenith of the lateral incisors and canines aligns with the mid-line of the tooth [30] (Figure 28.4).

While the position of the gingival margins and zeniths are important in achieving esthetic harmony, the architecture of the gingiva itself is also of importance. An ideal gingival architecture is described as one that depicts health, consisting of knife-edged gingival margins tightly adapted to the teeth, interdental grooves, and cone-shaped interdental papilla [36].



Figure 28.3 An ideal smile depicting how the incisal edges of the maxillary teeth follow the curvature of the lower lip.

Table 28.4 The ideal proportions for maxillary incisors, laterals, and canines as given by Magne et al. [32].

Tooth (unworn)	Width	Height	W/L Ratio
Maxillary Centrals	9.10	11.69	0.78
Maxillary Laterals	7.07	10.67	0.87
Maxillary Canines	7.90	10.83	0.73

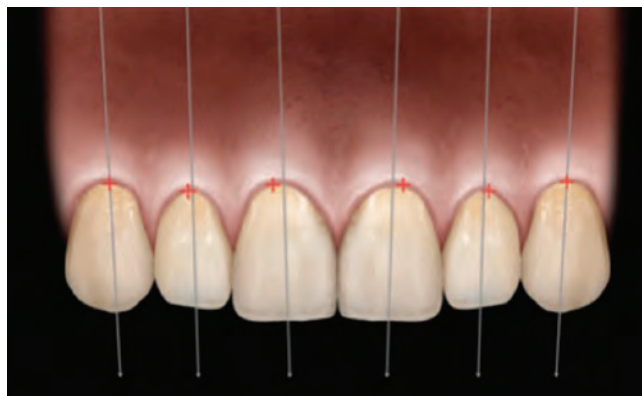


Figure 28.4 A depiction of the location of the ideal location of the gingival zeniths from Chu et al. [30].

Periodontal biotype

The gingival biotype refers to the thickness of the gingival tissue. Biotype is related to the thickness of underlying bone, gingival margin scallop, and tooth shape. Oscheinbein and Ross in 1969 first classified gingival anatomy as either flat or high scalloped with the suggestion that flat gingiva was related to a square tooth form and pronounced scalloped gingiva was related to a tapered tooth form [37]. More recently, Olsson and Lindhe in 1991 and De Rouck et al in 2009 identified two distinct biotypes. These two forms of gingival anatomy are referred to as thick or thin periodontal biotypes [38,39]. De Rouck noticed that thin biotype occurred in one-third of the study population and was most prominent among females. He found a thin gingival biotype to be associated with slender tooth form, narrow zone of keratinized tissue, and a high gingival scallop. The thick biotype was found mainly among males and corresponds with quadratic tooth form, broad zone of keratinized tissue, and a flat gingival margin. While

there is a strong association between tooth form and biotype, Kan describes a clinical means of assessing gingival biotype, noting that, if a periodontal probe when placed in the sulcus is visible through the tissue, then the biotype is thin and when the probe is obscured the biotype can be assessed as thick [40]. In 2009, Kan confirmed this method of clinical assessment when he found that differences in determination of gingival biotype with a periodontal probe were not significantly different than those attained through means of direct measurement using criteria of thin as less than 1.0 mm and thick greater than 1.0 mm. In 2011, Cook examined the link between biotype and labial plate thickness, finding that compared to a thicker biotype a thin biotype was associated with a thinner labial plate thickness and a greater distance from the cemento-enamel junction (CEJ) to the initial alveolar crest [41]. This increased distance to the alveolar crest means that, in a state of health, the gingiva of a thin biotype is laying directly on the root surface with no underlying bone for the first few mm from the free gingival margin. The delicate nature of thin tissue and its lack of bony support make it more prone to recession when faced with an insult than a thick biotype [42,43]. The thin labial plate, a larger distance from the CEJ to the alveolar crest, and a tendency for recession associated with a thin biotype make mucogingival management of these cases extremely difficult. There is also an increased chance of a show-through of titanium if an implant body is not covered by alveolar bone in the presence of a thin biotype. A gray shadow caused by titanium of an implant showing through the gingiva is noticeable in gingiva of 1.5 mm in thickness [16]. An important aspect of a patient with a thin biotype that makes replacement of a single tooth in the esthetic zone even more difficult is this biotype's association with a triangular tooth form. The location of the contact area in triangular teeth is more coronal than that of a square or trapezoidal. The increased distance between the contact point and the alveolar crest in triangular teeth as well as aspects of the thin biotype associated with this tooth form make papilla preservation particularly arduous. In 1992 and 2003 Tarnow demonstrated the effect of the distance between the contact point and the height of the alveolar crest, showing that as the distance between the two increases beyond 5 mm in natural teeth and 3.4 mm between implants there is a decreased chance in achieving papilla fill in the embrasure space [44,45]. A thin biotype is far less forgiving than a thick one and will show even the smallest errors in treatment planning and surgical execution. Determination of the biotype is an important and easy clinical assessment that can be made simply with a periodontal probe and observation of the tooth form. An understanding of biotype will greatly help in prediction surgical and prosthetic outcomes (Figure 28.5).



Figure 28.5 (a) A clinical image of a thick biotype portraying how the tip of the periodontal probe is not visible through the tissue. (b) Clinical photograph of a thin biotype. Note the visibility of the root prominences and the overall transparency of the tissue.

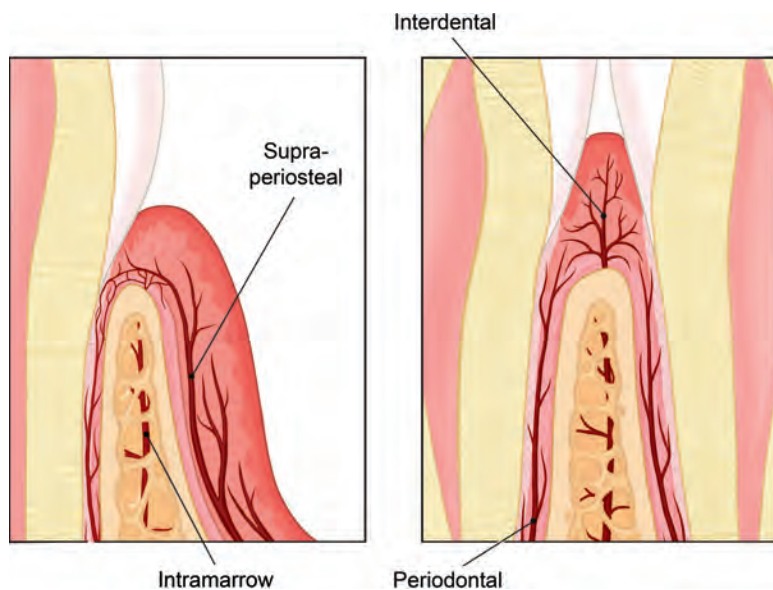


Figure 28.6 A depiction of the three sources of blood supply. The periodontal ligament, the suprapariosteal plexus, and the interdental vessels from the alveolar bone.

Biology–anatomy–vascularity

Blood supply to the oral cavity comes from the lingual, facial, and maxillary branches of the external carotid artery. The maxillary artery branches into the superior and inferior alveolar artery to provide a blood supply to the teeth, alveolar bone, and surrounding structures of the maxillary and mandibular arches, respectively [46]. Dental arteries branch from either the inferior or superior alveolar arteries to supply blood to the teeth, periodontal ligament, and surrounding alveolar bone. The dental artery supplies branches to the root canal, provides a blood supply to the apical portion of the PDL, and puts off an interseptal branch prior to entering the tooth socket (Figure 28.6). The interseptal branch perforates the alveolar bone and enters the socket, where it makes an anastomosis with the branches, which supply the PDL. The anastomosing of these branches of the dental artery forms the dentogingival plexus. The gingiva receives its blood supply from the suprapariosteal blood vessels, which are fed from multiple sources including the sublingual artery, mental artery, buccal artery, facial artery, greater palatine artery, infraorbital artery, and posterior superior dental artery. As these arteries run their course they put off branches that terminate in the suprapariosteal plexus, which supplies blood to the

gingiva. Another small source of blood supply to the gingiva are some vessels from the PDL that pass through the alveolar bone into the gingiva. The gingiva mainly receives its blood supply from suprapariosteal blood vessels while the periodontal ligament and alveolar bone receive their blood supply from the interseptal artery and inferior alveolar artery, respectively. The blood supply to the PDL and bone is largely independent of the blood supply to the gingiva. While these vessels do form anastomosis, the suprapariosteal blood vessels, not the periosteum, supply blood to the alveolar bone. However, while the supracrestal connective tissue lateral to the root cementum was found to be richly vascularized, the corresponding site in the peri-implant tissue was almost devoid of a vascular supply [47] (Figure 28.7).

Every surgical procedure performed in the oral cavity is induction of a controlled injury, whether it is soft tissue grafting or implant placement. The body's first reaction to this injury is an attempt at hemostasis through formation of a blood clot and it is this clot that matures and acts as the scaffold on which new tissue formation takes place [48]. A proper blood supply is essential for healing of both hard and soft tissue. The importance of the blood supply to healing and maintenance of osseous tissue is demonstrated by

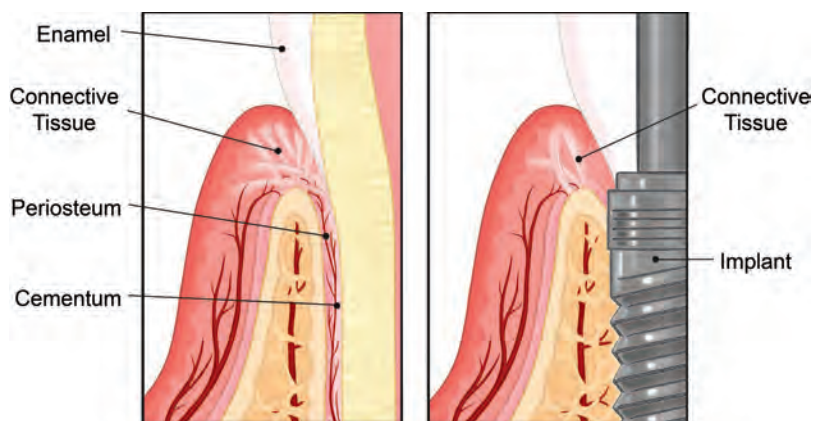


Figure 28.7 A depiction of the supracrestal connective tissue lateral to the root cementum that was found to be richly vascularized; the corresponding site in the peri-implant tissue is almost devoid of a vascular supply.

observing the healing and remodeling of different types of bone in the oral cavity following extractions, osseous surgery, and implant placement. Cortical alveolar bone is a dense mineralized tissue with a minimal blood supply provided by the Haversian system and cancellous bone is spongy, receiving its blood supply from its many marrow spaces. When injury is performed to cortical bone the outer layer resorbs via the Haversian canals in order to expose the blood supply to the injured or exposed area and allow for healing. In healing of osseous tissue there is a period of resorption or osteoclastic activity that is followed by repair or osteoblastic activity [49–53]. The blood supply to the alveolar bone is provided from within the osseous structure's marrow spaces and, contrary to popular belief, the blood supply to the alveolar bone is not provided by the periosteum. When alveolar bone is denuded the outer layer first resorbs to allow for bleeding through the marrow spaces, the formation of granulation and for healing to occur [49–54]. When a layer of periosteum is exposed the outer layer of bone must still undergo resorption in order to allow for blood supply and adequate healing [49–54]. Leaving the periosteum over exposed bone does not provide a blood supply to the underlying osseous structure. The role of the periosteum in osseous healing and blood supply is important for flap design and graft management [49–54].

Flap design is dictated by vasculature as an adequate blood supply to flaps during and following surgical procedures helps to ensure vitality of soft and hard tissue as well as adequate healing. Flaps should be wide and of full thickness at the base and to include gingival blood vessels. The flaps length to width ratio should not exceed 2:1. Suturing techniques should produce minimal tension.

Conclusion

One of the key steps between recognition of a mucogingival or ridge condition and choice of treatment modality is identification of the etiology. Failure to acknowledge an etiology or simply choosing a treatment modality based on defect presentation leads to inadequate and unsuccessful treatment, which is often followed by recurrence. Recognition of etiology begins with a thorough examination. Examination should include medical history, dental history, radiographic exam, and relevant findings, such as: identification of biotype, gingival margins and mucogingival junction, amount of keratinized tissue present, and variations in ridge form. When planning treatment, be sure to identify and eliminate the underlying cause of a defect before attempting a repair. As stated earlier, mucogingival therapy is the surgical and non-surgical correction of defects in both soft tissue and the underlying hard tissues. Mucogingival therapy is a large field divided into resective and regenerative treatments. These sections focus on soft tissue grafting, which is a major component of regenerative mucogingival therapy necessary for the longevity of a healthy soft tissue environment.

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Techniques of Soft Tissue Grafting in Implant Dentistry

Edgard El Chaar and Sarah Oshman

New York University, College of Dentistry, New York, USA

Introduction

A rich history of soft tissue management surrounding natural teeth along with advents in comprehension of wound healing have allowed adaptation and application of surgical techniques to be developed for teeth to implants. Since the development of dental implants, the standards for what was considered a successful implant have changed and become more stringent with advances in techniques and materials used in implant dentistry. The most basic criteria for implant success are those of function, but with implants role in esthetic dentistry new standards for success include form, function, and esthetics. Albrektsson proposed criteria for success that was defined by lack of mobility, the absence of peri-implant radiolucency, and a less than 0.2 mm annual bone loss [1,2]. Since Albrektsson, there have been other means of measuring implant success, namely the esthetic achievement. These new parameters included the pink ssthetic score, an assessment of papilla height, the pink and white esthetic score in a gingival display, and all the esthetic parameters reviewed in the previous chapter and contributes to the new assessment of dental implant success [3–7]. Today's clinicians must balance biology, functionality, and esthetics when treatment planning and executing implants. This and the following chapter will discuss manipulation and/or augmentation of existing soft tissue, rather than prosthetic gingiva, in combination with implant-supported crowns, to achieve an ideal esthetic result.

Implant failures can either be esthetic or functional. Failures that compromise the health of an implant fixture are inflammatory in nature and include peri-implantitis and peri-implant mucositis. While the result of these pathologic changes is often unesthetic, the underlying cause of the disease must first be addressed before steps can be made to restore the esthetics. When an implant is healthy but the result of the surgical and prosthetic placement is unsatisfactory to both the patient and clinician immediate steps can be taken to achieve a more desirable esthetic result. As with all dental treatment, the disease process and pathology must be eliminated or controlled before steps can be taken to repair the damage that it has caused. It is best to take measures to prevent both infectious and esthetic implant failures through proper planning and surgical execution. Techniques to both prevent and correct implant positioning failures in the early stages before prosthetic delivery will be covered with this chapter focusing on surgical management and prevention and the following chapter will be a discussion of corrections and treatment of failed cases.

Some common esthetic failures are loss of interdental papilla with “black triangles”, mid-facial gingival recession, a non-harmonious gingival margin, buccal concavities, and translucency of the implant body or prosthetic margins. There are steps that can be taken to avoid these failures during the planning and surgical execution of implant placement, including augmentation prior to implant placement, flap design during placement, and soft tissue management during second stage. The existing hard and soft tissue should be assessed prior to implant placement in order to determine if there is a need for augmentation prior to placement. Bone height and thickness are major determinants of soft tissue contours while implant placement, tooth morphology, contact point, and tissue quality also play a role [8,9]. The shape and dimension of the osseous crest and the three-dimensional placement of the implant within the osseous tissue affects how the soft tissue will appear surrounding an implant restoration. In order to achieve optimal esthetic and functional results as well as prevent translucency of the implant, a 1.5–2 mm of osseous structure is needed buccal to the fixture [9]. The angulation of the implant relative to its buccal lingual position affects the emergence profile of future restoration. For example, if the fixture is too palatal a buccal ridge lap-style restoration may be necessary, but if the fixture is at 45-degree angle to the occlusal plane optimal esthetics is easier to achieve [10]. This dimension of placement is of particular importance when placing implants in the maxillary anterior region due to the buccolingual and cervicoapical resorption pattern of the anterior maxilla following extraction [11]. The apicocoronal position of a fixture plays a role in determining the height of the gingival margin on the future restoration and is important in achieving a harmonious gingival margin between the implant restoration and the natural teeth. The vertical level of the bony crest around the implant should be approximately 3.0 mm apical to the CEJ of the adjacent teeth and the planned restoration [12].

Papilla fill is dependent on many factors, including biotype, contact, tooth morphology, height of the osseous crest, and adjacent dentition. The morphology of the teeth will determine the location of the contact point, with square teeth having a more cervical contact point and triangular teeth a more incisal contact point. In natural teeth, the distance between the osseous crest and the contact point affects the papilla as the distance beyond 5 mm increases the chances of complete papilla fill decreases [13]. Kan and Kois noted that the biotype also plays a role in the papilla fill as well as the distance from the contact point to bone, noting that in order to

achieve papilla fill a thick biotype needs 4.2 mm and a thin biotype can only tolerate 3.76 mm [14]. When a single implant is placed between two natural teeth, Choquet found that the distance between the osseous crest and the contact point also should not exceed 5 mm to have a complete papilla fill [15]. Grunder found that papilla presence is dependent on the attachment level of the adjacent tooth, noting that one has to account for the 1.5 mm of crestal bone loss around a dental implant in the vertical direction, which should be added to the distance from the contact point to that level [16].

Another factor affecting interproximal tissue is the distance between the dental implant and either the adjacent natural teeth or adjacent implant. A minimum distance of 1.5 mm is necessary between an implant and natural teeth to prevent interproximal bone loss and a distance of 3.0 mm is needed between adjacent implants [17,18]. When proper space cannot be achieved one should consider cantilevers or fixed bridges for a more esthetic result. "Peri-implant plastic surgery focuses on harmonizing peri-implant structures by means of hard tissue engineering and soft tissue engineering, and includes: bone structure enhancement; soft tissue enhancement; precision in implant placement; and quality of the prosthetic restoration." The decision to augment an area prior to implant placement should be based on established protocols and prognosis. Large defects in hard and soft tissue are best corrected prior to implant placement and moderate defects in soft tissue can be addressed during the placement or second stage. Three-dimensional soft tissue defects with vertical and horizontal components should be corrected prior to or at the time of implant placement because stability and vascularization is difficult at any other stage, while faciopalatal (horizontal only) deformities can be more easily corrected at any time through modified soft tissue flap design, soft tissue onlay grafts, and free autogenous subepithelial connective tissue grafts [19]. Once a final prosthesis is in place options and successful outcomes of soft tissue grafting become more limited and difficult to achieve. One way to prevent esthetic and physiologic complication is to insure adequate attached keratinized tissue at a planned site and if there is not enough at the time of placement consider grafting during a second stage procedure. However, even when there is adequate hard and soft tissue, one must be aware that surgical trauma delivered to soft and hard tissues during implant placement can influence the future esthetic result and care should be taken to minimize this trauma during surgery [20]. Flap design during implant placement and management of the soft tissue during initial and secondary stage surgery has an influence on the final outcome. Even if there is adequate crestal bone height prior to implant placement the flap design can affect the amount of crestal bone resorption following placement. Crestal bone loss is of practical importance and statistically significant when comparing two flap designs, one including the surrounding tissue of adjacent teeth and one preserving them, called "limited flap design". Less bone loss was noticed following the use of a "limited flap design" versus a "widely mobilized flap procedure", where the bone loss was 0.29 mm with the limited design versus 0.79 mm in the wide flap design.

Too often abutment placement is performed using a tissue punch technique. Clinicians need to be aware of the importance of second stage surgery and appreciate that it is an opportunity to either improve or correct soft tissue surrounding implants. Second stage surgery is a chance to manipulate the soft tissue around implants and enhance the esthetic and health outcome around dental implants to be restored, leading to a soft tissue architecture similar to that around natural teeth [16]. Many techniques have been described in the literature during second stage surgery.

Techniques

Techniques to create contour, thickness, and increase of the keratinized tissue

Roll technique

A roll flap procedure was developed by Abrams in 1980 as a means of correcting small Seibert class I ridge defects that result in a buccal concavity. This technique is useful in correcting a ridge defect at a future site for a pontic, or a small buccal concavity present in the area where an implant has been placed. If there is an implant present in the site, this technique can be used in combination with the uncover procedure. This technique employs a pedicle connective tissue graft that is harvested from the palate and then folded under into a pouch created on the buccal. The augmentation provided by the pedicle is meant to match the root eminences of the adjacent teeth; therefore, if the edentulous span is greater than one tooth multiple pedicle grafts may be prepared.

The roll technique presented here is a *modification* to the roll technique introduced by Scharf and Tarnow in 1992 [21] and will be illustrated in the series of figures (see Figures 29.1 to 29.5). It begins with making three measurements. The first measure is from the crest of the ridge or the anticipated gingival margin of the future crown to the most apical extent of the concavity, the second measure is the apical width 1 mm from the mesial side of each adjacent apex of the adjacent teeth, and the third measure is the interproximal distance between the adjacent teeth coronally accounting for the papillary-like tissue to be left on the side of each tooth. Those lines of measurements will form a trapezoid shape. These measurements will determine the size of the pedicle that needs to be harvested from the palatal area. The buccal limit of the donor site is the mid-crest of the pontic site preparation or above the middle of the cover screw for implants. This delineates the donor site with incisions extending to the underlying bone in all areas except the crestal limit, which will serve as the base of the pedicle. Once the site is delineated, it is important to de-epithelialize that area and sharply elevate the connective tissue pedicle to a full-thickness flap, leaving exposed bone on the palate. Some authors



Figure 29.1 Buccal and occlusal view prior to initiating the modified roll technique during the second stage. The modified role technique was used in the case to fill the ridge concavity that can be seen in the central incisor area.



Figure 29.2 Portrayal of the three pre-operative measurements used to determine the size of the trapezoid shaped donor pedicle from the palate. (a) Measurement from the crest of the ridge or the anticipated gingival margin of the future crown to the most apical extent of the concavity. (b) Distance of the apical width 1 mm from the mesial side of each adjacent apex of the adjacent teeth. (c) The interproximal distance between the adjacent teeth coronally accounting for the papillary-like tissue to be left on the side of each tooth.

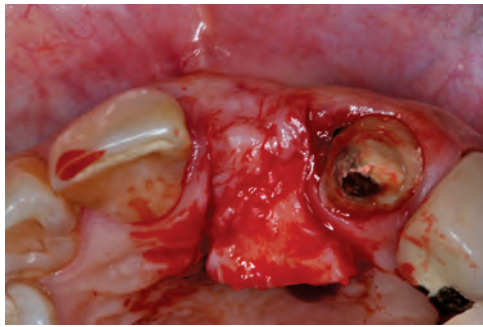


Figure 29.3 Full-thickness flap elevation of the trapezoidal area of donor tissue on the palate as well as creation of a full-thickness buccal pouch.



Figure 29.4 The palatal flap is rolled and tucked into the buccal pouch. This folded flap is held in place in part by the provisional cylinder or a healing abutment and is also sutured into place.

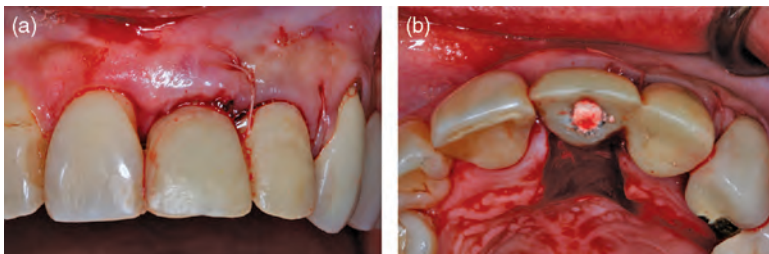


Figure 29.5 Immediately post-operative (a) buccal and (b) lingual views of the modified roll technique with provisionalization. Note the exposed osseous structure on the palate from raising a full-thickness flap.

suggested dissecting the pedicle graft and leaving behind the periosteum, but doing so risks severing the suprapariosteal capillary bed, which may lead to flap necrosis and jeopardize the end result. Full thickness elevation also reduces the risk of perforation of the pedicle flap, allows for a thicker graft, and maintains the supra-periosteal blood supply to the graft. Once the pedicle is elevated to the buccal transition area, create a full thickness pouch in the area of the defect on the buccal following the planned trapezoidal architecture. After elevation of the pouch, roll the pedicle graft into the area of the buccal defect. At this time the pedicle may be trimmed and adjusted to fit. Once the graft is in place, place two stabilizing sutures apically on either side of the trapezoid and two on the coronal area through the neighboring tissue. At this point, the healing abutment can be placed and any periosteum or any osseous structure over the implant cover screw should be removed.

Apically repositioned flap

When there is an inadequate band of keratinized tissue in the anticipated buccal area of the dental implant, of at least 2.0 mm, an apically repositioned flap can be employed on the buccal side of the site. Begin with an envelope flap design (H design), placing a crestal incision lingual to the cover screw(s) with a minimum 2.0 mm band of keratinized tissue. Displace this tissue apically using two cross arch incisions, which extend vertically avoiding the papilla-like tissue on the proximal side of the adjacent teeth. Elevate the flap to full thickness and apical position it with the edge of the keratinized band buccal of the now exposed implant fixture(s). Switch all cover screws to healing abutments and begin to stabilize the apically repositioned flap through suturing. First suture the apical end of the buccal vertical incisions followed by affixing the coronal part of the flap to the buccal tissue. If there are multiple implants in a row, suture the buccal flap to the lingual. The caveat of this technique will leave an area of interimplant crestal bone to heal in a second intentional manner (see Figures 29.6 to 29.8).

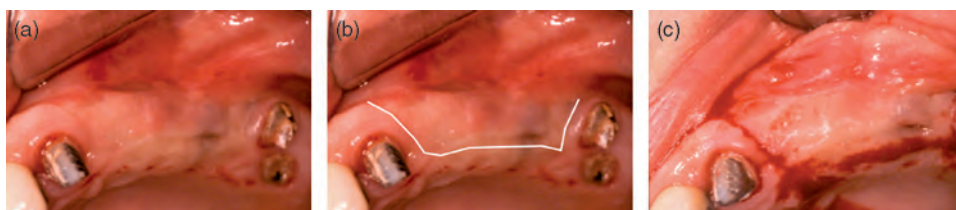


Figure 29.6 (a) Three implants are to be uncovered in the maxillary posterior region employing an apically repositioned flap to increase the zone of keratinized tissue. (b) The flap outline with a papilla sparing design is depicted. (c) The flap with a papilla sparing incision is depicted.



Figure 29.7 The healing abutments are placed and the flap is sutured apically. Note the exposed osseous structure when the buccal and lingual flaps are sutured together between the implants. This results in healing by secondary intention and flattened interimplant papilla, a major drawback of using this technique with more than one implant in a row.

Auto subepithelial connective tissue graft (CTG) or a free gingival graft (FGG)

In case of a lack of keratinized tissue surrounding the implant fixture or in case there is not enough tissue present to be displaced apically or rolled buccally, a free gingival graft (FGG) or an auto connective tissue graft (CTG) may be employed. Connective tissue grafts can be used to increase tissue thickness and/or to increase attached keratinized tissue in areas of esthetic concern. A free gingival graft can also be used to increase a zone of keratinized tissue but will heal with a more blanched looking tissue and it is not advised in areas of esthetic concern. The main advantage of using a connective tissue graft is the color match with the surrounding tissue compared with the free gingival graft. These techniques are



Figure 29.8 After healing with the final prosthesis in place. Note the deep vestibule for ease of hygiene and the large zone of keratinized tissue on the buccal.

easiest to perform at the time of the second stage surgery or implant placement, but can be done with a prosthesis in place if necessary, although that would require a more diligent and refined execution.

Free gingival graft (FGG)

This technique (see Figures 29.9 to 29.12) is mainly used to increase the amount of keratinized tissue while preserving the marginal gingiva. A beveled incision is made in the gingival margin extending past the alveolar crest of bone and the extent of the incision depends on the extent of the area to be treated. At the margins of this area place either two vertical incisions or extend the incisions curving apically.

Flap design should reflect an ability to reposition the flap apically following split thickness reflection. Apically reposition the tissue and secure the position with vicryl 5.0 absorbable sutures. Once the flap is secured measure the recipient area to determine the amount of tissue that needs to be harvested from the palate. Next, harvest a full thickness graft from the palate to place in the area of deficient tissue. The donor tissue should be taken at least 2 mm from the palatal gingival margin as tissue contraction occurs during healing and recession may occur as a result of the wound edge being too close to teeth. The shape of the donor tissue is outlined with a scalpel at right angles to the palate at the desired depth, which can be gauged by the bevel on a 15C scalpel blade (approximately 1 mm). The blade is then turned parallel to the palate and a graft of the desired uniform thickness is removed by sharp dissection from the palate.

The donor tissue is transferred to the recipient site to check the fit and modified if needed.



Figure 29.9 Free gingival graft placement at the time of the second stage. Note that the exposed edge of the mandibular left implant cover screw is surrounded by mucosa. Use of a tissue punch in this case would result in a prosthesis surrounded by mucosa rather than keratinized tissue on the buccal. A free gingival graft was used in this case rather than an apically repositioned flap because there is not enough keratinized tissue present to reposition.

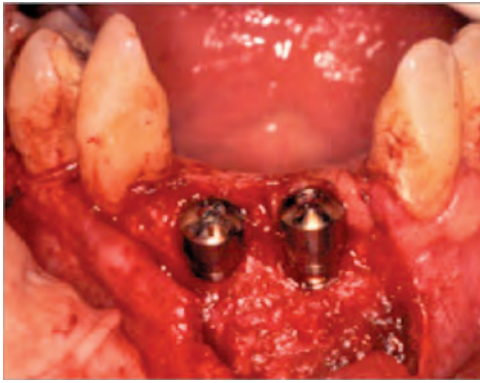


Figure 29.10 Full-thickness flap elevation and placement of the healing abutments.

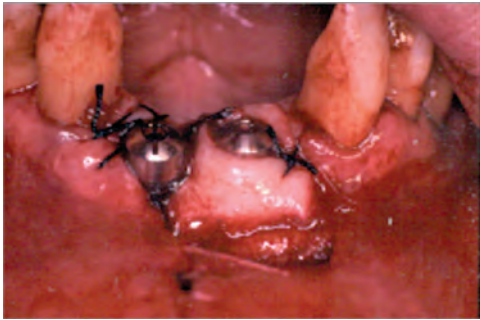


Figure 29.11 The free gingival graft is sutured in place.

Suturing techniques vary widely, but stabilization of the graft is the most important principle and can be accomplished using stabilizing structures adjacent to the surgical site such as interproximal tissue or a sling suture placed around the teeth or the implant crowns. The apical muscle group and the periosteum can be used to stabilize the graft using 5-0 Vicryl absorbable sutures. Reducing graft mobility and dead spaces between tissues will improve the graft success and after an average of 8 weeks the donor and recipient sites are healed. This technique does give a high discomfort at the palate site reported by most patients regardless of which kind of cover is used over the donor site and does not provide a high esthetic result due to the color mismatch.



Figure 29.12 Here the final prosthesis is in place. Note the wide band of keratinized gingiva along the entire buccal limit of the prosthesis.

Connective tissue grafts (CTG)

Following the development and use of free gingival grafts, Langer and Calagna in 1980 described the subepithelial connective tissue graft for root coverage and ridge augmentation as the second major type of free soft tissue autograft [22]. The esthetics advantages, healing period, and superior color match of CTG versus FGG make CTG the most widely used soft tissue autograft technique used in periodontal plastic surgery [23]. A connective tissue graft used under a pedicle flap yields to mean root coverage of 89.3% around natural teeth [24].

When the palatal masticatory mucosa is used as an autogenous donor material for a connective tissue graft it is important to control the thickness of the graft harvested. Harvesting a thick graft aids in vascularity and ease of manipulation of the donor tissue but delays the healing period, while use of a thin graft decreases the healing time but often results in graft shrinkage or early necrosis [25,26]. Therefore surgeons should have a thorough knowledge of the anatomy of the palatal masticatory mucosa and different anatomical landmarks used to harvest an adequate graft. The thickness of the palatal masticatory mucosa was measured through various means such as direct bone sounding with a periodontal probe, ultrasonic devices, and computed tomography, which was shown to range from 1.0 to 12.0 mm [19,27–31]. Histological analysis of the mucosa by Yu et al. showed that the thickness of the lamina propria decreased toward the posterior palatal area and mid-palatal suture, while that of the submucosa increased [32]. Yu's results suggest that the most appropriate donor site is the region 3–9 mm below the CEJ between the distal surface of the canine and the mid-line surface of the first molar. When harvesting from this area also keep in mind the anatomical landmarks of the palate. The greater and lesser palatine foramina are located apical to the third molar at the junction of the vertical and horizontal components of the palate. The greater and lesser palatine vessels and nerves lie in a bony groove, the greater palatine groove, which traverses the palate anteriorly at the junction of the horizontal and vertical palate.

It is important to avoid the nerves and vessels located along this neurovascular line [19]. The location of this line relative to the CEJ varies with the palatal vault depth. In shallow palatal vaults the average distance between the neurovascular line and the CEJ is 7 mm, whereas in high vaults the maximum average distance is 17 mm. In an average vault there is about a distance of 12 mm from the neurovascular line to the CEJ [33]. Major problems can occur when the surgeon violates the neurovascular area, such as paresthesia and excessive bleeding. Paresthesia of the anterior palate is more noticeable to the patient during speech due to the phonetic impact of an absence of feeling in this area. This paresthesia is generally temporary and often dissipates over the span of 6 to 12 months due to regeneration of nerve fibers. Bleeding can be a major problem in the palate but most bleeding can be controlled by pressure, increasing the amount of sutures, and the use of chemical or electrical coagulants. Taking into account an incision started 2 to 3 mm from the free gingival margin and ending 2 mm prior to the neurovascular line then the maximum width of donor tissue will vary from 3 mm in the shallow vault to 13 mm in the high vault, with an average width of 8 mm in the average vault. If the average amount of donor tissue needed for a site is 5–9 mm, this means that harvesting a graft from an individual with a shallow palatal vault may not be adequate and doing so could risk neurovascular damage. In these cases a clinician should consider allogeneic grafting as the best treatment option [33].

A connective tissue allograft can be used in two different ways. One is to increase the bulk of tissue in the area of a small concavity or thin mucosa and the other is to increase the zone of keratinized tissue. If the intention is to increase the zone of keratinized tissue one should employ a free connective tissue graft, while if tissue thickness needs to be increased a classical connective tissue graft procedure should be applied. These two connective tissue grafting techniques will be presented separately.

A free connective tissue graft

A free connective tissue graft is pre-formed in the same manner as a free gingival graft at the recipient site and the harvesting from the palate is performed by dissecting the connective tissue rather than harvesting a full thickness graft. When harvesting connective tissue from the palate begin by doing a single horizontal incision 2 mm apical to the gingival margins, especially at the first molar without vertical incisions, and then elevate a full thickness envelope flap from which connective tissue is dissected out and the remaining flap epithelium cover is left attached to the remaining palatal tissue. Once the graft has been removed, the remaining flap will be sutured to the adjacent immobile palatal tissue.

Covered connective tissue graft

A conventional connective tissue graft is useful in areas where one needs to increase the thickness of the buccal tissue around an

implant or in areas where it is necessary to improve the quality of the tissue. In a covered connective tissue graft the flap created at the donor site is placed over the graft and positioned apically. A coronally advanced flap covering a connective tissue graft increases the graft survival and success and the overlaying flap also adds to the thickness of the grafted area [34]. Two different manners of executing a connective tissue graft will be described below, one using a tunneling technique and one another with an open flap.

Coronally advanced flap with CTG (Figures 29.13 to 29.16)

- 1 Begin with preparation of the recipient bed: lay a full-thickness envelope flap exposing the bone in the area that needs augmentation. Use intrasulcular incisions on the coronal portion of the flap in areas of surrounding natural teeth and use a submarginal incision sparing a 1 mm band of keratinized tissue in the area of the implant. All interproximal papilla should be sliced (de-epithelialized), exposing the underlying connective tissue and leaving the base intact and attached to the underlying bone. If any elements of the implant fixture is exposed following flap elevation, these areas should be disinfected following the clinician's chosen protocol. No vertical incisions will be done, which allows a better blood supply to the flap and more predictable stability to the graft.
- 2 As done in previous techniques, measure the area of the defect and harvest a connective tissue graft from the palate.

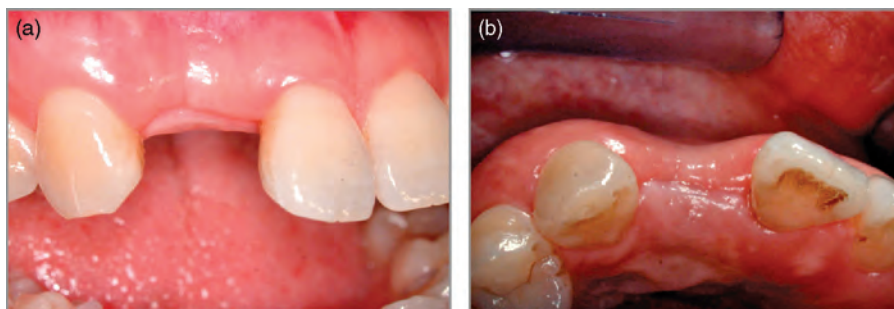


Figure 29.13 In this case there is a buccal concavity visible in the area of implant 7 and a connective tissue graft was employed during the second stage to add bulk to the ridge.

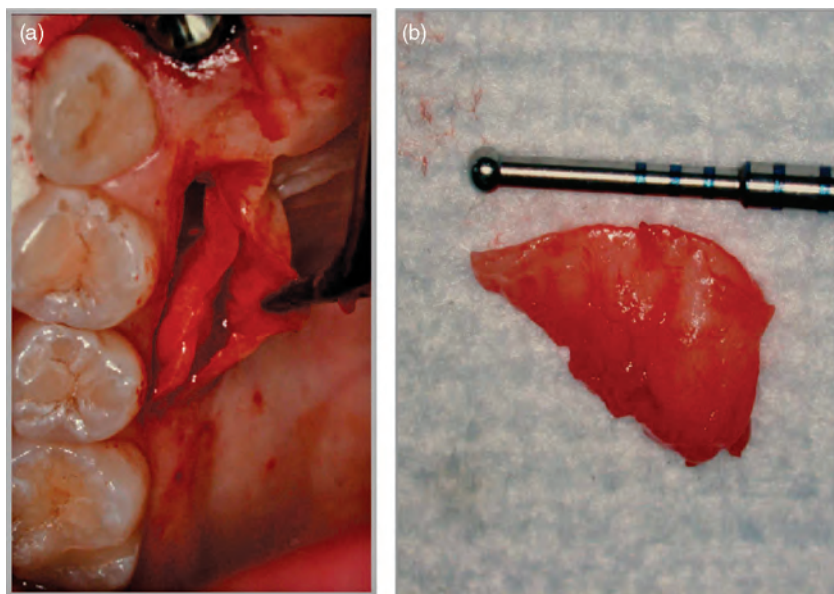


Figure 29.14 Depict harvesting of the connective tissue from the palate.

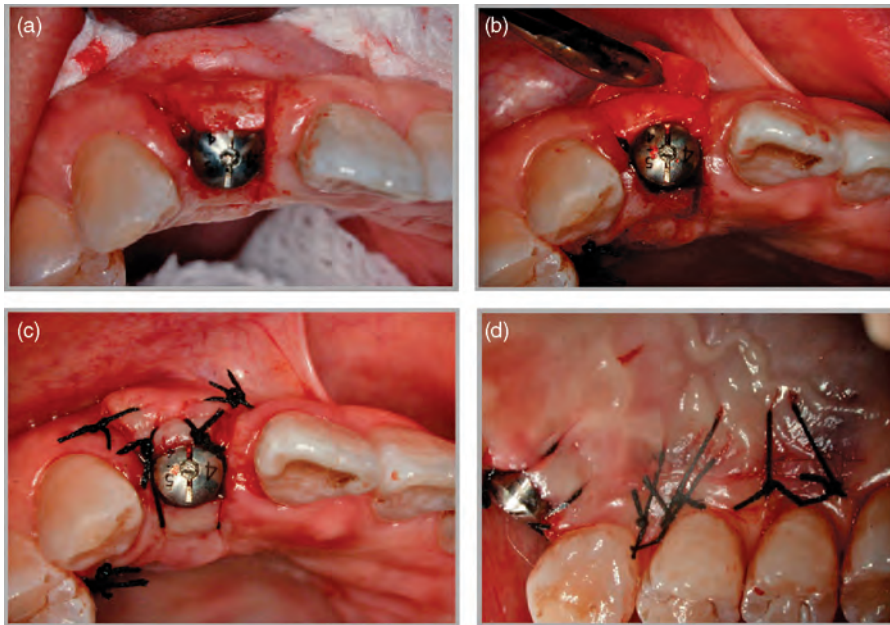


Figure 29.15 (a) A full-thickness flap with a papilla sparing design is elevated to both create the recipient bed for the connective tissue graft and expose the implant cover screw. (b) A healing abutment and the donor tissue is put in place. (c) The flap is secured over the donor tissue and the healing abutment is left in place. (d) The donor tissue is also sutured.

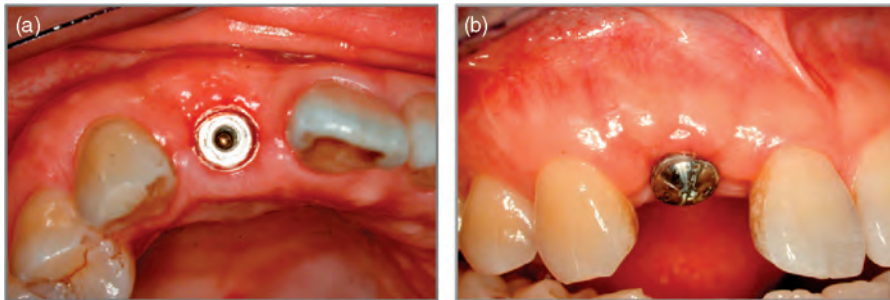


Figure 29.16 Post-operative images. Note the fill in the area of the buccal concavity and the re-established continuity of the ridge.

- 3 Place the CTG into the opened flap and suture it to the interproximal papilla with interrupted sutures using polypropylene 6.0 sutures.
- 4 Stretch the elevated flap and cover the now stabilized graft. Affix the overlying flap using single sling 5.0 vicryl sutures.
- 5 If the overlying tissue is mainly from mucosa another step may be done following healing where the mucosa is split to expose the underlying matured tissue.

Tunnel technique (Figures 29.17 and 29.18)

The tunnel technique allows for placement of a connective tissue graft without reflection of a conventional flap. A tunnel flap is in essence an alteration of a pedicle flap as it maintains blood supply

from the papillary and the mucogingival aspects. This increase in blood supply as compared to a conventional flap aids in graft stability and circulation [19]. A full-thickness dissection prepares the donor site to receive the connective tissue graft. This style of flap is difficult and time consuming when compared to a conventional flap. This technique of reflection should only be undertaken after many conventional flaps have been reflected and a working knowledge of the anatomy is learned. This technique has many advantages as it allows for increased blood supply, graft stability, and a more rapid healing due to the nature of the tunnel flap [35–38].

- 1 In a tunnel technique, the recipient bed is a tunneled full-thickness pouch spanning the area of the defect. Once the defect area is identified, create two vertical incisions approximately the



Figure 29.17 In this case the tunnel technique with a connective tissue graft was employed to increase the tissue thickness in the area of implant 8.



Figure 29.18 (a) A vertical incision is made distal to the defect and a tunnel-like pouch is elevated to full thickness. (b) The harvested connective tissue is passed into the tunnel pouch. (c) The donor tissue is sutured in place.

height of the defect spanning the mucogingival junction and not extending the free gingival margin. The incisions should be at the depth of the osseous structure as a full-thickness pouch is to be dissected in the plane of the incision.

- 2 Elevate the tissue with a tunnel technique in the area of the defect without opening the flap at the gingival crest. Ensure the instrument tip is resting underlying the osseous structure and with a gentle back and forth pushing motion develop and dissect a full-thickness pouch under the tissue. Extend the plane of dissection close to but not breaking the free gingival margin.
- 3 Harvest the connective tissue graft from the palate as previously described. In this case after orienting the connective tissue graft over the defect affix a suture to one end of the graft and then thread the suture through the created pouch positioning your graft.
- 4 Once the graft is satisfactorily placed into the defect area suture it into place through the flap while coronally elevating the flap using a continuous sling suture. The vertical incisions can be closed with interrupted sutures.

Allograft dermis

While autografts such as connective tissue and free gingival grafts have been considered the gold standard for soft tissue grafting, improvement in processing mechanisms and development of soft tissue allografts have made them a predictable alternative to autografts [39,40]. There are many different acellular dermises available on the market, each type differing in processing and sterilization techniques, but all serve a sterile acellular collagen matrix that acts as a scaffold for ingrowth of surrounding tissue [41,42]. The current processing technique involves complete removal of the epithelium by uncoupling the bond with the dermis, ensuring no damage to the dermal structure, and maintaining the basement membrane. The dermal cells are removed with low molecular weight non-denaturing detergents, whereas the matrix is stabilized through the inhibition of metalloproteinases. The tissue is freeze-dried without damaging components essential for revascularization and repopulation by the recipient's normal cells. This process renders the dermal matrix free from cellular components, while

the graft still contains blood vessel channels, collagen, elastin, and proteoglycans [43]. Using an acellular dermal matrix allows for a more organized and rapid healing response due to the biologic scaffold for normal tissue remodeling. The acellular dermal matrix allograft is in the thin to medium range of graft thickness (0.75–1.4 mm) [42,44].

Allografts should be selected in instances where a patient's own tissue cannot overcome a defect or a clinician feels a patient cannot tolerate harvesting of an autograft. The use of an acellular dermal matrix is technique sensitive and its success is highly dependent on case selection. Highly vascularized areas with limited surgical scarring best serve soft tissue allografts as an adequate blood supply will aid with healing and less fibrous tissue will allow for the primary closure necessary for use of soft tissue allografts. The use of platelet-derived growth factor concomitant with acellular dermal matrix products can aid in accelerating the healing process [45]. Allograft dermis cannot be predictably used as a free graft due to the rate of necrosis and delay in vascularization when not covered by a flap. The major advantages of this technique are the unlimited amount of donor material available and the lack of post-operative complications related to the palatal wound. It is recommended that the allograft dermis be completely covered by the patient's tissue for a successful result and can therefore only be used in place of an autograft in some of the techniques presented above. Allograft dermis in the implant therapy can be used in place of connective tissue in the tunnel and open flap. However, connective tissue grafts heal an average of 2 to 3 weeks faster, with more keratinized soft tissue than the acellular dermal matrix grafts [38,39] (see Figures 29.19 to 29.21).

Techniques for papilla management

Second stage surgery or soft tissue augmentation in sites with multiple implants in a row presents a very specific challenge, which is managing the interproximal implant tissue. When using the roll technique, apically repositioned flaps, free gingival, or connective tissue grafts during the second stage around multiple implants, the interproximal areas are left exposed to heal through secondary intention. This type of healing can lead to interimplant crestal bone

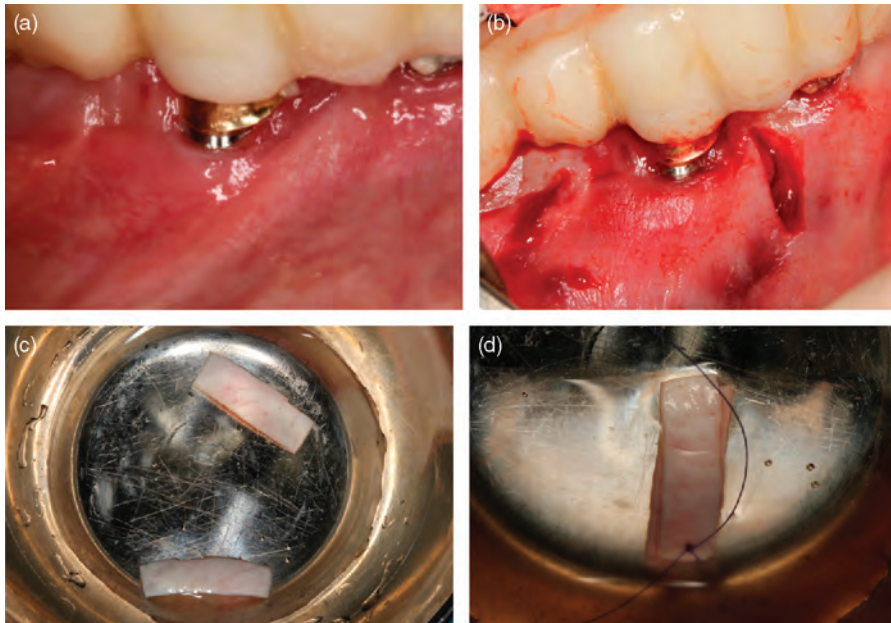


Figure 29.19 (a) There is thin tissue and a shallow vestibule in the area of this mandibular implant. A tunnel technique to place the allograft dermis was used to thicken the tissue and deepen the vestibule. (b) Two vertical incisions are made and a full-thickness tunnel flap is elevated. (c) The allograft dermis is hydrated. (d) The allograft dermis is doubled and a suture is placed on one end to aid in pulling the allograft dermis through the tunnel.



Figure 29.20 (a) The allograft dermis is passed through the tunnel. (b) The allograft dermis is sutured in place and the vertical incisions are closed.

loss and the formation of flat or even inverted intimplant papilla tissue. All of these outcomes are of extreme esthetic detriment and prevent adequate embrasure space fill following final restoration. Fortunately there are techniques to manage soft tissue in a way to correct or minimize this set-back.

Rotated pediculated marginal tissue (Palacci)

Palacci in 1995 described a technique to create papilla-like formation. The attached gingiva is displaced buccally beginning with a crestal incision in line with the palatal or lingual limits of the implant cover screws, two vertical releasing incisions, and a full thickness flap. The flap is elevated and pushed buccally while the healing abutments are placed to hold the flap buccally. The excess buccal tissue is dissected into pedicles that are then rotated into the interproximal spaces. Dissection and rotation is done with semilunar incisions, starting from the distal and rotation of the pedicle at 90° in the palatal direction. The pedicles should be sutured without tension or engagement of the pedicles; an eight-shape figure suture is suggested to hold them in place [46].

Rotated pediculated lingual marginal tissue (El Chaar)

A major modification to the Palacci technique takes advantage of the abundance of soft tissue on the palate while reducing the risk of buccal gingival recession, which can be caused by use of the buccal

as a donor site. In this modification the attached gingiva is displaced buccally beginning with a crestal incision either directly over the center of the implant cover screws or shifted slightly buccally. Two vertical releasing incisions, sparing the papilla-like tissue at the proximal of adjacent teeth, are placed and a full-thickness flap is elevated. The elevated flap is displaced buccally and is held in place by the healing abutments. The excess palatal tissue is then dissected into pedicles with semilunar incisions beginning distally. These pedicles are then rotated into the interproximal spaces. Contrary to the Palacci technique, the pedicles are created from the palatal tissue and rotated forward rather than from the buccal. This is advantageous because no buccal keratinized tissue is sacrificed. Here areas of the palate can be left to heal through secondary intention without fear of creating visible recession and pedicles can be harvested without risk of a deficient width of buccal keratinized tissue. The rotated pediculated papilla-like tissue is sutured to the buccal flap using horizontal mattress sutures. The sutures started from the buccal flap, allowing the pediculated papilla to cover the interproximal bone and lie passively in the interproximal space, which is a very important variant to the Palacci technique, securing the rotated pedicle more and accelerating the revascularization between the two joining tissues. This technique can be utilized anywhere including the anterior area. In cases where the two sides right and left are both involved, one might end up having two rotated papillae

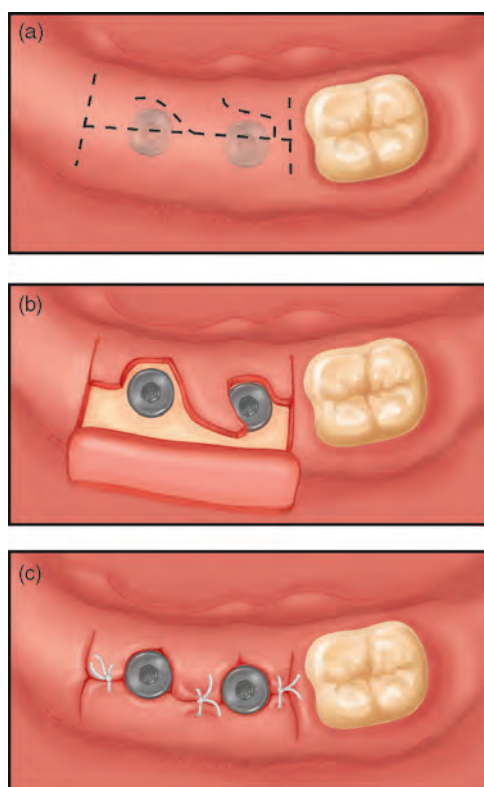


Figure 29.21 (a) A crestal H incision is made, sparing the papilla-like tissue at the proximal of adjacent teeth. A full thickness flap is elevated. (b) The elevated flap is displaced buccally and is held in place by the healing abutments. A semilunar incision is made in the excess palatal tissue in the mesiodistal direction, as shown in (a), dotted lines. (c) The pedicle is then rotated into the interproximal space and sutured to the buccal flap. Contrary to the Pallaci technique, the pedicle is created from the palatal tissue and rotated forward rather than from the buccal. The pedicle is sutured with a vertical mattress.



Figure 29.22 Maxillary posterior prior to placement of two adjacent implants and closure using the rotated pediculated lingual marginal tissue the El Chaar technique. This technique can be used at the time of the single stage implant placement or during implant uncovering of adjacent implants. Note the adequate keratinized tissue on the buccal.

in the mid-line or interimplant in positions 8 and 9. Before committing the two sides, one has to measure the interimplant space. If the mid-line interproximal space is 3 mm then one side's (right or left) rotated pedicle should fill the space. If that space exceeds 4 mm, then the two pedicles from both sides right and left should be rotated to fill the space. If needed, those two pedicles can be affixed together via 6.0 polypropylene sutures. (Figures 29.22 to 29.24).

Conclusion

This chapter presented an overview of how to apply the biology and esthetic considerations (presented in the previous chapter) to prevent soft and hard tissue defects surrounding planned implants. It also presents information that aids the clinician in deciding the best time during treatment to correct any identified deformities. This chapter outlines multiple techniques that can be used to both prevent and manage the soft tissue surrounding implant fixtures,



Figure 29.23 (a) A full-thickness flap is elevated, exposing the area. (b) After the implants are placed a pedicle is dissected out of the lingual tissue and rotated to the interproximal position. (c) The healing abutments are placed and the pedicle is sutured into place.

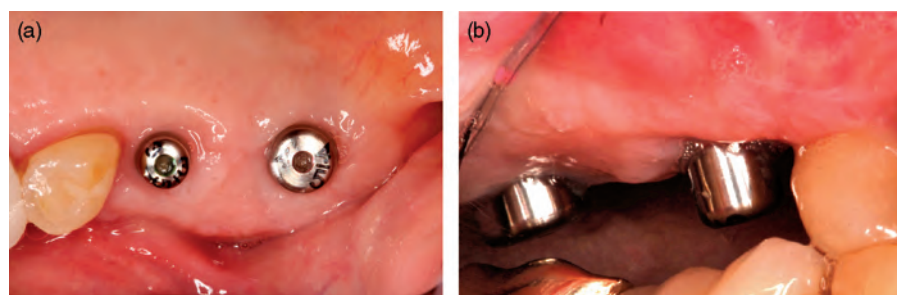


Figure 29.24 Note the abundant soft tissue height and papilla-like structure present between the two healing abutments most visible in the buccal view.

such as: connective tissue grafts, free gingival grafts, acellular dermal matrix grafting, and rotated pedicle grafts. While this chapter does distinctly present surgical techniques, it is not simply a manual. The indications as well as the pros and cons of each approach are also reviewed in order to help a clinician make the best choice for each specific case he/she may encounter. The methods presented here can be applied to correction and prevention of a wide variety of soft and hard tissue defects, ranging from buccal concavities, lack of keratinized tissue, and deficient papilla between implant fixtures. The biologic rationale and surgical indications provided alongside these techniques will aid in proper treatment planning and execution of successful surgical procedures.

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Management of Complications of Soft Tissue Grafting in Implant Dentistry

Edgard El Chaar and Sarah Oshman

New York University, College of Dentistry, New York, USA

Introduction

This section will discuss the management of soft tissue complications surrounding restored implants. Complications surrounding restored implants can be either inflammatory or esthetic in nature, with inflammatory pathologies often causing esthetic issues. Inflammatory problems include peri-implant mucositis and peri-implantitis; diagnosis and treatment of these pathologies must be addressed before attempting to correct the esthetic defects caused by the disease process. Purely esthetic complications are those present with no signs of inflammation and can often be the result of implant positioning, restoration, or inadequate soft and hard tissue. While it is best to ensure correct positioning and adequate hard and soft tissue prior to implant placement and restoration circumstances still arise where this is not always possible. While one may be tempted to remove a healthy osseointegrated implant for the sake of achieving better positioning or building a site prior to placement, rather than attempting to surgically mask or correct a hard or soft tissue problem restarting the case from the beginning is not always the best treatment option. One important thing to consider when choosing a course of action, implant removal and replacement with multiple surgeries can be time consuming and traumatic for patients, tissue that has healed from multiple procedures is often fibrous and difficult to handle and has a reduced blood supply, and a decrease in the success rate often follows multiple surgical procedures. It is important for surgeons to have alternative options other than restarting cases from scratch in their repertoire. The following chapter will include case presentations and management of soft tissue problems at implant sites. It will also review how to distinguish inflammatory and non-inflammatory complications as well as management of both types of complications. The most complicated failures are those that are inflammatory in nature. Diagnosis and treatment of these as well as repair of the destruction they cause will be discussed through three case reports in this section.

Diagnosis/treatment of inflammatory complications

Peri-implantitis and peri-implant mucositis are diagnostic terms to describe an inflammatory pathology surrounding implants. Peri-implant mucositis involves inflammation of the soft tissue

surrounding implants and peri-implantitis is inflammation of both the hard and soft tissues surrounding implants and is distinguished from peri-implant mucositis by the crestal bone loss that accompanies the soft tissue inflammation [1]. The diagnosis of peri-implantitis is based on clinical observations of bleeding or suppuration on palpation or probing and radiographic analysis of crestal bone levels [1]. The diagnosis of peri-implantitis cannot be made with the same set of objective assessments used to diagnose periodontal disease surrounding teeth. Probing to assess attachment loss around implants is not a valid diagnostic tool. The validity of probing around implants is questionable as the fibrous arrangement and insertion surrounding implants varies from that around natural teeth [2,3]. Probe penetration is highly dependent on force and in the case of implants probe penetration has been shown to penetrate up to 0.2 mm from the crest of bone [4]. Diagnosis of peri-implantitis and peri-implant mucositis is mostly made by clinical observation of tissue and radiographic examination. If a clinician determines that there is an inflammatory aspect to the soft tissue complications surrounding an implant it is necessary to first address and treat the inflammatory disease before addressing repair of the aesthetic aberrations.

The 6th European Workshop in Periodontology put forth a consensus statement that successful treatment of peri-implantitis must be surgical in nature [5]. The primary objectives of surgical treatment of peri-implantitis should include resolution of inflammation and preservation of the supporting bone as well as surface decontamination and debridement. In the following cases decontamination and debridement by implantoplasty was selected due to the survival rates of implants treated with implantoplasty. Another reason implantoplasty is used as a treatment of peri-implantitis prior to correction of defects is that GBR and re-osseointegration is successful around adequately disinfected previously infected implants [6,7]. The decision to surgically treat rather than remove and replace an implant should be made on a case by case basis by the clinician. The following protocol is not advised for mobile or failed implants [8]. The surgical protocol followed when peri-implantitis was an element of the diagnosis in the following cases was presented in a poster presentation at the 100th meeting of the American Academy of Periodontology and is as follows [9]:

- 1 Debridement
- 2 Defect assessment
- 3 Implantoplasty
- 4 Decontamination with phosphoric acid
- 5 Grafting of amenable defects with puros cancellous graft and pericardium membrane; osteoplasty if necessary.

Soft tissue grafting and adaptation of the techniques presented in the previous chapters can be used concurrently with this protocol or in a separate surgical procedure following the resolution of peri-implantitis.

Case reports

Case 1

A 59-year-old female, presented with purulent exudate on the buccal of an implant in position of mandibular right canine and 1st premolar. Intraoral examination revealed a lack of keratinized tissue and gingival margin recession (Figure 30.1). In this case one option was to remove the dental implant, prepare the site, and replace the implant in a more amenable position. This option would require removal and replacement of the entire round-house prosthetic bridge as well as a large economic and time commitment from the patient. A more conservative option, and the one that was chosen for this case, was surgical treatment of the inflammatory pathology and grafting to correct the resulting defects. The procedure was performed in one sitting and there was no need to remove the patient's existing prosthesis.

A full-thickness mucoperiosteal flap was elevated and it was visually confirmed that the implant was partly placed outside of the buccal bony housing. Two intrabony defects, classified as three wall periodontal defects, were also noted on the mesial and distal (Figures 30.2 and 30.3).



Figure 30.1 Purulent exudate and a lack of keratinized tissue with recession on the buccal of implant in position of mandibular right canine and 1st premolar to be treated with implant decontamination and connective tissue graft.

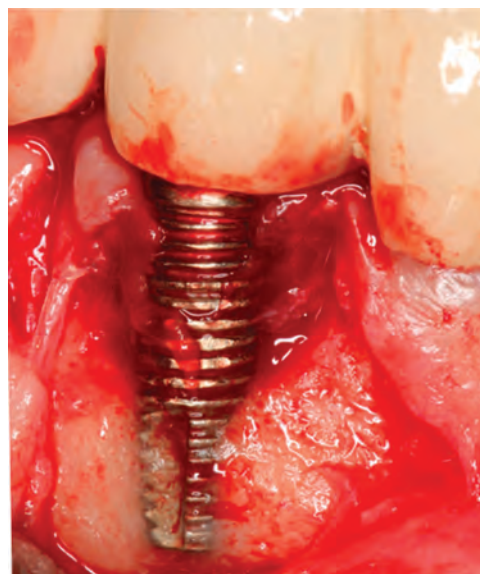


Figure 30.3 Once the flap was elevated it was confirmed that the implant was placed outside of the bony housing. Note the infrabony defects present on both the mesial and lingual of the implant. The area was debrided and prepped for implantoplasty.



Figure 30.2 The procedure began with debridement and elevation of a full-thickness flap.

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Figure 30.4 High-speed handpiece and irrigation was used to preform implantoplasty on all exposed areas of the implant.

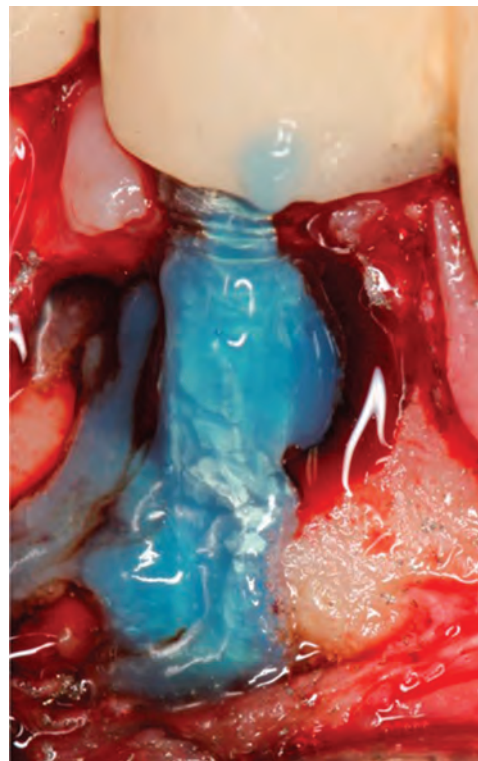


Figure 30.5 Following implantoplasty, the implant surface was treated with phosphoric etch solution and then thoroughly irrigated with saline.

The dental implant had a roughened surface and was deemed contaminated due to the presence of purulence. In cases such as this the first step is to perform a disinfection of the dental implant surface. In this procedure it was done via implantoplasty and surface treatment with phosphoric acid followed by a saline rinse. The implantoplasty physically removes surface contamination while creating a smooth surface. The phosphoric re-etches the implant surface, creating minor roughness. This treatment of the contaminated implant surface will help create an amenable environment for the regenerative aspects of this procedure (Figures 30.4 and 30.5).

A cancellous mineralized allograft bone graft was placed in the intrabony defect on the mesial and distal (Figure 30.6). The photograph in the Figure 30.6 clearly shows blood filling the spaces between the cancellous graft material. This blood graft mix will form the clot and scaffold necessary for wound healing and tissue regeneration.

Following bone grafting, a connective tissue autograft was collected from the palate of 20 mm x 10 mm in length and width (Figure 30.7) and laid over the treated area. This soft tissue graft was secured by interrupted resorbable Vicryl 5.0 sutures on the interproximal papilla areas of the recipient site. The mucoperiosteal flap was stretched and coronally repositioned achieving a complete coverage. Post-operative instructions were reviewed and antibiotic therapy coverage was given along with pain control medications (Figure 30.8).

This treatment led to a successful complete coverage with the formation of a thick keratinized tissue of a keloid nature around the dental implant, as shown in the figure of three years follow-up (Figure 30.9). The patient was placed on a rigorous periodontal maintenance of three months recall two months after the surgical procedure was done.

A review of how treatment planning and surgical decisions made during this case influenced and led to a successful outcome will be presented prior to discussing further cases. Successful treatment is dependent on proper diagnosis, treatment planning, and laying out of surgical goals. In this case both inflammatory and esthetic complications were observed. Proper investigation and diagnosis revealed the cause of the inflammation and the esthetic complications were the result of both the positioning of the implant and the lack of keratinized tissue. The treatment goals were resolution of the existing inflammation and soft tissue enhancements to both prevent recurrence of inflammation and correct damage caused by the existing pathology. The chosen surgical treatment was a direct reflection of these goals.

A full thickness flap was elevated giving access to debride and decontaminate the area achieving the first surgical goal, resolution of inflammation. Following debridement and decontamination the area needs to be assessed and choices need to be made regarding achievement of the next surgical goal, rebuilding of the soft tissue. In this case two periodontal intrabony defects on either side of the implant were present and a decision to regenerate and augment the hard tissue along with the soft tissue was made. The two wall bony defects have the potential to contain and provide blood supply to the graft [10]. When placing the bone graft a mineralized cancellous allograft graft was intentionally chosen. The clinician in this case chose mineralized cancellous allograft over mineralized cortical allograft because of its density as well as its ability to wick more blood in between the graft particles, allowing for better healing [11]. Blood supply to the grafts also drove the clinician's choice not to use a resorbable barrier over the bone graft. In bone regeneration therapy, the use of a resorbable barrier is recommended to contain the bone graft and inhibit the soft tissue in growth. In this case, placing a barrier over the bone and below the connective tissue graft (CTG) would interfere with the healing CTG by inhibiting the blood being supplied to it from the supporting bone [12,13]. All of the choices made during the execution of treatment for this case were based on diagnosis, surgical goals, blood supply, and wound healing, which helped lead to a successful treatment outcome.

(continued)



Figure 30.6 A cancellous mineralized allograft bone graft was placed in the intrabony defect on the mesial and distal. Note the wicking of the blood into the area between the bone particles and the creation of an overall red tone to the otherwise white graft material.



Figure 30.8 The flap is elevated over the donor tissue and both the flap and graft are sutured into place.

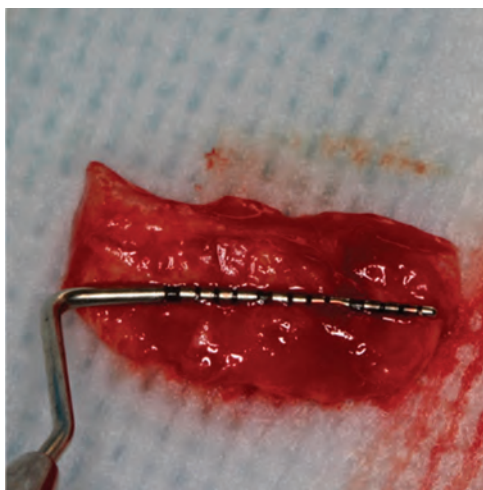


Figure 30.7 A thick connective tissue graft was harvested from the palate for placement over the defect.



Figure 30.9 A three-year follow-up shows thick firm pink healthy tissue surrounding the implant.

Case 2

A 49-year-old female presented with mucositis on the implant in the position of the maxillary right 1st premolar area (Figure 30.10). Clinically the area exhibited a lack of keratinized tissue with metal translucency and the patient exhibited pain upon passing a periodontal probe over the area. Clinically, it appeared that the implant was placed buccally with the possibility of having it outside the bony housing after the restorative dentist removed the crown and placed a cover screw for maxillary right 1st premolar implant (Figure 30.11). Two treatment options were presented to the patient, one to remove the implant, rebuild the site, and replace the dental implant and the other to increase the connective tissue in the buccal area. The patient opted for the latter and it was decided to increase the amount of keratinized tissue by using our modified rolled technique, discussed in Chapter 29.

Trapezoidal measurements needed to perform the modified rolled technique were made on the buccal and palatal incisions were made replicating the desired shape (Figure 30.12). The pedicle was elevated to full thickness and was de-epithelialized using a new 15C blade. The buccal pouch was prepared exposing an implant surface devoid of buccal bone. At this point implantoplasty was performed to disinfect that surface as thoroughly as possible and a phosphoric acid etch was applied for 40 seconds and washed out with saline (Figure 30.13).

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Figure 30.10 There is a lack of keratinized tissue, pain upon probing, as well as metal translucency in the maxillary right 1st premolar implant. Clinically the implant appears buccally placed and outside the alveolar housing. This area was treated by using the modified roll technique.

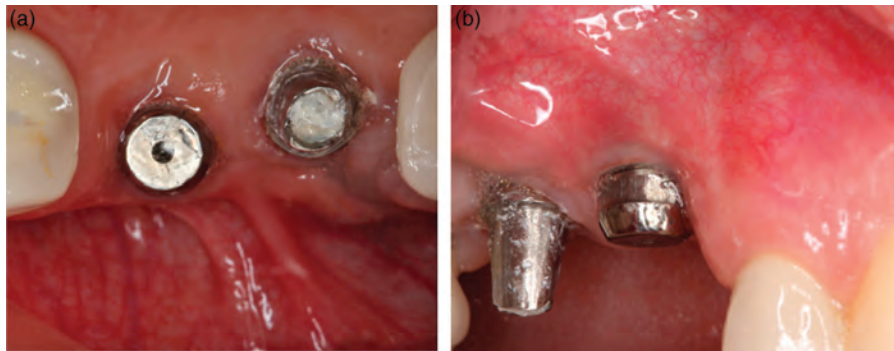


Figure 30.11 The restorative dentist removed the prosthetic components and replaced them with the healing abutments in the areas of maxillary 1st and 2nd premolars.



Figure 30.12 Trapezoidal measurements needed to perform the modified rolled technique were made on the buccal and palatal incisions were made replicating the desired shape.

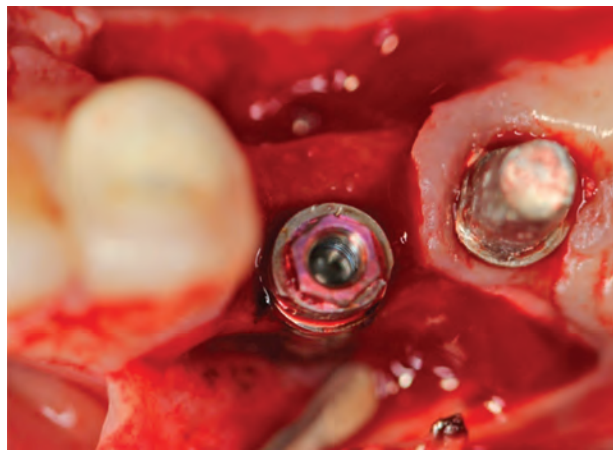


Figure 30.13 The pedicle was elevated to full thickness and was de-epithelialized using a new 15C blade. The buccal pouch was prepared, exposing an implant surface devoid of buccal bone. At this point implantoplasty was performed to disinfect that surface as thoroughly as possible and a phosphoric acid etch was applied for 40 seconds and washed out with saline.

(continued)

Following cleaning of the exposed implant surface, the trapezoidal pedicle was rolled under the buccal flap. The pedicle was sutured apically mesially and distally and next on the coronal level (Figure 30.14). The donor site was covered with a resorbable collagen matrix and stabilized using a methylacrylate-based glue that was applied all around the edge (Figure 30.15). Immediately after the surgery, a temporary crown was placed over the implant (Figure 30.16).

The modified rolled technique led to a substantial increase in soft tissue thickness and in the amount of keratinization (Figure 30.17). In 8 weeks time, the tissue had settled and the final restoration was redone, as shown in the five years post-restorative images depicting the clinical state of that site both buccally and lingually (Figure 30.18).

In analyzing the treatment rendered and explaining the reasoning behind the success achieved, one can notice that the inflammatory complications around this dental implant were due to the erroneous positioning of the implant as well as the lack of keratinized tissue. In this case resolution of the inflammation and esthetic correction of the thin soft tissue can be conceptualized as two treatment goals, disinfection and soft tissue enhancement. The first goal of reduction of inflammation was achieved by following the previously discussed protocol for treatment of infected implant surfaces. The second goal of soft tissue augmentation was achieved through use of a pediculated graft. A connective tissue graft receives a blood supply from the underlying bone but in this case the CTG is being placed over both vascularized bone and a non-vascularized implant surface [14]. In order to increase the success of this graft and compensate for a reduced blood supply caused by the presence of the implant surface a pediculated style graft was chosen [15]. Note that the graft was dissected to full thickness to prevent disturbing the blood supply within the pediculated flap. Also the full-thickness pouch was created to allow direct contact between the CTG and the underlying bone as well as maintaining the suprapariosteal capillary bed within the flap as a third source of blood supply to the pedicle graft [13,16]. The three sources of blood supply to this graft were the overlying flap, the base of the pedicle, and the underlying bone; it was the attention to the blood supply and its role in successful wound healing and surgical outcome that allowed an effective outcome in these cases. Lastly, the trapezoidal design of the pedicle was chosen because it allows a vast coverage of the defect area, allowing the grafted tissue to blend into the surrounding area without the obvious demarcated bump, which occurs in the original rolled technique promoted by Scharf and Tarrow [17].

Case 3

In this case, the patient presented with a dental implant in the position of maxillary left central incisor. Examination revealed a thin biotype with a mid-buccal soft tissue dehiscence about 4 mm apical to the gingival margin (Figure 30.19). There was no mobility and the patient expressed no discomfort in the area. Radiographically there was a pronounced radiolucency around the dental implant (Figure 30.20). The patient expressed financial difficulties and requested to save the implant and the restoration costs. The surgical goals in this case were to increase the soft tissue over the buccal side in the area of the maxillary left central incisor implant to correct and prevent further soft tissue complications and elimination of any inflammation that could be causing bone loss, which presented as radiolucency around the implant. In this scenario it was decided to use a tunnel technique and sandwich an autogenous connective tissue graft (CTG) harvested from the palate under the buccal flap following surgical decontamination of the exposed implant surfaces.

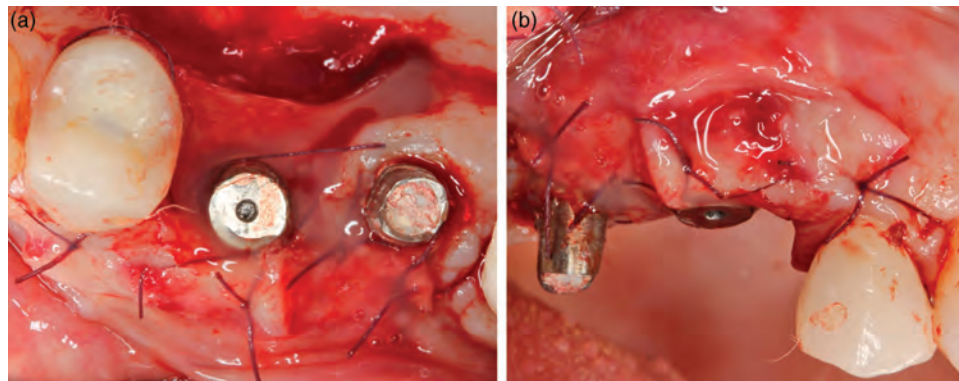


Figure 30.14 Following cleaning of the exposed implant surface, the trapezoidal pedicle was rolled under the buccal flap. The pedicle was sutured apically mesially and distally and next on the coronal level.



Figure 30.15 The donor site was covered with a resorbable collagen matrix and stabilized using a methyl acrylate based glue that was applied all around the edge.

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Figure 30.16 A temporary crown was placed over the implant.



Figure 30.17 An 8-week surgical follow-up.

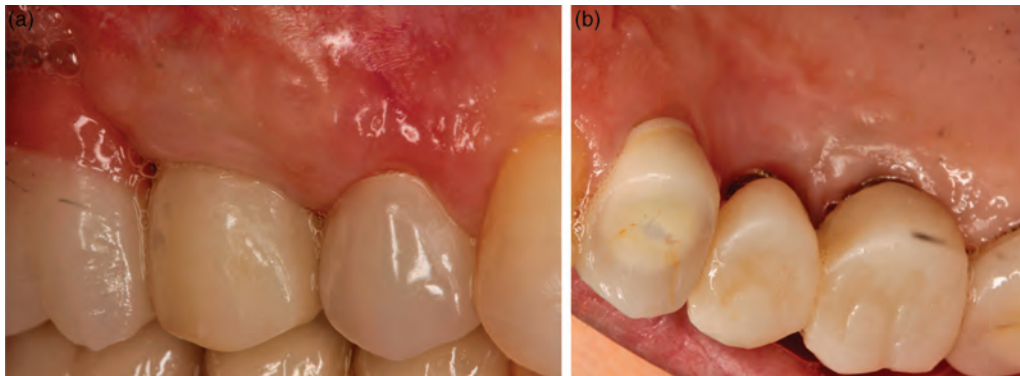


Figure 30.18 A five-year post-restorative follow-up. Note the firm pink thick healthy tissue in the area of the maxillary right 1st premolar implant as compared to the pre-operative figure.



Figure 30.19 There is a buccal dehiscence present in the area of the maxillary left central incisor implant as well as a thin biotype. In this scenario it was decided to use a tunnel technique and sandwich an autogenous connective tissue graft (CTG) harvested from the palate under the buccal flap following surgical decontamination of the exposed implant surfaces.

(continued)



Figure 30.20 The radiographic exam depicts a pronounced radiolucency around the dental implant 9.



Figure 30.21 The 5-mm vertical incision was made interdentally 5 mm from the papilla on the mesial side of the implant one tooth over. The area was elevated to full thickness and dissected past the mucogingival junction and extended laterally to allow adequate mobility for passage of the CTG.

As discussed earlier, this technique was introduced in the mid-1990s and has been very successful around natural teeth [18–20]. The difficulty with this approach lies in creating a pouch large enough to pass a thick CTG through without perforating the flap or ripping the interdental papilla. Many modifications have been described in the literature and recently it is mostly employed with a dermis allograft, but it can also be used with an autogenous CTG [21]. With either alloplast or autogenous grafts this technique is indicated for satisfactory correction of Miller Class I and II gingival recession around natural teeth [21]. In this scenario there is not gingival recession around natural teeth but rather a dehiscence type of gingival aberration in the area of an implant adjacent to natural teeth with a well-maintained periodontium. The challenge in performing the tunnel technique in this case resides in avoiding creation of a gingival recession on the adjacent teeth while creating a large enough pouch for graft access to the implant.

One 5-mm vertical incision was made interdentally 5 mm from the papilla on the mesial side of the implant one tooth over. A fine surgical periosteal elevator was used to elevate a full-thickness pouch flap. The pouch was dissected past the mucogingival junction and extended laterally to allow adequate mobility for passage of the CTG (Figure 30.21).

The area over the implant was examined and a very careful implantoplasty was performed, accessing the surface through the vertical incisions as well as the mid-buccal perforation. Phosphoric acid was placed over the polished implant surface and rubbed for 40 seconds and rinsed out with saline (Figures 30.22 to 30.24).

Next the needed size of CTG was measured. Here it was decided to harvest the CTG from the left palatal side, which was partially edentulous distal to tooth 12. A sizeable CTG was harvested and passed through the right vertical incision by threading a 5.0 Vicryl suture that was affixed to one end of the CTG through the tunnel flap. Once the CTG was in place it was stabilized with interrupted sutures. The mid-buccal dehiscence was closed using a peri-acryl glue (Figures 30.25 to 30.28).

At eight weeks, the tissue finished its maturation and can be seen in the included photograph (Figure 30.29). At six months post-operative, a radiograph was taken and showed gain in bone re-cortication and resolution of the radiolucency (Figure 30.30). Clinically, the perforation was closed but the tissue in the area of the dehiscence remained thinner than the adjacent tissue (Figure 30.31). This is attributed to the buccal tilt of the implant. At this time the patient was placed on a rigorous three months recall to prevent recurrence of inflammation.

Discussion of the justification for decisions made during this case and how they are related to the outcome are as follows. Once again clinicians must diagnose the underlying cause of the soft tissue aberration surrounding the implant in order to set surgical goals that both eliminate the cause and correct the existing defect. The cause of the inflammation surrounding this implant was due to the erroneous positioning of the implant and the lack of keratinized tissue. The surgical goals in this case were to eliminate the existing inflammation using the presented protocol for implant decontamination and enhancement of the soft tissue using a CTG.

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Figure 30.22 Implantoplasty was carefully preformed through the incisions made for the tunnel flap using diamond burs with irrigation and a high-speed handpiece.



Figure 30.23 Next the surface was treated with phosphoric etch and thoroughly rinsed with saline.



Figure 30.24 This figure depicts the flap and implant following decontamination.

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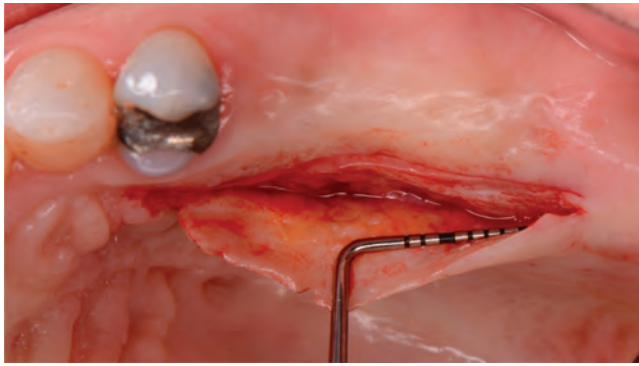


Figure 30.25 A single palatal incision in the premolar region for the harvesting of a connective tissue graft.

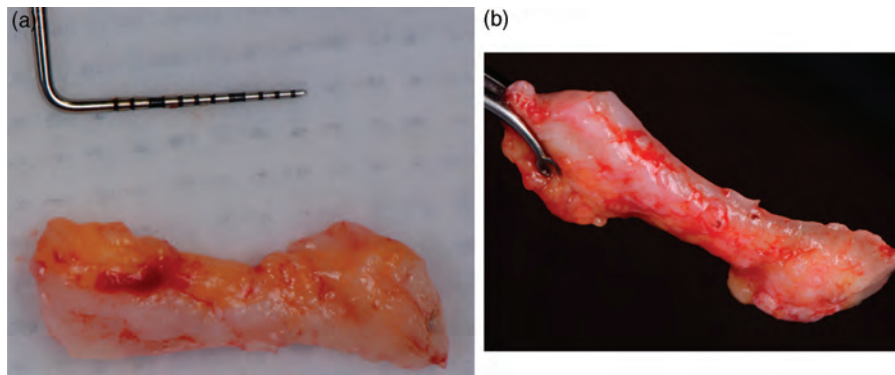


Figure 30.26 A thick connective tissue graft was harvested from the palate.



Figure 30.27 The graft was carefully put into place through both the vertical incision and the existing dehiscence with the help of a 5.0 Vicryl suture affixed to one end of the graft.



Figure 30.28 The graft was sutured in place and the vertical incision was closed. The mid-buccal dehiscence was closed using a peri-acryl glue.

The existing inflammation was removed using the established implant decontamination protocol and soft tissue enhancement was achieved using a CTG along with the tunnel technique. A full-thickness tunnel flap was used because of its ability to stabilize the CTG as well as provide enhanced blood supply. The CTG received its blood supply from the underlying exposed bone of the adjacent teeth and the areas surrounding the exposed implant surface as well as the overlaying flap. The full thickness design of the tunnel flap and the choice to extend it to the adjacent teeth increased the contact area between the CTG and

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Figure 30.29 Eight weeks post-operative clinical photograph.



Figure 30.31 A six-month post-operative clinical photograph. Note that the dehiscence is closed and the surrounding tissue is thicker but there is still a dip in the tissue topography in the area of the previous dehiscence.

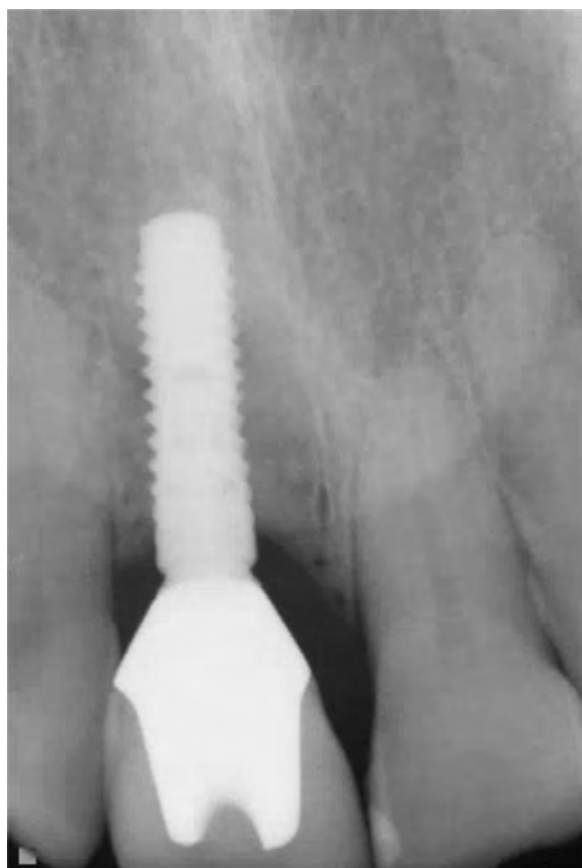


Figure 30.30 Six months post-operative radiograph showing gain in bone recortication and resolution of the radiolucency.

underlying bone. The area of the exposed implant is unable to provide vascularization to the graft and in order to increase the percentage of the graft that is in direct contact with a blood supply the graft size was increased and the recipient bed was extended to include the adjacent teeth. In this case the graft is placed directly over the cortical buccal bone. The cortical bone contains Haversian canals that link directly to the blood-rich cancellous bone underneath, but it takes about 2–4 days for the Haversian canals to internally resorb and increase to a diameter that is large enough to allow blood to flow from the marrow out to the graft [22]. During these initial days of compromised blood supply to the graft from the underlying bone the CTG is more dependent on the blood supply from the overlaying flap. To help increase the blood supply from the flap a tunnel flap was chosen rather than an open flap due to the pedicle nature of the tunnel flap. Despite the challenges of the lack of vascularity in the area of the exposed implant as well as the dehiscence of the overlaying flap, the CTG survived and will continue to thrive in the area as long as further inflammation of the implant area is prevented through proper maintenance.

Conclusion

The three presented cases share common theme: incorrect placement of a dental implant that lead to an inflammatory condition due to inadequate hard and soft tissue support. The soft and hard tissue complications in all of these cases could have been avoided had the fundamentals of implant placement, described in the previous chapter, been respected and followed. It is understood that errors occur. Proper management of these errors needs to be addressed. In the management of existing complications, the pros and cons of correction verses implant removal and replacement need to be weighed on case-by-case bases. There is a great deal of risk, time commitment, and cost in redoing an unsuccessful implant case but it should be noted that surgical correction is also highly technique sensitive, requiring both surgical skill and a deep understanding of inflammation and wound healing. Proper diagnosis and elimination of inflammatory pathology should always be eliminated prior to correction of the damages it caused in order to prevent a recurrence. It is suggested that any operator should only embark on the above-described techniques after mastery of soft tissue management and an understanding of wound healing and vascularization. The details of soft tissue grafting around implants has been thoroughly covered in the previous three chapters and stands as an excellent starting point to the incorporation of the covered techniques into any clinician's repertoire.

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SECTION VII

Tissue Engineering in Implant Dentistry

Alveolar Bone Augmentation via In Situ Tissue Engineering

Robert E. Marx

Division of Oral and Maxillofacial Surgery, University of Miami Miller School of Medicine, Miami, Florida, USA

Introduction

In situ tissue engineering refers to the regeneration of missing tissue directly within a defect without the use of an autogenous graft. Related to ridge augmentation, it is capable of fulfilling the ideal criteria for dental implant placement, i.e.:

- 1 One hundred percent viable bone without residual non-viable particles.
- 2 Sufficient height for a 10-mm implant length.
- 3 Sufficient width for a 4.0-mm implant width without cortical dehiscence.
- 4 Sufficient mineral density to attain primary stability.

In situ tissue engineering, like all tissue engineering, must combine cells capable of tissue regeneration with a signal to promote proliferation and differentiation of these cells together with a matrix (scaffold), onto which the tissue can regenerate [1,2]. This is frequently referred to as the tissue engineering triangle (Figure 31.1) [3]. In the case of bony ridge augmentation, the classic tissue engineering triangle is achieved by combining platelet rich plasma (PRP) (the cells) with recombinant human bone morphogenetic protein-2/absorbable collagen sponge (rhBMP-2/ACS) (the signal), and a crushed cancellous freeze-dried allogeneic bone (CCFDAB) (the matrix). Even with this, the host bone within the defect contributes substantially to the osteoprogenitor cells and stem cells in PRP and conversely the cell adhesion molecules in PRP (fibrin, fibronectin, and vitronectin) contributes to the matrix upon which the bone regenerates [4,5].

Surgical approach to alveolar ridge augmentation (vertical and horizontal) in implant dentistry

General considerations

- 1 Because there is no need to harvest autogenous bone, in situ tissue engineered grafts can be accomplished under local anesthesia alone or complimented with intravenous sedation in a clinical/office setting.
- 2 Due to the particulate texture of in situ tissue engineered grafts space maintenance is required, which should also serve to stabilize and protect the graft from occlusal forces and/or pressure from provisional appliances during the healing period [6]. This

may be achieved with the use of a reinforced membrane, titanium mesh, or resorbable mesh.

- 3 While the bone regeneration from in situ tissue engineering is predictable, the soft tissue healing is not. The surgery should realize that a bone deficiency is most always accompanied by a soft tissue deficiency that is often very subtle. The soft tissue is often contracted, scarred and is poorly vascular. The periosteum also cannot be relied upon to be osteogenic or angiogenic because it has been injured by tooth extraction, previous periodontal inflammation, and often previous flap reflections. Therefore, the surgeon must be prepared to design the incision in unaltered tissue and be prepared to extensively undermine the mucosa to gain a tension-free primary closure (Figures 31.2 and 31.3).
- 4 For ridge augmentation involving a focal defect of a three-tooth replacement area or less, 3 ml of PRP is adequate, which requires 20 ml of whole blood drawn through phlebotomy. For greater than a three-tooth replacement area, 7 ml or 10 ml of PRP should be used, using the guideline of 1 ml of PRP per tooth area. These quantities of PRP require 60 ml of whole blood drawn by phlebotomy.
- 5 The correct and most cost savings dose of rhBMP-2/ACS is 0.5 mg/tooth replacement area [7]. That is the smallest commercially available rhBMP-2/ACS dose, 1.05 mg, which may be used in a one- or two-tooth replacement area. The next higher dose of 2.1 mg is used for a three- to four-tooth replacement area and proportionally through the succeeding doses available of 4.2 mg and 8.4 mg.
- 6 Crushed cancellous mineralized allogeneic bone is the preferred primary matrix over demineralized allogeneic bone, cortical bone particles, or xenogeneic bone. This is due to the superior surface area of allogeneic cancellous bone and its ability to adhere to the cell adhesion molecules of fibrin, fibronectin, and vitronectin [7].

Specific approach for ridge augmentation in maxilla or mandible

The blood drawn for platelet-rich plasma is best accomplished immediately prior to the case or as part of the intravenous (IV) access, if IV sedation is used. A double-spin controlled centrifugation device (e.g., Harvest–Terumo, Denver, CO) is required as the only double-spin device that is proven to capture sufficient platelets for a four- to sevenfold increase over baseline to enhance stem cell proliferation [8].

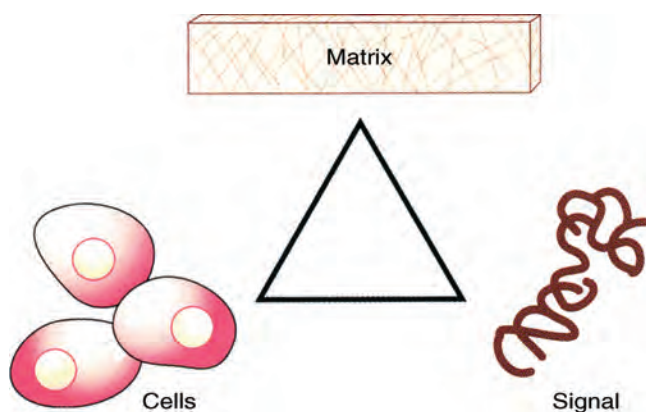


Figure 31.1 The classic tissue engineering triangle requires cells–signal matrix to regenerate tissue.

Although mid-crestal incisions are common and may be used, the author prefers a vestibular incision because the mid-crest is the most scarred and poorly vascular area and is the centerpoint of tension during the first few days of edema (Figure 31.2). A vestibular incision allows for closure and an unscarred area with better vascularity and one that is under less tension.

The mucosal reflection should reflect periosteum from the facial surface wound, the ridge crest, and include palatal periosteum. Since some scarred remnants of the periosteum often remain on the bony surface, it is prudent to remove it with a bur in the sense of roughing up the bony surface rather than decorticating it or placing bur holes in it. It is also prudent to reflect the flap thoroughly so as to facilitate the fitting of the space maintaining mesh or reinforced membrane (Figure 31.4).

Prior to fitting the mesh or membrane it is best to undermine the flap at this time for the eventual closure (Figure 31.3). This will allow a better access in which to try in and remove the mesh or membrane several times and will also allow for identification and control of bleeding points prior to the closure. The undermining is started by an incision in the periosteum followed by the introduction of sharp scissors. The scissor is used to bluntly make space beneath the mucosa followed by sharply cutting through septa created by the spreading maneuver. The plane of undermining should be

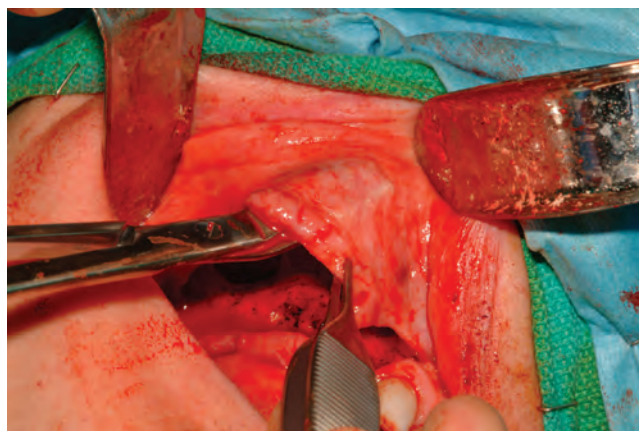


Figure 31.3 Significant undermining of the mucosa is required to gain a tension-free closure.

superficial to the buccinator muscle just deep to the mucosa itself (Figure 31.3). In this manner, cheek movement during the post-operative period will not pull the tissue at the wound closure.

The next maneuver is to fit the mesh or reinforced membrane. However, while this is being accomplished one member of the surgical team should remove the PRP from the centrifugation device and place it into the crushed cancellous allogeneic bone so that the cell adhesion molecules can bind to the surfaces of the allogeneic trabecular bone network. Additionally, the PRP should be activated using 5 drops of a mixture obtained by placing 5 ml of 10% CaCl_2 into 5000 units of topical bovine thrombin. This activates the platelets to secrete their numerous growth factors into the environment of the graft material. It should be noted that the use of topical bovine thrombin is common today in a multitude of uses and represents a safe product. In the mid-1990s, some bovine thrombin products became contaminated with bovine factor Va, which produced antibodies that cross-reacted with human factor Va, resulting in excessive bleeding in a rare number of patients [8]. From 1998 forward, purification of bovine thrombin eliminated bovine factor Va, which eliminated this complication.

The author frequently uses resorbable mesh (e.g., Resorb-X, KLS Martin, Tuttlingen, Germany), which maintains rigidity for six months and slowly resorbs over six to nine months without excessive hydrolysis. This has the advantage of eliminating the



Figure 31.2 An incision design avoiding the crestal scar reduces the incidence of dehiscence.

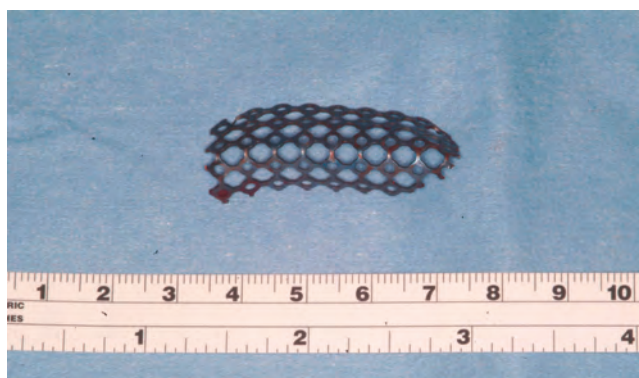


Figure 31.4 Titanium mesh crib contoured to the ideal ridge form will maintain the shape and space for the graft to regenerate new bone.



Figure 31.5 Resorbable cribs of PLA/PLGA ratios will maintain the shape and a space for the graft without negatively affecting bone regeneration and will obviate the need to remove the crib during implant placement.

need to re-flap the tissue in order to remove a metal mesh and also eliminates the inherent recoil of metal meshes and reinforced membrane's that place a further tension on the closure (Figure 31.5).

Titanium mesh and reinforced membranes can be adapted in situ or on a pre-made model sterilized and modified for an ideal fit before being loaded with the graft. Resorbable cribs require in situ shaping using a hot water bath and flushing warm water over the mesh in situ for an ideal adaptation.

While the mesh or membrane is being fitted and after the PRP has been combined with the crushed cancellous allogeneic bone, the rhBMP-2/ACS is prepared. This requires combining the correct amount of sterile water into the vial of lyophilized rhBMP-2 powder until completely dissolved. It should be noted that only the prescribed amount of water as indicated on the package and only water should be used. Using other than water (e.g., saline, D5W, etc.) or a different amount changes the pH of the solution, reducing the rhBMP-2/ACS activity [9]. Additionally, rhBMP-2 is a protein with a specific tertiary structure. Therefore, shaking the vial rather than swirling it to gain dissolution may disrupt the active site of the protein and is discouraged. Once the rhBMP-2 is completely dissolved, it is placed evenly on the absorbable (acellular) collagen sponge (Fig. 31.6) and allowed to bind to the sponge for 15 minutes,

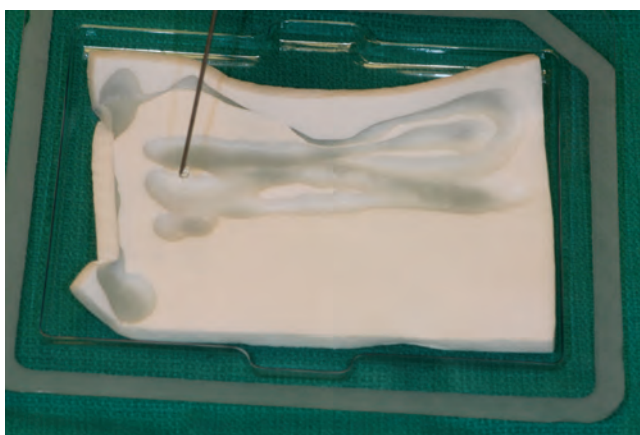


Figure 31.6 RhBMP-2 as it is added to the absorbable (acellular) collagen sponge (ACS).



Figure 31.7 Absorbable (acellular) collagen sponge completely saturated with rhBMP-2; 93% saturation occurs in 15 minutes.

which binds 95% of the protein (Figure 31.7). After the 15-minute binding time, the rhBMP-2 loaded ACS is cut into squares of about 5 mm × 5 mm (Fig. 31.8a) and mixed thoroughly on to the activated PRP-CCFDAB composite (Figure 31.8b).

At this time, the mesh is loaded with the graft material, which now supports all three legs of the tissue engineering triangle

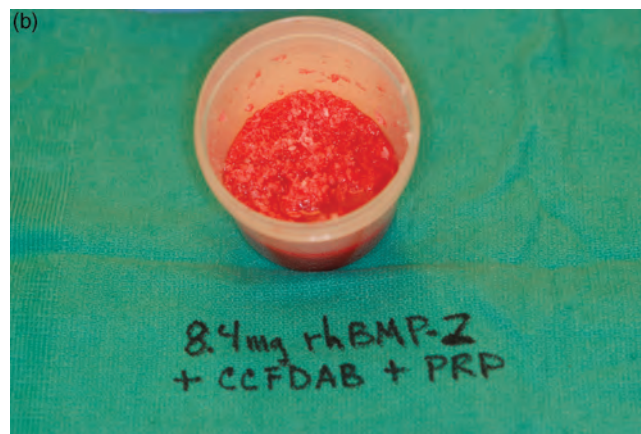


Figure 31.8 The rhBMP-2/ACS is (a) cut into small squares and (b) added to the crushed cancellous freeze-ried allogeneic bone (CCFDAB) and platelet-rich plasma (PRP).

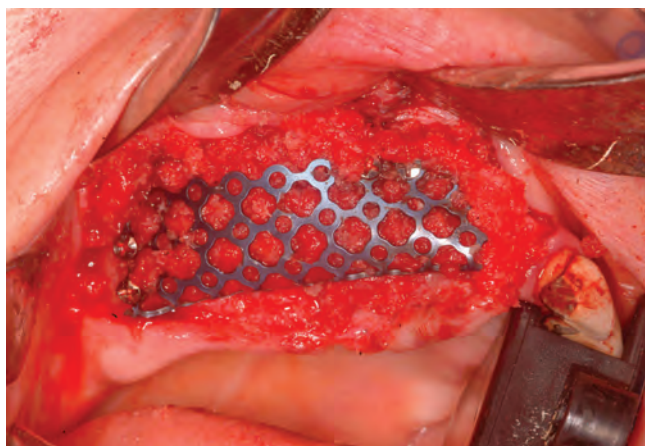


Figure 31.9 Composite graft of rhBMP-2/ACS-CCFDAB-PRP placed within the titanium crib.

(Figure 31.9). The mesh is then fixated with 1.5-mm titanium screws or with sonic weld screws, if a resorbable mesh is used. Additional bony defects or a sinus lift preparation may also be filled with the graft composite, if required.

The undermined flap is then advanced and closed over the graft using a double-layered closure consisting of a horizontal mattress closure and an overclosure of continuous running “baseball”-type sutures (Figure 31.10a). The regenerated bone is sufficiently mature for implant placements at 6 months (Fig. 31.10b).

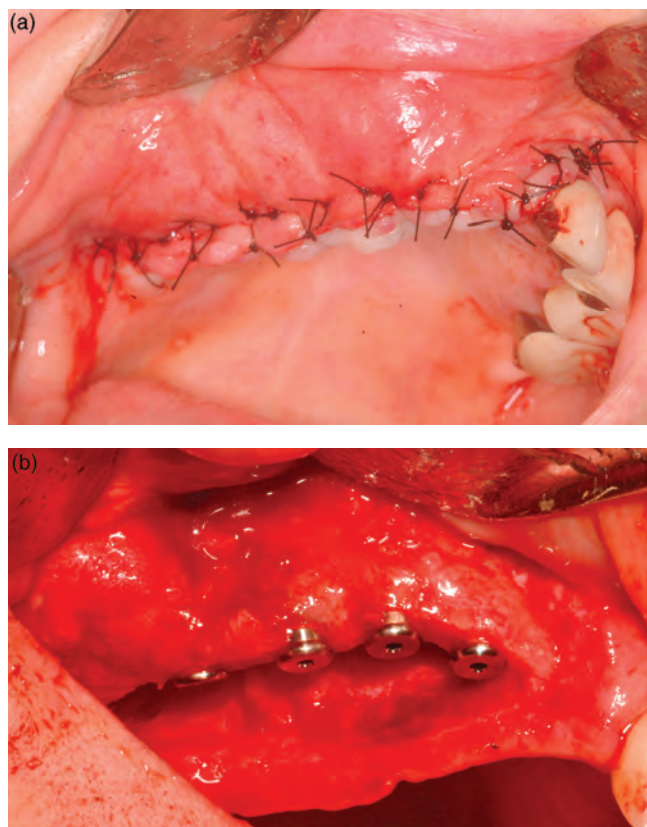


Figure 31.10 (a) Horizontal mattress closure is a preferred closure over cribs containing graft material. (b) Bone regenerated and implants placed from composite in situ engineered graft.

The author uses Unasyn 3 gm intravenously as an antibiotic of choice or Doxycycline 100 mg in the penicillin allergic patient during the surgery as well as 12 mg of Dexamethasone to reduce edema. For cases using local anesthetic only, similar antibiotic and Dexamethasone may be used orally one hour before the procedure.

The biology of the graft and its importance in the follow-up period

Because rhBMP-2/ACS attracts and proliferates osteoprogenitor cells and stem cells and it is essentially hypertonic, it will produce a greater amount of edema than most other grafts [10]. Therefore, provisional prostheses may not be possible for the first three weeks or, if it has been made, should be relieved and relined to avoid compressing the graft site.

The rhBMP-2 uncouples from the ACS within 21 days [11]. It chemo attracts osteoprogenitor cells and stem cells, it induces their proliferation and differentiation into functioning osteoblasts [12]. Because the rhBMP-2/ACS was mixed into the graft composite, this forms numerous centers of bone formation throughout the volume of the graft. rhBMP-2 also up-regulates the vascular endothelial growth factor (VEGF) [10], which acts together with the VEGF from PRP, and together with participation of the platelet-derived growth factors (PDGFaa, PDGFbb, and PDGFab), transforming growth factors 1 and 2 (Tgfb-1, Tgfb-2), and stromal-derived activation factor 1-alpha (SDAF-1a) in PRP, the graft is rapidly revascularized.

The rapid revascularization and cellular proliferation induced by these growth factors allows the graft to get through the critical first two weeks of the graft life when a graft is most vulnerable to dehiscence, infection, and instability during this time. Therefore, the surgeon should caution the restorative team member about post-operative edema and to either defer provisional restoration or fabricate it off the graft site for the first three weeks. This becomes especially important when a wound dehiscence occurs, exposing the membranes or implanted mesh within the first 14 days. This early mesh or membrane exposure will most likely cause an infection with either partial or complete graft loss (Figure 31.11). If the dehiscence exposing a mesh or membrane occurs after 14 days, the graft revascularization is present and beyond a critical point. Epithelization then occurs under the exposure and does not negatively affect the graft outcome (Figures 31.12 and 31.13).



Figure 31.11 This mid-crestal dehiscence occurred on day 3 and resulted in loss of the graft due to infection.



Figure 31.12 This mid-crestal dehiscence occurred on day 21. The graft had already revascularized under the mesh, resulting in complete bone regeneration.

By 14 to 21 days the osteoprogenitor cells and stem cells have differentiated into osteoblasts and have begun secreting osteoid on the surface of the cell adhesion molecules adherent to the cancellous allogeneic bone surface [13]. The separate centers of bone formation represented by the position of the rhBMP-2/ACS sponge pieces fuse together to consolidate the graft. This is seen radiographically as a loss of the particulate appearance of the graft and formation of a condensed ossicle.

The initial bone that is formed is osteoid, which can be seen histologically as very cellular bone lacking in lamellar architecture and Haversian systems (osteon) (Figure 31.14). This bone resembles embryonic bone or the type of bone seen in a fracture callous (woven bone). This initial bone will undergo an obligatory osteoclast mediated resorption–remodeling cycle, which replaces this immature bone with a less cellular and more mineralized bone containing lamellar architecture and early Haversian systems (Figure 31.15). *At six months*, this graft represents type 2 or type 3 bone sufficient for implant primary stability (Figure 31.16).



Figure 31.13 Complete bone regeneration despite the dehiscence and mesh exposure seen in Figure 31.12.

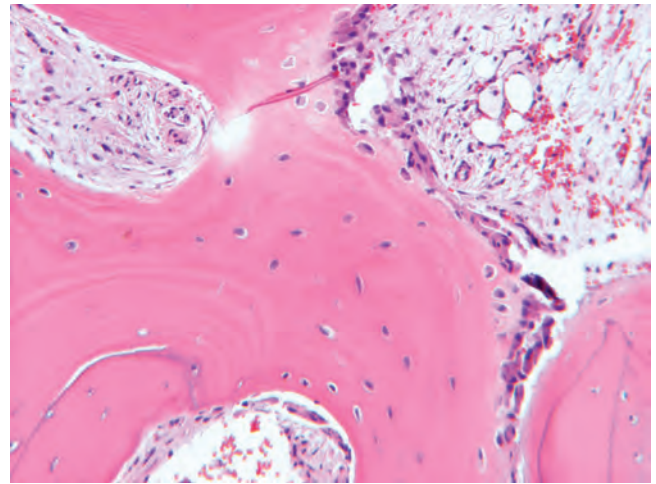


Figure 31.14 Viable osteoid forming (single arrow) on non-viable allogeneic bone (double arrows) by plump osteoblasts (triple arrows) induced by the rhBMP-2 seen in the first 2 months.

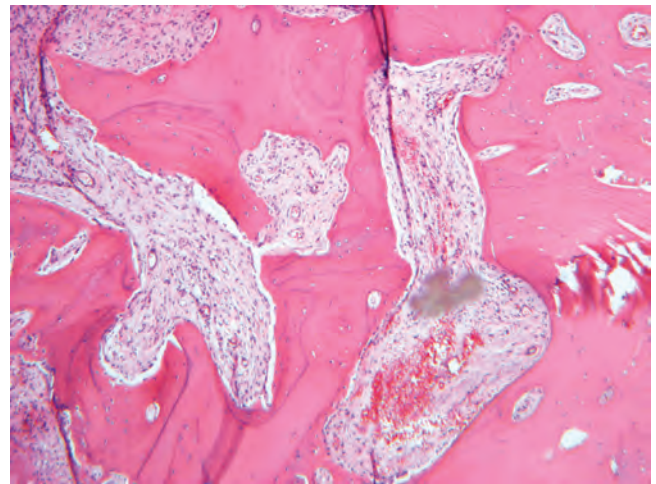


Figure 31.15 Between 2 and 6 months a mixture of mature and immature bone is seen along with some as yet unresorbed non-viable allogeneic bone particles.

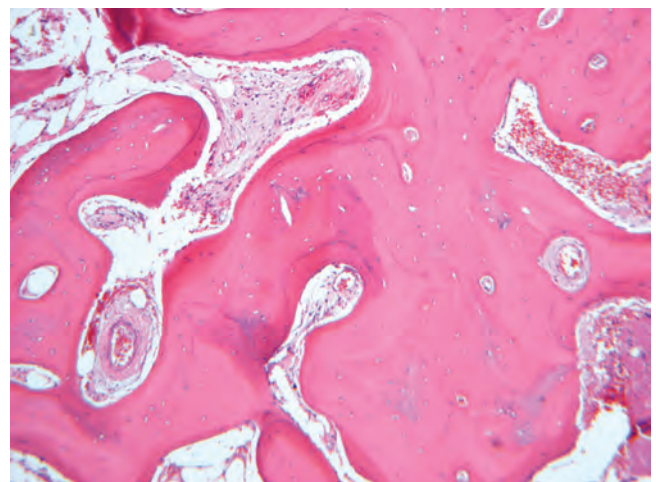


Figure 31.16 By 6 to 9 months the in situ tissue engineered graft is mature with no residual non-viable allogeneic bone particles.

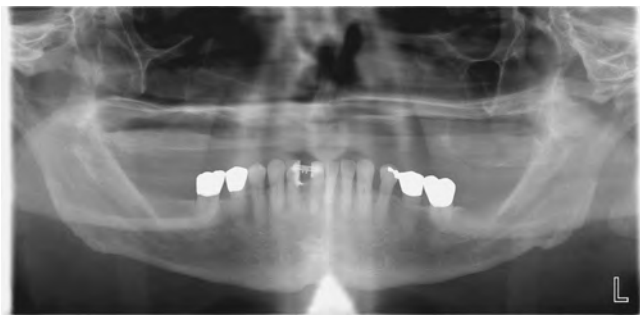


Figure 31.17 Severe maxillary vertical and horizontal bone loss from “combination syndrome”.



Figure 31.18 In situ tissue engineered bone graft just after implants were placed.

Once implants are placed, the graft undergoes a rapid maturity seen radiographically as the development of a trabecular mineralized bone. This maturation process is further accelerated by functional loading (Figures 31.17 to 31.20).

The value (advantages) of in situ engineered vertical and horizontal ridge augmentation is the avoidance of the time, second surgical site, pain, and morbidity of harvesting autogenous bone. The author accomplished a randomized open label study comparing the outcome of in situ tissue engineered grafts to similar autogenous grafts from the tibial plateau used specifically for ridge augmentation (Table 31.1). The results from this study clearly indicate equal outcomes related to bone regeneration,

Table 31.1 Maxillary vertical ridge augmentation.

	Tissue engineered	Autograft	P value
N	40	40	0.99
Bone regeneration	37	37	0.99
Trabecular bone area	72%	64%	0.95
Osseointegrated implants	137/148 (92.6%)	140/156 (89.7%)	0.93
Donor sites	N/A	40/40	–
Average cost	\$5700	\$5200	0.09
Average time of procedure	48 minutes	78 minutes	P=0.05



Figure 31.19 Stimulated bone maturation by the surgery of dental implants is evidenced by the emergence of a well-defined trabecular bone pattern.

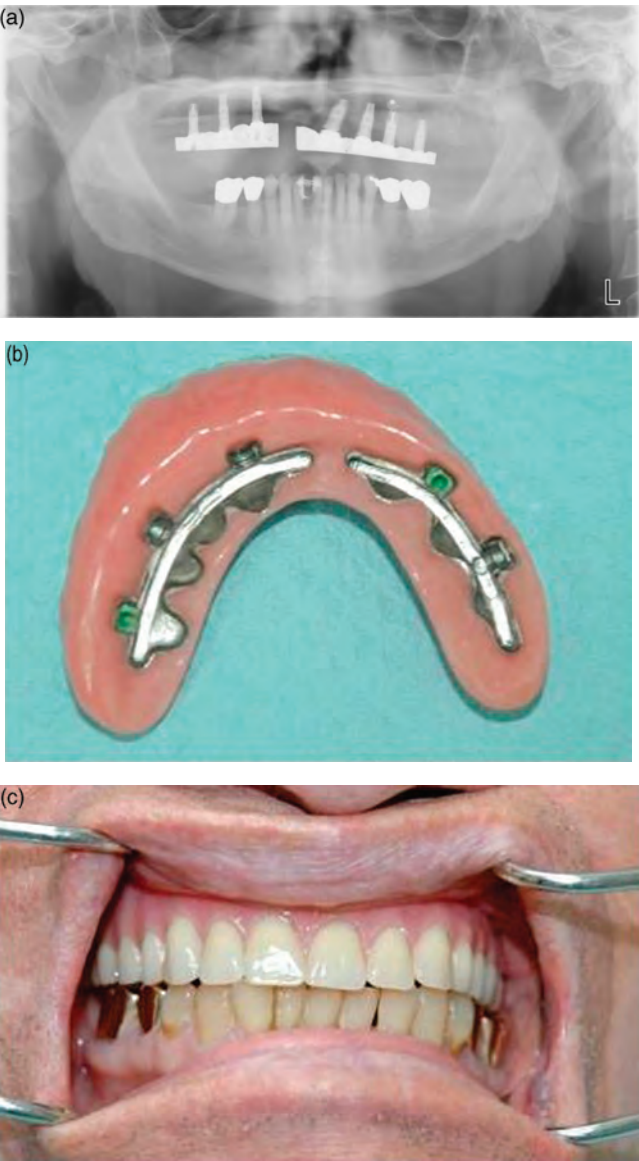


Figure 31.20 (a) Six-year follow-up of implants in an in situ tissue engineered graft supporting a milled maxillary appliance. (b) Milled bar complete denture fabricated for implants placed within in situ tissue engineered graft. (c) Clinical view of a stable maxillary appliance against natural dentition.

osseointegration of implants, bone maturity, and complications. Moreover, there was no statistical difference in the cost of the procedure due to the time saving and/or second operator–second assistant savings inherent in in situ tissue engineered grafting.

A technique modification for defects requiring only horizontal ridge augmentation

Not infrequently a knife ridge presentation identifies the need for horizontal ridge augmentation without the need for a vertical ridge correction (Figure 31.21). This can be accomplished using another form of in situ tissue engineered bone grafting. In this situation a cortical-cancellous *allogeneic block* is used that is shaped and sized to fit into the defect with maximum bone contact and the desired amount of horizontal gain.

Once again, the recipient site is rough surfaced with a bur. The cancellous network side of the allogeneic cortical-cancellous block is saturated with activated PRP over which two layers of the rhBMP-2 loaded ACS is attached (Figure 31.22). The block graft is then placed with the PRP-rhBMP-2/ACS side on to the host bone surface and compressed using two 1.5-mm titanium screws in a lag screw fashion (Figure 31.23).

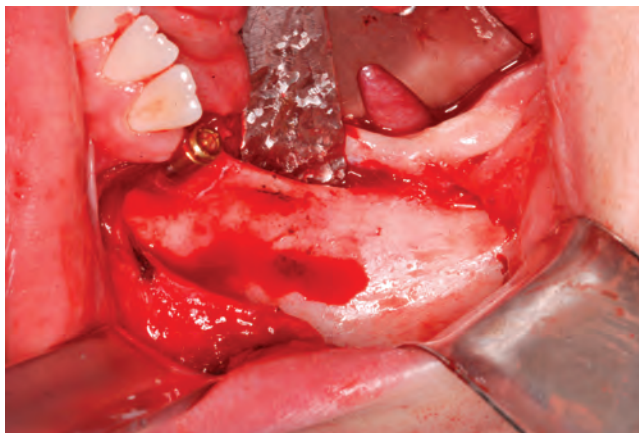


Figure 31.21 Thin “knife edge” edentulous mandibular ridge.

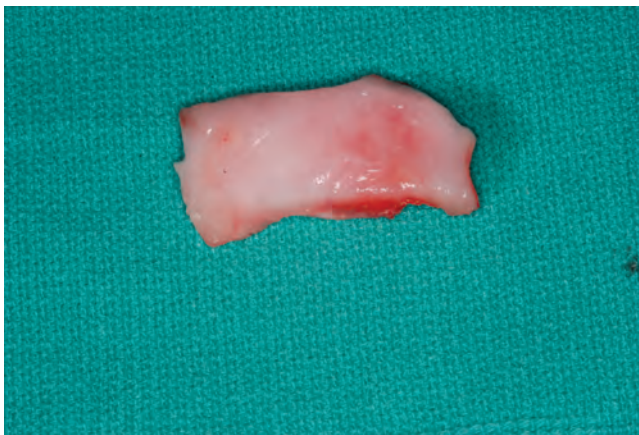


Figure 31.22 Allogeneic block bone with rhBMP-2/ACS draped over the cancellous surface prior to placement.

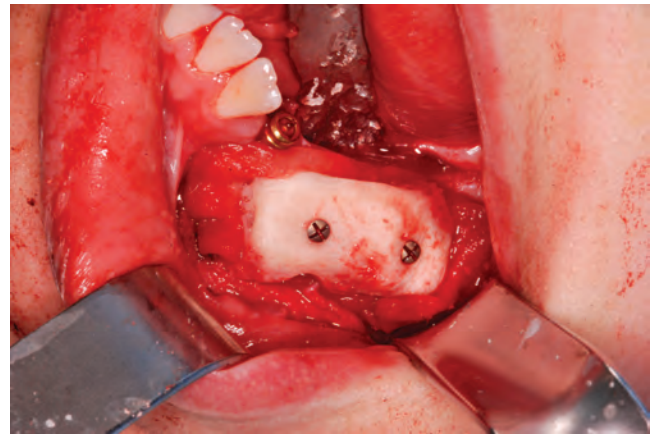


Figure 31.23 Allogeneic block bone with rhBMP-2/ACS between the host bone ridge and cancellous surface fixated with two screws using a lag screw technique.



Figure 31.24 Re-entry into the graft site reveals a completely incorporated graft rebuilding the ridge width and acceptable for implant placement.

This graft approach will ensure fusion of the allogeneic block to the host bone surface and reduce the volumetric contraction of the graft. Upon the re-entry, one will find the screw heads flush with the original bone surface and edges of the block graft rounded, indicative of bone remodeling (Figure 31.24). One will also observe the bleeding nature of the graft during implant site preparation, indicative of graft revascularization.

Conclusion

Directing bone regeneration in the very site where bone is needed using the patient's own cells combined with a proven safe and effective signal and matrix represents a straightforward approach achievable by almost all surgically trained dental providers today. Such in situ tissue engineering provides patients with the benefit of predictable bone regeneration and implant acceptable sites with a greatly reduced risk and morbidity that is inherent in open autogenous bone harvests.

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Growth Factors and Alveolar Bone Augmentation

R. Gilbert Triplett,¹ Jay P. Malmquist,² and Sterling R. Schow¹

¹Department of Oral and Maxillofacial Surgery, Texas A&M University, Baylor College of Dentistry, Dallas, Texas, USA

²Private Practice, Portland, Oregon, USA

Introduction

Alveolar bone reacts to various insults such as injuries, trauma, disease, tooth loss, and stress, and usually results in bone loss and remodeling. The repair process occurs through osteoconduction, osteoinduction, and osteogenesis [1]. Following the injury, a series of events are initiated in an attempt to repair the damage. A blood clot is formed at the wound site, releasing growth factors such as platelet derived growth factor (PDGF) and transforming growth factor beta (TGF- β) from degranulating platelets [2]. These mitogens attract mesenchymal stem cells (MSCs) and fibroblasts into the osseous wound site and stimulate proliferation and differentiation of osteoblast precursors.

The process of repair and regeneration includes the formation of granulation tissue as a source of mesenchymal connective tissue cells (osteoblasts, fibroblasts, etc.). Mesenchymal cells are transformed into osteoprogenitor cells by locally expressed bone morphogenic proteins (BMPs). The use of exogenous growth factors to stimulate the restoration of alveolar bone has been a major advancement in regenerative medicine/dentistry. Bone growth factors are able to attract mesenchymal stem cells and induce the transformation (differentiation) into bone forming cells (osteoblasts) that then undergo cell division (mitogenesis) and form bone. A major focus of tissue engineering has been to manufacture these signaling proteins for use in clinical osteogenesis in order to attract the appropriate cells and stimulate them to differentiate, multiply, and form the desired tissue to regenerate the wound [2].

Techniques for restoring the alveolar ridge are numerous and in certain situations many materials are useful and predictable with and without the use of barrier membranes. Basic concepts of wound healing, however, should be strictly adhered to in order to achieve good results. It is generally agreed that the more pronounced the defect in need of regeneration, the more robust the graft materials should be. Other factors to be considered are space-making and resistance to deformation and movement while new bone is forming. The vascularity is critical and the site should support the recruitment of adjacent cells for regeneration. In some situations, such as in irradiated tissues, sclerotic bone, or regions with dense scarring, osseous regeneration may not be possible. However, in most cases, the results can be improved by using materials with greater osteogenic potential and careful development of the recipient site. This decision will be influenced by the site and the situation,

the predictability, cost, time of regeneration/maturation of the bone, the patient's desires, and morbidity of the procedure.

Growth factors have been studied extensively. Recombinant bone morphogenetic protein (rhBMP-2) and PDGF-BB are both FDA approved, signaling proteins (growth stimulation factors) that have application in augmentation of the alveolar ridge. The choice of augmentation materials should take into consideration the risk benefit ratio and the patients' expectations. PDGF-BB is only FDA approved for regeneration of periodontal defects and will not be addressed here.

Infuse[®] (Medtronic, Sofamor Danek, Memphis, TN) bone graft, rhBMP-2 plus absorbable collagen sponge (rhBMP-2/ACS) carrier, has been studied extensively in animals and humans. Randomized human multicenter trials have been conducted that show excellent outcomes in appropriate situations. Infuse[®] has been approved for orthopedic indications in the spine and tibial fractures and in the maxillary sinus floor and maxillary buccal wall defects in the maxillofacial skeleton. Although many case reports demonstrate the efficacy for its use in other indications in the jaws, these applications have not been submitted to the FDA for formal approval. Therefore, use in other sites is considered off-label and documentation must be placed in the patient's record to justify its use.

Socket/alveolar ridge preservation is performed frequently to minimize alveolar ridge resorption, preserve crestal buccal plate integrity, and reduce the need for future ridge augmentation prior to conventional or implant-based prosthetic therapy. Current methods for guided bone regeneration (GBR) at the time of extraction include the use of particulate autograft or allograft, alloplast, xenograft, graft substitutes and bone signaling protein (Infuse[®]). Principles of guided tissue regeneration (GTR) deal with the regeneration of supporting periodontal apparatus (cementum, PDL, and alveolar bone). Guided bone regeneration (GBR) deals with the formation of alveolar bone alone. GBR is based on the principle of promoting ingrowth of osteogenic cells and preventing the migration of undesirable cells into the wound from overlying tissue. A barrier membrane may be used to exclude the faster growing epithelial and connective tissue cells and allow the slower moving pluripotent and osteogenic cells to repopulate the GBR site. Four principles must be met for successful results: (1) exclusion of epithelial and connective tissues; (2) space maintenance; (3) stability

of the blood clot; (4) primary wound closure (tension-free primary closure is important) [3].

The regeneration of bone is dependent on creating new blood vessels that bring osteoprogenitor cells and nourishment to the GBR treated site. Capillaries precede new bone formation and angiogenesis is a multistep process with capillary extension from existing blood vessels. The blood clot releases growth factors such as PDGF and cytokines that serve as a precursor for the vascular granulation tissue that will replace it. Granulation tissue contains numerous blood vessels, which transport cells and nutrients to the site. Osteogenic cells form osteoid that is then mineralized forming woven bone that undergoes further bone remodeling, resulting in lamellar bone [4].

Bone morphogenetic proteins are differentiation factors that are part of the transforming growth factor beta super family (TGF- β) that have multiple effects, including the ability to differentiate osteoprogenitor cells. New bone growth develops from the differentiation of pluripotent mesenchymal cells along the osteoblastic cell pathway.

RhBMP-2 has been extensively studied since the protein was cloned and reported by Wozney et al. [5]. There have been numerous studies with animals and humans to demonstrate the safety and efficacy of this growth factor. Fiorellini et al. reported the results of alveolar ridge augmentation in a multicenter (8) prospective, randomized, double-blind controlled clinical trial using 80 patients [6]. The investigators selected patients who had defects $\geq 50\%$ of the buccal wall of the extraction site. These study sites were in the maxilla from the second bicuspid anteriorly. The patients were randomized to one of four treatment groups: (1) no treatment; (2) absorbable collagen sponge (ACS) alone; (3) RhBMP-2/ACS as a carrier with a dose of 0.75 mg per ml; (4) rhBMP-2/ACS dose of 1.5 mg per ml. RhBMP-2 was suspended in sterile water and absorbed on to the sterile collagen sponge Helistat[®] (Integra Life Sciences, Plainsboro, NJ) (Figure 32.1). Numerous carriers were investigated, but the collagen sponge was the most favorable, not releasing the protein too fast or too slow. Clinical and radiographic evaluations for healing alveolar sockets were followed over time. Data were collected for height and width changes four months following extraction and treatment. There were significant differences in alveolar bone height lost between the unfilled sockets with a missing buccal wall and those filled with the absorbable collagen sponge alone compared to the sockets filled with Infuse[®] bone grafts, in which only minimal loss of height was found (Figure 32.2). Likewise, the bone loss at the socket crest at four months was significantly greater in the unfilled and ACS-filled sockets compared

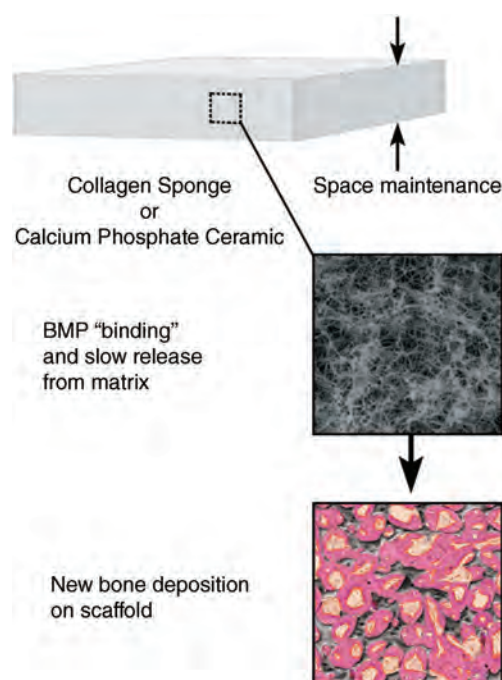


Figure 32.1 Helistat[®] collagen sponge showing configuration of the collagen type I bovine collagen. Medtronic, Inc. Reproduced with permission of Medtronic.

with those of the Infuse[®] filled socket (Figure 32.3). Histological specimens obtained from core samples from the implant site at the time of implant placement 6 to 12 months post-grafting demonstrated vital bone cells, with no inflammation or residual collagen matrix from the sponge in the newly formed bone. There was no difference between the newly induced bone and that of native bone. The conclusion of the study was that the stimulation of host healing responses with rhBMP-2 *enhanced* predictability of regeneration and improved bone height and volume. This randomized, masked, placebo controlled study confirmed the effectiveness of rhBMP-2/ACS on the *de novo* bone formation, which ultimately allowed placement and maintenance of dental implants in function [6].

Infuse[®] graft material is very soft and spongy, compressible and displaceable, and is therefore more effective in sites where volume can be preserved and where space can be maintained. Barrier membranes have been used in conjunction with Infuse[®] but the

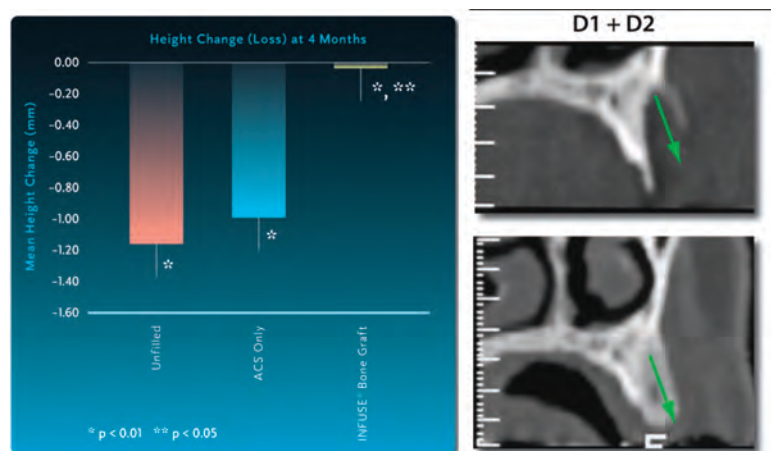


Figure 32.2 Height change in the buccal wall defect sockets showing how well the alveolar bone was regenerated and maintained compared to unfilled and absorbable collagen sponge (ACS) filled sockets. Medtronic, Inc. Reproduced with permission of Medtronic.

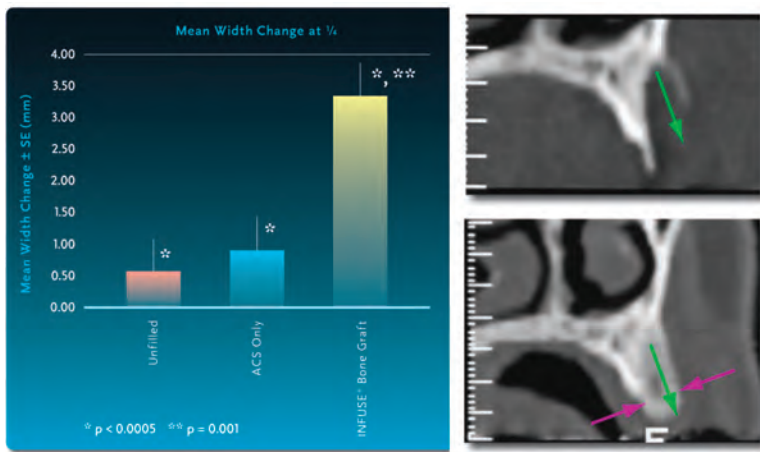


Figure 32.3 Width change at the socket crest in buccal wall defect sockets. There is minimal loss of alveolar width in rhBMP-2 filled sockets compared with the unfilled and ACS filled alveolar sockets. Medtronic, Inc. Reproduced with permission of Medtronic.

membrane must be stiff enough to resist displacement and compression. Commonly used resorbable collagen membranes alone are usually unsatisfactory for this purpose. Tenting pins/screws have been used with some success to maintain space in selected cases but the surgeon should be satisfied that wound closure and normal oral function or prosthetic use will not create movement at the graft site. Rigid devices such as titanium mesh, mini bone plates and titanium-reinforced membranes that provide a secure secluded space and minimize motion are preferred. However, with these devices, dehiscence and mesh exposure are a common occurrence that can compromise and complicate the outcome, particularly with titanium mesh. Louis et al. reported a 52.27% (23 of 44 patients) exposure rate in augmentations with autologous grafts when using a titanium mesh. Seven of these (15.9%) had early exposures requiring removal of the mesh [7]. In our experience, the rate of exposure and compromised outcomes is also high with the titanium mesh. Others have reported generally satisfactory outcomes, noting that early exposures (first 2 weeks) have resulted in inadequate bone regeneration. Late exposures have been less problematic. Another observation in cases that have utilized mesh trays is the inevitable production of a thick connective tissue layer, which develops beneath the mesh and occupies space that would better be occupied by bone. Experience with titanium trays and a non-resorbable membrane (e-PTFE) in the 1960s to 1980s did not observe this connective tissue layer inside the tray. Instead there was a dense layer of connective tissue overlying the tray, making tray removal tedious.

Strategies to improve the results with all bone grafting materials continue to be developed. Minimizing the amount of hardware and employing other methods to maintain the volume of the space being regenerated has significantly reduced complications and failures. Infuse® has been successfully used to re-graft cases that failed with other grating materials. A resorbable, easily adaptable polymer (poly-DL-lactic acid) membrane Sonic Weld Rx® (KLS Martin, Tuttlingen, Germany) [8] has recently received attention as a space maintainer for grafts that causes less reactive soft tissue response and breakdown. However, the number of cases reported to date are thus far inadequate to recommend Sonic Weld Rx® as an evidence-based technique.

Frequently overlooked components of bone regeneration are the basic principles of maxillofacial bone grafting:

- 1 There is no substitute for a good, precise surgical technique.
- 2 Correct flap design is important with atraumatic reflection of the mucoperiosteal (MP) flap with an adequate vascular pedicle to assure an adequate blood supply.

- 3 Adequate good tissue quality graft bed that can support and nourish the graft.
- 4 Adequate space to accommodate the graft.
- 5 Stability of the graft.
- 6 Tension-free primary closure of the MP flap with everted wound margins and a watertight closure with the incision line supported over native bone, not over the graft material, if possible.
- 7 Properly adjusted and relieved prosthesis to minimize/eliminate forces on the grafted site.
- 8 Plan or accommodate for post-operative edema and swelling.
- 9 Appropriate and thoughtful use of anti-infective agents.

Preparation of Infuse® bone graft

The concentration of the Infuse® is 1.5 mg per ml of sterile water. The material is reconstituted by mixing sterile water with lyophilized rhBMP-2 in a syringe and distributing it on to the collagen sponge. This allows the protein to bind to the collagen for delivery to the grafting site (Figure 32.4). The material should be undisturbed on the sponge for a minimum of 15 minutes before use. This is necessary to allow the protein to bind to the collagen so that it can be delivered to the site. It has been determined that after 15 minutes approximately 95% of the active BMP-2 is bound to the sponge and it will not be displaced during delivery. Delivery of the sponge should not be delayed longer than two hours because of possible degradation of the protein. Once placed in the recipient site, the signaling protein (rhBMP-2) is released from the sponge in two phases: an initial burst phase within hours of implantation and

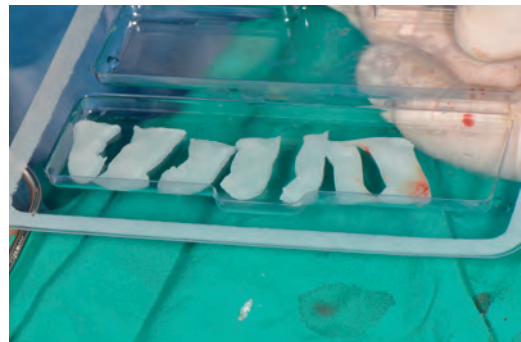


Figure 32.4 The ACS is soaked with rh-BMP-2 solution and the sponge is undisturbed for at least 15 minutes to allow for binding.

a second prolonged release phase governed by the carrier (ACS) and its geometric characteristics [7]. The ACS carrier is an inert material that is used to transport and contain the protein within the defect site, thereby maintaining sufficient physiological concentrations of BMP-2 for promotion of a clinically significant osteogenic response. However, there are also other chemical and mechanical factors that affect the ability of growth factors such as BMP-2 to predictably induce bone formation besides binding and release of the protein from the carrier. These include a microenvironment at the implant site conducive to bone healing, the ability of the cells and growth factors to migrate or diffuse into the site, and space for cells to multiply, differentiate, and form bone and proper mechanical and biological factors for bone remodeling. Neither highly cellular autogenous bone nor rhBMP-2 placed into a compromised defect can overcome poor bone quality [9].

The regeneration of *horizontal bone loss* has been a focus for clinicians for the past 30 years. It has become even more important since the advent of osseointegration and implantology in oral reconstruction. The concept of guided tissue and bone regeneration has had a positive and profound influence on our ability to restore lost bone. The concept is important in selecting graft materials and growth factors to replace or supplement autogenous bone grafts. The same concept of providing secluded space for cell migration and cell growth in GBR apply to the use of Infuse®. In addition to the signaling protein (rhBMP-2/ACS), a matrix has been recognized as a key component for regeneration with the Infuse® bone graft. This was a clinical observation resulting from use of Infuse® alone, which achieved disappointing results in *larger graft sites*. Infuse® has subsequently been combined with bone allografts, autografts, and alloplasts with predictable results [10]. The matrix maintains space and volume while ultimately being replaced by newly forming bone. A number of the investigators recommended that components of an augmentation graft with rhBMP-2 consist of both a matrix and provisions for space maintenance if the defect does not structurally provide this. Examples of natural space-making areas are extraction sockets, the maxillary sinus floor, and intra-osseous defects. Horizontal alveolar augmentation or reconstruction of continuity defects in most cases will usually require provisions to maintain space.

The surgeon should expect more post-operative edema with Infuse® than seen with conventional bone grafts or guided bone regeneration procedures and patients should be advised of this before surgery. The edema is frequently two to three times that seen with conventional grafts and it will last up to three weeks depending on the size of the graft and the amount of Infuse® (milligrams) used. This is due to the mechanism of action of the protein and is not an inflammatory reaction alone.

How much graft material should be used?

Experience will guide the surgeon as to the amount of Infuse® required for any specific defect. Addition of a matrix such as cancellous bone allograft will reduce the amount of Infuse® needed for the augmentation. Currently, surgeons are using about one-third of the amount of Infuse® that would be used without a matrix. We recommend that the kit size be selected based on tooth size segments from 1 to 10 segments using XX small to large kits (1.05–12 mg of rhBMP-2) (see Table 32.1). Medium and large kits are usually reserved for large segment grafts such as continuity defects, full arch augmentations, or for severe alveolar atrophy. Mineralized allografts or other bone substitutes can successfully act

Table 32.1 Guide for Infuse® kit size selection in alveolar deficiencies.

Tooth size segments	Kit size	Sterile water	Infuse®
1–2	XX Small	0.7 mm	1.05 mg
3–4	X Small	1.4 mm	2.10 mg
5–7	Small	2.8 mm	4.2 mg
8–10	Medium	5.6 mm	8.4 mg
Large segments	Large	8.0 mm	12 mg

as a matrix for Infuse® and add volume to the graft without compromising the bone formation. The materials should provide particles large enough to create space and not be easily displaced by overlying tissue or prosthetic devices. Particles less than 1 ml do not provide adequate resistance or volume in large defects. Cancellous particles ≥ 4 mm can easily be crushed and are ideal for this purpose (Figure 32.5).

Method of graft confinement

The use of titanium mesh has been a common method of containing bone grafts in the maxillofacial region because of its rigid structure, its tissue tolerance, and relative “ease of use”. Several configurations are commercially available. It is advisable to adapt the titanium mesh prior to surgery whenever possible to reduce surgery time, minimize contamination of the surgical field, and improve adaptation to the site.

A clinical case is presented in Figures 32.6 to 32.12. The patient presented with failing implants in the upper left lateral incisor and canine area. There was significant bone loss in the upper left central incisor area also (Figure 32.6). The implant team planned for removal of the tooth and implants with subsequent reconstruction. Three months after extraction and implant removal imaging and study models were obtained (Figure 32.7). (A computer-generated model could have been used instead of the stone model.) The model was used by the surgical team to plan the configuration of the augmentation and adapt a titanium mesh to fit the defect (Figure 32.8A to C). The osseous defect was surgically exposed via a full-thickness mucoperiosteal flap with wide exposure. Reflection of the flap was generous enough to allow meticulous debridement of the defect and placement and fixation of the titanium mesh tray (Figure 32.9A to D). This can be difficult on the palatal aspect of the maxilla and on the lingual alveolus of the mandible. The Infuse®



Figure 32.5 Cancellous allograft particles used as a matrix and to maintain volume of the Infuse® bone graft.



Figure 32.6 Radiograph showing implants in the upper left lateral incisor and canine sites and bone loss in the upper left central incisor to canine area.

bone graft and allograft were loaded into the tray and the tray was secured to the marginal bone with bone screws. The surgeon verified the position of the graft and eliminated any sharp or protruding edges of the mesh. The mucoperiosteal flap was undermined and periosteal releasing incisions used to assure mobility for a tension-free closure. The flap design is critical in these cases and the surgeon should take time in considering the blood supply to the soft tissue flap when planning the case. Appropriate suture material should be chosen to allow support for at least 2 weeks. Significant post-operative edema should be expected and prosthesis wear should be delayed until the edema has subsided. Images that were made 5 months after grafting show adaptation of the mesh tray and consolidation of the graft. The soft tissue healed uneventfully (Figure 32.10A and B). The site was planned for re-entry, mesh removal, and implant placement 6 months after grafting. The re-entry flap provided the same exposure to the grafted area as the original flap to allow for exposure and removal of the titanium mesh (Figure 32.11A). There was a dense fibrous connective tissue capsule beneath the mesh tray, which was excised and discarded, exposing the regenerated bone (Figure 32.11B). A



Figure 32.7 Clinical appearance of the anterior maxillary defect.

surgical guide was used to locate the planned sites for dental implants (Figure 32.11C). Two implants were placed in sites of the central incisor and canine and an integration period of 5 months was followed. The final prosthesis was delivered 6½ months later (Figure 32.12A and B).

Mini bone plates and screws can be used to help maintain the volume of the soft tissue envelope, confine the Infuse® bone graft, and protect against displacement and deformation. These small plates come in several configurations and are easy to adapt and secure with bone screws to host bone with monocortical bone screws of various lengths (Figure 32.13). It is desirable to use mineralized allograft chips or cubes in conjunction with the mini plates to maintain space and prevent collapse of the overlying soft tissue and to eliminate dead space. The cancellous cubes, which are 4 mm × 4 mm in dimension, are easy to crush and mold to the defect. The Infuse® can be layered between the allograft particles to achieve a homogeneous mixture of allograft and Infuse®. The combination holds space well, is stable, and has reduced complication rates. Soft tissue dehiscence exposures have been minimal when attention is paid to flap design, adequate tissue mobilization, and closure. A continuity defect from the resection of an ameloblastoma bridged by the immediate reconstruction plate is shown in Figure 32.14A. Two mini bone plates were secured to the lateral and inferior borders of the mandible to confine and protect the graft during consolidation and bone regeneration. The Infuse® bone graft used for this reconstruction was layered in the defect with cancellous allograft particles (Figure 32.14B). The wound was closed and the healing was uneventful. The post-operative radiograph is shown in Figure 32.14C. The reconstructed alveolar bone was exposed 6½ months after grafting and three dental implants were placed. The final prosthesis was delivered 11 months after an initial resection (Figure 32.15A to C).

Sonic Weld Rx® membrane (KLS Martin LP, Jacksonville, FL) can be used to confine and protect the bone graft during osseous

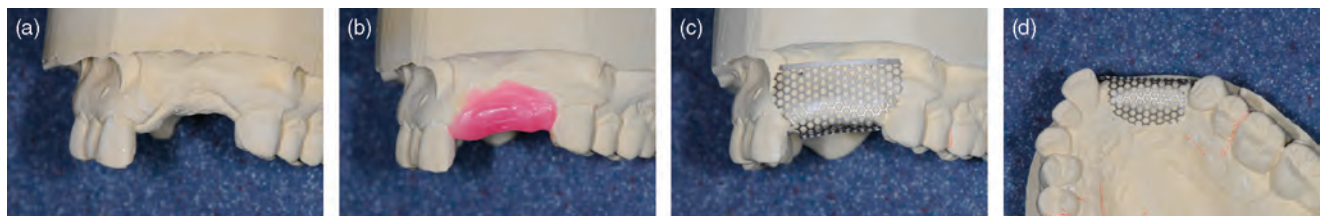


Figure 32.8 (A) Stone model of maxilla that was used to plan the case and adapt the titanium mesh. (B) Defect is waxed to the desired augmentation. (C) Mesh is adapted and trimmed to the planned augmentation showing buccal and crestal configuration.

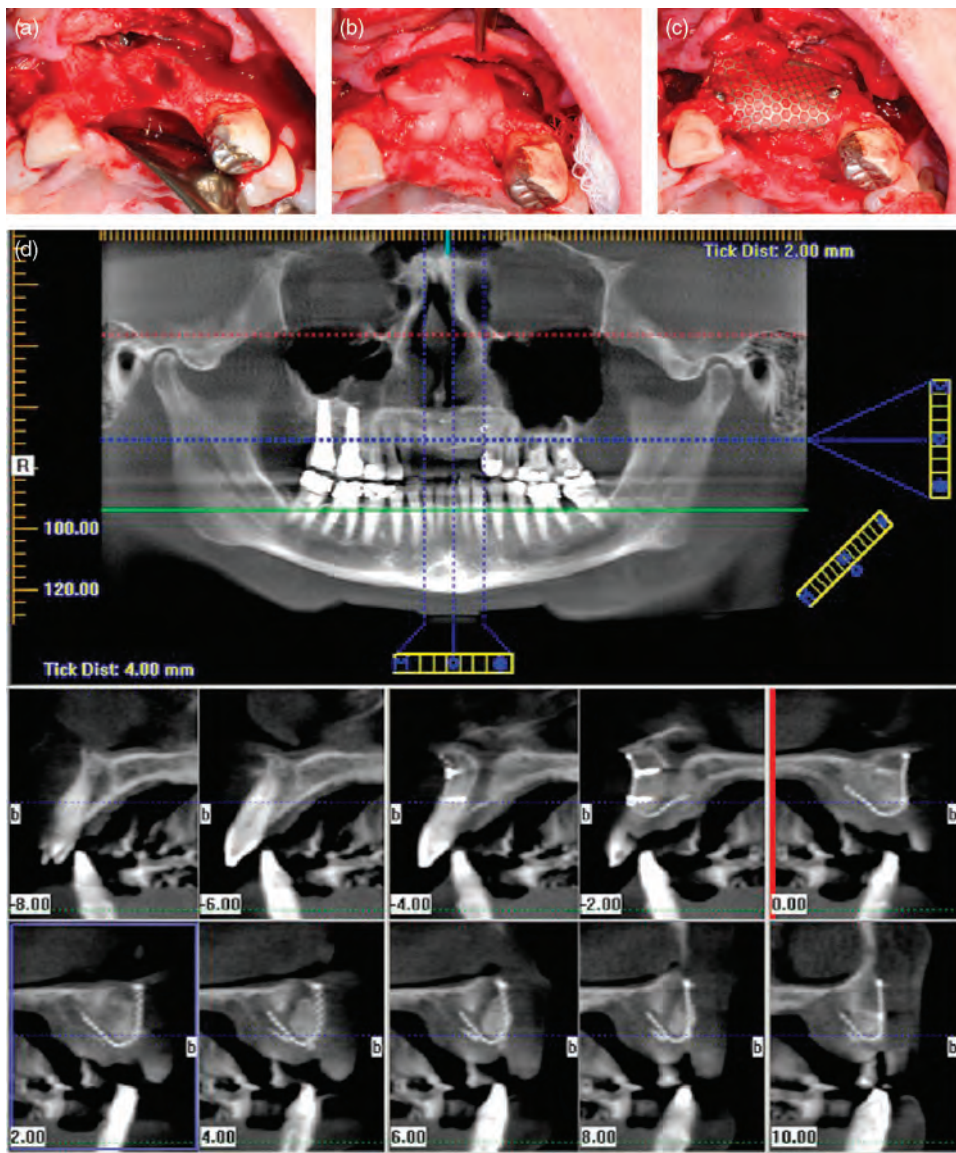


Figure 32.9 (A) Osseous defect is exposed to receive the bone graft. (B) Infuse[®] bone graft is delivered to the site. (C) Titanium mesh is secured into the grafted site to confine and protect the graft during bone regeneration. (D) Imaging demonstrating the position of the mesh & graft.

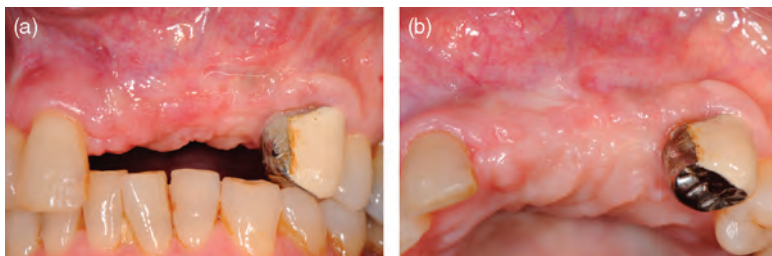


Figure 32.10 (A) Clinical photo showing augmentation that was achieved at 6 months post-grafting. (B) Occlusal view demonstrating width of the augmentation.

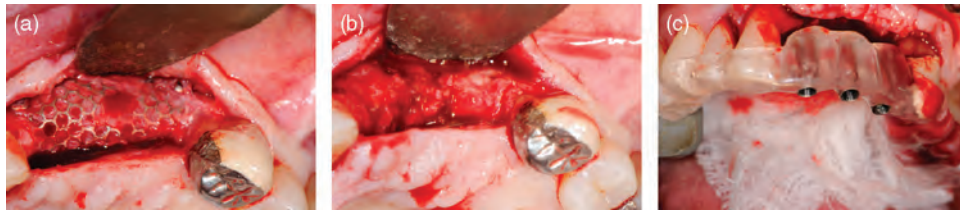


Figure 32.11 (A) Exposure of titanium mesh 6 months after grafting. (B) Exposure of grafted alveolus after removal of the titanium mesh tray. Note that the center of the graft has not achieved the same volume of bone regeneration as the lateral margins of the graft next to the remaining adjacent teeth. (C) Guide splint in place to place up to three implants; implants were placed in the central incisor and canine regions.



Figure 32.12 (A) Final prosthesis showing restoration of height and width of the deficient ridge. (B) Esthetic results with patient smiling.

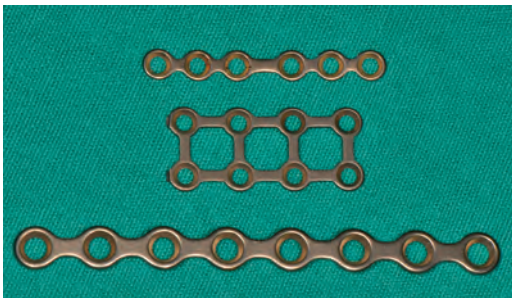


Figure 32.13 Mini bone plates are easy to adapt and secure to protect bone graft material (see Figure 32.14).

induction and maturation. The advantage of a restorable membrane is not only eliminating the need for removal after graft healing but also because the fibrous scar band seen with titanium mesh is scant or absent with Sonic Weld Rx[®], allowing more space for bone formation. The early experience with Sonic Weld Rx[®] membrane is encouraging. Figures 32.16 to 32.18 illustrate its use in the anterior mandible. This patient had a horizontal and vertical osseous defect following a failed attempt at guided tissue regeneration associated with periodontal bone loss in the anterior central incisor area. These teeth were extracted, the defects were debrided, and the site was grafted with Infuse[®] and an allograft. Sonic Weld Rx[®] membrane was used to confine and protect the graft. The membrane was stabilized with polymer pins, which are also restorable. The site

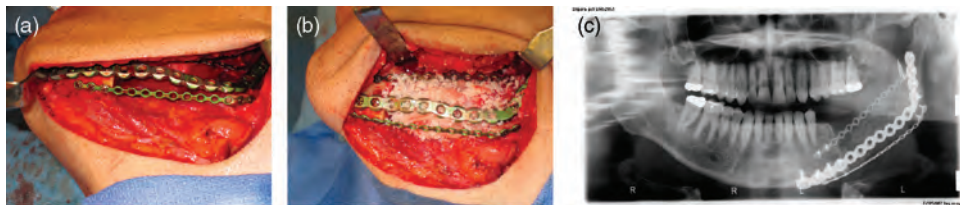


Figure 32.14 (A) Arrangement of bone plates to stabilize mandible (large plate) and mini plates to contain and protect the graft during bone regeneration. (B) Bone graft is placed into the defect which consists of Infuse[®] that is layered with mineralized cancellous allograft. This can be packed into the site to the desired volume. (C) Post-operative radiograph showing the bone plate position and Infuse[®] bone graft and matrix particulate allograft.



Figure 32.15 (A) Final prosthesis restoring lower left second and first molars and second premolar teeth. (B) Occlusal view of restoration. (C) Radiograph of final implant supported bridge.

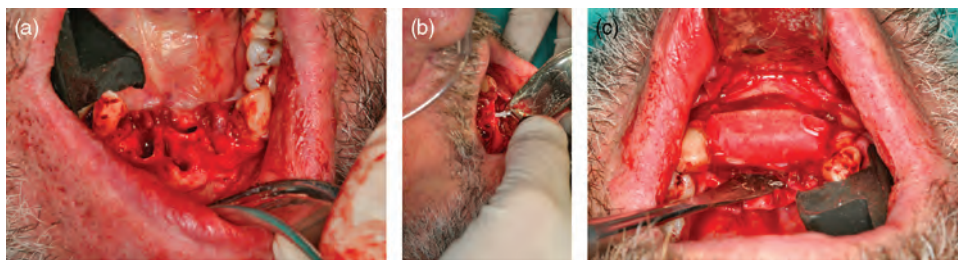


Figure 32.16 (A) An osseous defect in anterior mandible following removal of non-restorable lower incisors. (B) After debridement of the site and augmentation with Infuse® bone graft, Sonic Weld RX® membrane was placed and secured with resorbable pins. (C) Grafted site in the anterior mandible with Sonic Weld RX® membrane in place.



Figure 32.17 Augmented anterior mandible with implants in place. Note, the excellent width that has been achieved.

protecting the graft from compression, displacement, and loss of volume, while providing space for cell attraction and bone regeneration is necessary when using growth factors. The use of a matrix such as cancellous bone allograft can aid in maintaining space and expanding the application of the Infuse® bone graft, particularly in restoring larger defects. The confinement and protection of the Infuse® bone graft is critical to the outcome. Titanium miniplates, mesh, and resorbable rigid membranes have all shown utility for confining the graft. Surgical experience, meticulous surgery, and compliant patients are also important factors in achieving the desired outcome.

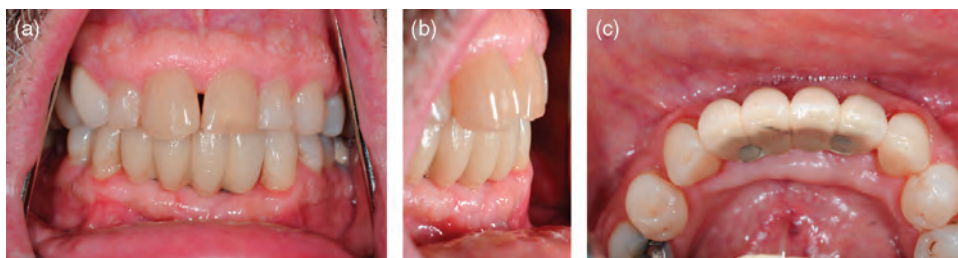


Figure 32.18 (A) Final prosthesis showing occlusion and soft tissue emergence of the implants. (B) Lateral view demonstrating the ridge width that was achieved. (C) Occlusal view demonstrating the ridge width.

healed uneventfully and implants were placed six months later. The membrane was not removed although some remnants remained but did not interfere with implant placement. Excellent osseous augmentation had been achieved and the final prosthesis was delivered 9 months after grafting and 3 months after implant placement.

Conclusion

Bone growth factors can be utilized efficiently and effectively as either an adjunct or substitute for bone grafting procedures. In many cases they have been shown to be as effective as autologous bone for alveolar bone reconstruction. Proper utilization of the material is critical to achieving the desired outcome. Delivery of the graft to the deficient alveolar site must include mechanisms for

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Platelet-Rich Fibrin: Natural and Biologic Blood Concentrate

Joseph Choukroun¹ and Alexandre-Amir Aalam²

¹SYFAC (International Symposium of Growth Factors), Nice, France

²Herman Ostrow School of Dentistry of USC, Los Angeles, California, USA

Introduction

Wound healing is a complex biologic process that includes active participation of cells, connective tissue, extracellular matrix (ECM), and soluble factors, as well as their continuous interaction. It appears that local delivery of multiple growth factors could enhance soft and hard tissue formation. Since angiogenesis is closely linked with osteogenesis, the ideal scenario is to deliver a cascade of multiple growth factors to induce bone formation.

During a normal wound healing process, a fibrin clot forms immediately after trauma and contains platelets, fibrin, and ECM proteins. In the field of platelet concentrates, the concept of platelet-rich fibrin (PRF) is to obtain a fibrin clot by a centrifugal spin. A PRF clot with integrated growth factors and cytokines provides a favorable environment for cell migration and rapid vascularization. This chapter describes the biology and benefits of PRF in bone grafting and implant dentistry.

Platelet-rich fibrin (PRF): a natural fibrin matrix concept

Choukroun et al. first developed PRF in France in 2001 [1]. The concept of PRF is to collect an autologous growth factor concentrated fibrin clot. This technology requires a centrifuge and a blood collection system. The PRF protocol is very simple. A blood sample is taken without anticoagulant in 10-ml tubes that are immediately centrifuged at 750g for 12 minutes. The absence of anticoagulant and a specific tube design allow for quick activation of the blood sample platelets that are in contact with the tube walls and the release of the physiologic coagulation cascade. Fibrinogen is initially concentrated in the top layer of the tube before the circulating thrombin transforms it into fibrin. A fibrin clot is then obtained in the middle layer, just between the red corpuscle at the bottom and acellular plasma (platelet-poor plasma, or PPP) at the top (Figure 33.1).

The success of this technique entirely depends on the speed of blood collection and its transfer to the centrifuge. Certainly, without anticoagulant, the blood samples start to coagulate almost immediately upon contact with the glass tube, and it takes a minimum of eight minutes of centrifugation to concentrate fibrinogen in the middle and top part of the tube. Quick handling is the only way to obtain a clinically usable PRF clot.

By driving out the fluids trapped in the fibrin matrix, practitioners can obtain very resistant autologous fibrin membranes.

What is fibrin?

Fibrin is an activated form of fibrinogen, which is a soluble fibrillar glycoprotein abundantly present in both plasma and platelet alpha-granules. It plays a determining role in platelet aggregation during hemostasis. It is transformed into biologic glue that aids in establishing the initial platelet clumping, and results in a protective wall for the ruptured endothelial vessel lining. Fibrinogen is transformed into an insoluble fibrin by thrombin while the polymerized fibrin gel constitutes the first healing matrix for the injured site [2].

Platelets and cytokines

Platelets

Platelets are trapped in large numbers in the fibrin mesh. They are formed in bone marrow from pinched-off cytoplasmic fragments of megakaryocytes into the circulation. They are discoidal and anuclear structures with an 8–10 day lifespan. Platelets contain alpha-granules, dense granules, and other granules that are secreted at the time of activation. Alpha-granules contain platelet specific proteins (β -thromboglobulin), non-platelet specific proteins (fibrinogen, thrombospondin, fibrinogen) and other coagulation factors, growth promoters, fibrinolysis inhibitors, and immunoglobulins. Dense granules contain adenosine diphosphate (ADP), adenosine triphosphate (ATP), ionized calcium, histamine, and serotonin. A platelet phospholipid double-layer membrane contains glycoproteins that function as receptors for collagen and other molecules. Activation is fundamental to initiate hemostasis due to platelet aggregation at the injured site and in the interaction with coagulation mechanisms [3,4].

Cytokines

Cytokines and growth factors are small proteins released from platelet alpha granules after clotting, whose function is mediated through specific cell receptors. The release of cytokines during

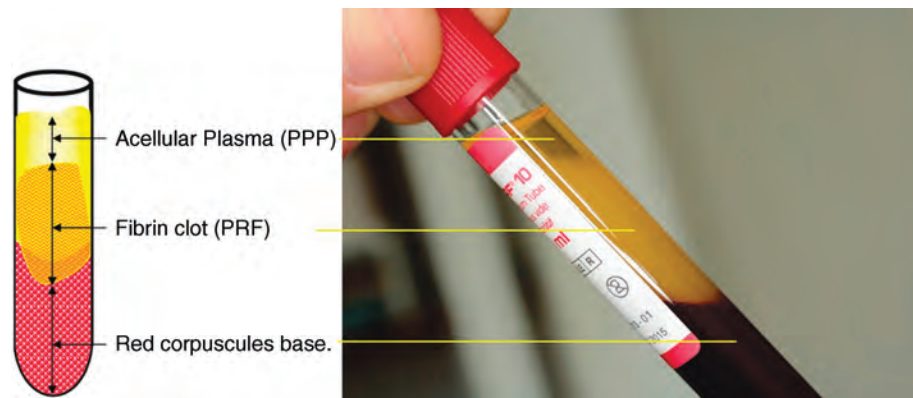


Figure 33.1 Blood tube after centrifugation.

degranulation stimulates cell migration and proliferation within the fibrin matrix, launching the first stages of healing [2].

- **TGF β -1: fibrosis agent.** Transforming growth factor β β β (TGF- β) is one of more than 30 members of the TGF β β superfamily. *In vitro*, its effects are largely varied depending on the amount applied, matrix environment, and cell type. It had been shown that it could stimulate the osteoblast proliferation just as easily as it can cause osteoblast inhibition. Although its proliferation effect is highly variable, for a great majority of cell types it constitutes the most powerful fibrosis agent among all cytokines. In other words, it induces synthesis of matrix molecules such as collagen type 1 and fibronectin, whether by osteoblasts or fibroblasts. Though its regulation mechanisms are particularly complex, TGF β -1 can be considered an inflammation regulator through its capacity to induce fibrous cicatrization.
- **PDGF: mesenchymal cell mitogen.** PDGF (platelet-derived growth factor) is an essential regulator for migration, proliferation, and survival of mesenchymal cells. According to its specific receptor distribution, PDGF is able to stimulate as easily as inhibit the development of these cells. This ability of regulation plays a major role during embryonic development and all tissue remodeling mechanisms. For this reason, PDGF is important in the physiologic healing mechanism as well as pathogenesis of atherosclerosis and many other fibroproliferative diseases (i.e., neoplasia, pulmonary, and renal fibrosis).
- **The IGF axis: protective cell agent.** Insulin-like growth factors (IGFs) I and II are regulators of normal physiologic cell proliferation and differentiation as well as pathologic proliferation of tumor cells (which use the IGF system to increase their survival potential). Although these cytokines promote cell proliferation, they also send survival signals inhibiting programmed cell death (apoptosis). Even though IGFs are released during platelet degranulation, they are also present at large in blood circulation [5,6].
- **The slow release of growth factors by the PRF membrane.** Our studies clearly demonstrate that the PRF membrane sustains a substantial slow release of key growth factors for at least 1 week [7]. This translates into stimulation of remodeling of the surrounding tissues. It is now known that the most important factor for stimulation is not the amount of growth factors but the length of time they are maintained at a constant gradient in the milieu [8].

The properties of this natural fibrin biomaterial thus offer a great potential during wound healing. Moreover, a substantial release of

Thrombospondin-1 from the PRF membrane opens a new range of applications for this biomodifier.

White blood cells and fibrin: two key parameters

The literature dealing with platelet concentrates often ignores the impact of white blood cells and fibrin, which are two key participants. Several studies have shown the anti-infectious and immune system regulation role of white blood cells (leukocytes). Additionally, white blood cells produce large amounts of VEGF and PDGF that are crucial for the angiogenesis promotion. White blood cells account for around 50% of the PRF volume [9,10].

Clinical use and indications

All known clinical applications of PRF highlight its effect on the accelerated wound healing by promotion of neovascularization, new tissue formation, and absence of infection. These initial findings inspire future PRF evidence-based clinical application in medicine and dentistry [10].

PRF membranes are able to simultaneously provide three key factors to healing and soft tissue maturation: angiogenesis, immunity, and a scaffold for the epithelial growth. The angiogenesis property of fibrin matrix is explained by the three-dimensional structure of the fibrin gel and by the simultaneous actions of matrix trapped cytokines. Furthermore, main angiogenesis soluble factors such as the fibroblast growth factor (FGF), vascular endothelial growth factor (VEGF), angiopoietin, and platelet-derived growth factor (PDGF) are present in the fibrin gel. Some studies indicate that FGF and PDGF can bind to fibrin with high affinity. Therefore, direct fibrin angiogenesis induction can be explained by fibrin binding of many different growth factors.

The ECM provides structural and functional support to cells and tissues, and consists of several molecules, such as collagen, proteoglycans, heparin sulfate, chondroitin sulfate, hyaluronic acid, elastin, fibronectin, and laminin. A few plasma-derived proteins such as fibrin, thrombospondin, and fibronectin act as provisional ECM. Soluble factors include cytokines, chemokines, hormones, nucleotides, electrolytes, free ions, and growth factors. The primary focus of this review is the platelet-derived growth factors PDGF, EGF, VEGF, TGF β , basic FGF (bFGF), and IGF-1, which are known to play a vital role in tissue repair and regeneration.

Clinically, PRF is used as a tissue matrix and as a recipient bed for growth factors. Clots are prepared in a metallic PRF container, which permits their slight compression into membrane or plug

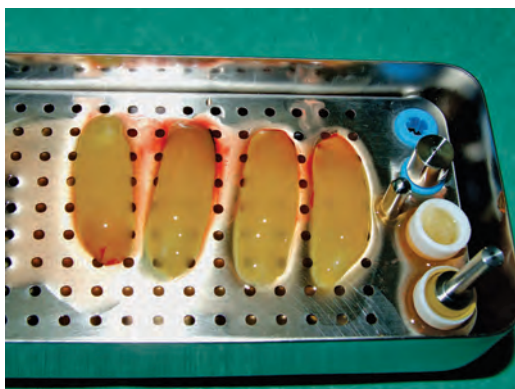


Figure 33.2 Clots on the PRF box grid.

form. This form allows for the easiest clinical application [11] (Figures 33.2 and 33.3).

- 1 **Ridge preservation.** After extraction, the socket is filled with the PRF plugs to the fullest. PRF is a natural matrix and does not need to be covered by the flap. The surgical site can be left open and fibrin can be exposed. Sutures are only used for stabilization of PRF in the socket. Primary closure is not a concern. Subsequently, fibrin matrix will be transformed into a new tissue: bone in the socket and soft tissue at the surface. Healing of the site is completed within 3 months (Figures 33.4 to 33.6).
- 2 **Bone grafting.** PRF is used as a provisory ECM, which provides quick vascularization and serves as a recipient bed for growth factors. It must be combined with bone substitutes. PRF

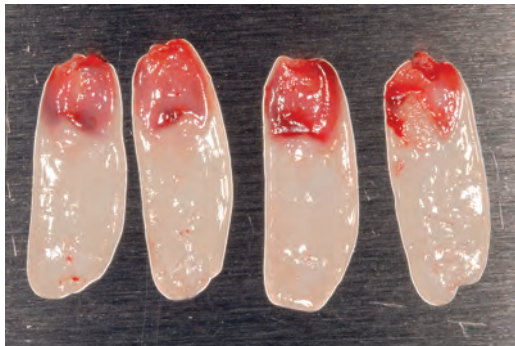


Figure 33.3 Membranes after compression (few minutes).



Figure 33.4 Socket filling with PRF.



Figure 33.5 Healing at 3 weeks.

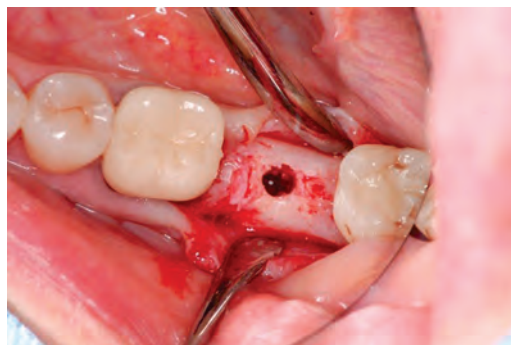


Figure 33.6 After 3 months: implant placement.

membranes are cut with scissors into small fragments and mixed with the bone graft to the fullest. PRF can be used as a sole graft material in the sinus if the volume is maintained by the dental implant insertion and elevation of the Schneiderian membrane, creating a stable space for bone formation (Figures 33.7 and 33.8).

Figure 33.9 demonstrates a case of two sinus lift procedures with immediate implant placement. The subantral augmentation was done solely with PRF (four membranes in each sinus). Two PRF membranes also covered both bone windows. No collagen membrane was placed inside or outside. The loading of the inserted implants started after 4 months. The quantity and quality of bone in the sinus floor region were excellent.

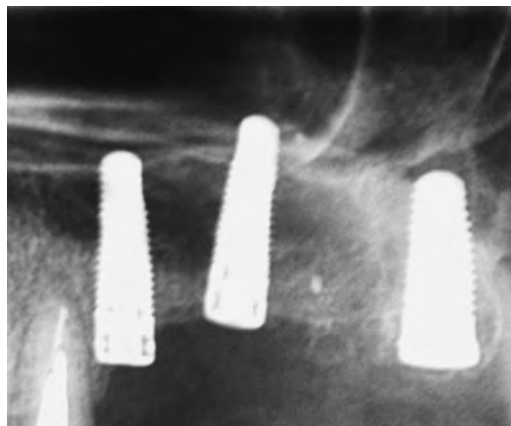


Figure 33.7 Sinus filled with PRF: implants inserted.

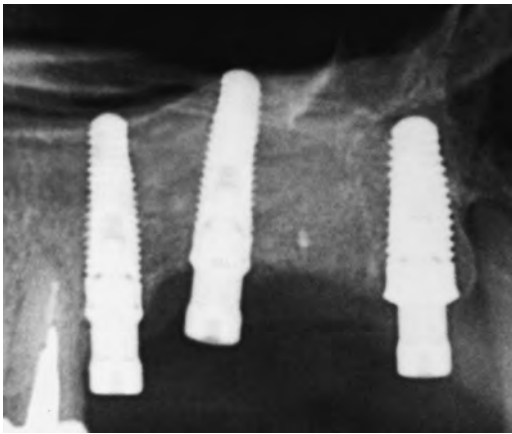


Figure 33.8 Bone formation after 6 months.

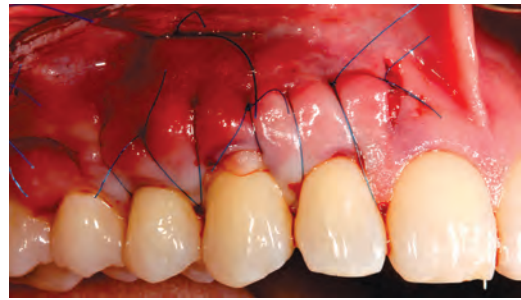


Figure 33.11 Suture: PRF exposed.



Figure 33.9 (a) Panoramic radiograph demonstrating a case of two sinus lift procedures with immediate implant placement using PRF as a sole "graft" material. (b) Intraoperative photograph demonstrating a successful sinus lift procedure. PRF as the sole "graft" material was placed under the intact lifted Schneiderian membrane and on to the sinus floor. PRF was also used for the bone window coverage. (c) Panoramic radiograph demonstrating a case completion: two sinus lift procedures with immediate implant placement using PRF as the sole "graft" material were performed with no complications and good bone fill.



Figure 33.10 Gingival recession treated by A-PRF (tunnel).



Figure 33.12 Follow-up at 4 months.

3 Soft tissue management. The PRF matrix can be utilized to treat gingival recession. PRF is used in place of a connective tissue graft as well as the palatal donor site dressing. PRF may also be an alternative to a connective tissue graft when treating multiple gingival recession sites, minimizing the number of surgical procedures. Suturing of the PRF membrane over the exposed palatal donor site allows for a reduced healing time and decreased morbidity (Figures 33.10 to 33.12).

Figures 33.13 and 33.14 demonstrate a clinical case report of root coverage with a sole PRF membrane in the mandible. This technique can be used in root recessions as a less invasive treatment with little post-operative discomfort. Figure 33.14 shows a follow-up at 6 months.

Evolution of PRF protocol

Advanced PRF (A-PRF)

Since 2012, considerable evidence exists about the role of white cells in vascularization and bone formation [12]. Granulocytes play a major role in vascularization and improve the function of monocytes that are now named "supercells for bone regeneration" [13]. Monocytes and macrophages produce BMP-2 [14]. The synergy of the fibrin and monocytes is evident. Understanding the *g*-force role on the white cell loss during the spin leads to a reduction of the centrifugal speed (in rpm). An increased amount of white cells in the clot was found with a *g*-force of 200. Introduction of a special

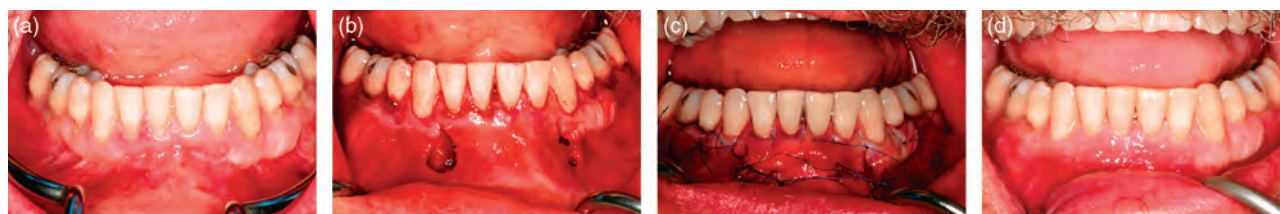


Figure 33.13 (a) Demonstrating a clinical case report of root exposure with root erosion of several posterior mandibular teeth that was treatment planned for root coverage with PRF membrane. (b) Intraoperative photograph demonstrating mobilized mandibular buccal gingival flaps for the root coverage. (c) Photograph at the completion of the case, demonstrating coronally advanced flaps after root coverage was achieved with a sole PRF membrane. (d) Photograph of the early post-operative period after periodontal treatment of the dental erosion with root coverage with PRF membrane in the mandible.



Figure 33.14 Photograph of the late post-operative period after periodontal treatment of the dental erosion with root coverage with PRF membrane in the mandible (6-month follow-up).

glass tube, which induces a more rapid clotting, allows a spin time reduction to 8 minutes (A-PRF tube). The fibrin clot is richer in white cells. However, the fibrin is less dense and is more quickly invaded by the cells. Thus, the matrix function is improved [15].

Injectable PRF (i-PRF)

With the same concept of a non-additive system, the i-PRF was designed. Blood drawing is made into a specially designed tube that is centrifuged with a very low speed (60 g-force) and for a short time (3 minutes).

The objective is to get a liquid form of PRF at the end of the spin that clots after several minutes. This technique allows liquid injection into the site (gingiva or PDL) or into the bone graft. When the i-PRF is injected in the bone graft (already mixed with the A-PRF fragments), it clots very quickly (1 min) and permits a more cohesive and malleable bone graft.

This technique is specifically interesting for sinus lifting where a more solid bone graft reduces a bone graft particle migration in the maxillary sinus. The stability of the bone graft particles embedded in a fibrin clot allows a much easier adaptation and more rapid vascularization.

Conclusion

The PRF is a simple and inexpensive technique that provides an autologous fibrin matrix with a slow release of growth factors. We can say that the PRF properties are dose-dependent – the quantity of fibrin directly influences the capacity to induce new tissue formation.

After 15 years of experience and more than 300 articles available in Medline, we can say that the PRF is a technique with sufficient scientific evidence. However, it is a technique in progress and many enhancements will be made in the future with the evolution of tissue engineering.

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Practical Implications of Stem Cell Technology: Functional Tooth Restoration Using Bioengineered Organ Regeneration and Bio-Hybrid Artificial Organ Replacement

Masamitsu Oshima^{1,2,3} and Takashi Tsuji^{2,3,4}

¹Department of Oral Rehabilitation and Regenerative Medicine, Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University, Okayama, Japan

²Research Institute for Science and Technology, Tokyo University of Science, Noda, Chiba, Japan

³RIKEN Center for Developmental Biology, Kobe, Hyogo, Japan

⁴Organ Technologies Inc., Tokyo, Japan

Introduction

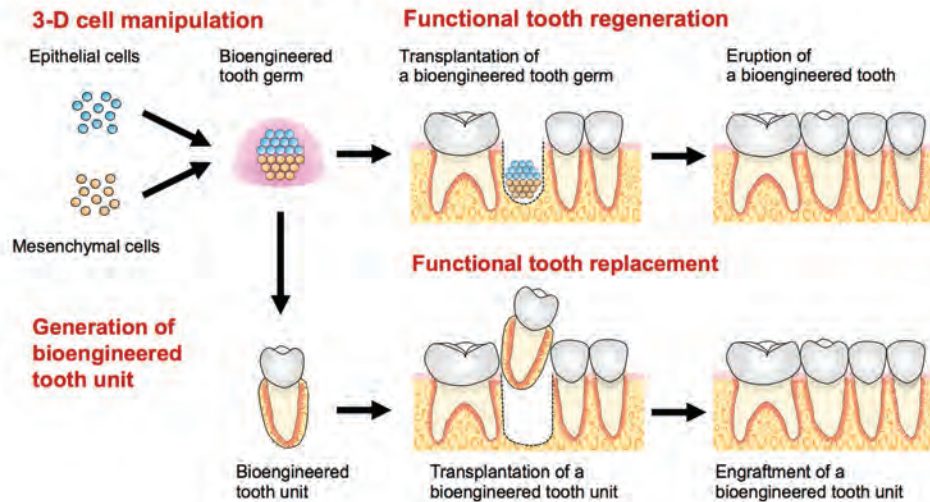
Oral functions including mastication, enunciation, and swallowing are important for oral and general health in human life [1]. Tooth physiological functions are exerted efficiently by the characteristic three-dimensional multicellular structure, which is made up of distinctive hard tissue and soft connective tissues that can establish functional cooperation with the maxillofacial region [2,3]. Tooth loss due to dental caries, periodontitis, and trauma causes fundamental problems for oral function and associated general health [1]. To restore the occlusal or aesthetic problems after tooth loss, several dental therapies have been conventionally performed that involve replacement with artificial material, such as fixed dental bridges and removable dentures [4,5]. In addition, an osseointegrated dental implant that directly connects with the alveolar bone independent of the periodontal ligament (PDL) has been widely applied for the rehabilitation of tooth loss [6,7]. Although these artificial therapies have been widely applied for oral rehabilitation, further technological improvements based on biological findings are needed to restore the physiological functions of the tooth [8].

Recent advances in future regenerative therapy have been developed due to accumulation of knowledge regarding embryonic development, stem cell biology, and tissue engineering technology [9–13]. As a new regenerative strategy, stem cell transplantations using tissue-derived stem cells, embryonic stem (ES) cells, or induced pluripotent stem (iPS) cells have been attempted for repairing damaged tissues due to structural and functional diseases [14–17]. In dentistry, basic research on stem/progenitor cells has provided new insights into tooth-tissue-derived stem cells, including dental pulp stem cells (DPSCs), stem cells from human exfoliated deciduous teeth (SHED), and stem cells from apical papilla (SCAP) that have been isolated from dental pulp tissue and are thought to be a potential resource for stem cell-mediated dentin pulp regeneration [18–21]. Furthermore, periodontal ligament-derived stem cells (PDLSCs), which can differentiate into

all periodontal cell types after transplantation, have also been identified, and cell sheet engineering using PDLSCs has been attempted for clinical trials of periodontal tissue regeneration [22]. Although these treatments contribute to partial tissue repair, many researchers expect the development of further therapeutic technologies using dental stem cells that can regenerate a whole tooth [23,24].

Organ replacement regenerative therapy, unlike stem cell transplantation, holds great promise for the replacement of dysfunctional organs via a regenerative strategy by reconstructing a bioengineered organ using three-dimensional cell manipulation *in vitro* [13,22]. It is anticipated that next-generation bioengineering technology will eventually enable the creation of fully functional bioengineered organs through the proper arrangement of several cell components and the functional cooperation with artificial organs. In the dental field, the tooth regenerative strategy involves two attractive concepts for achieving whole-tooth replacement via the transplantation of bioengineered teeth or bio-hybrid artificial teeth into regions of tooth loss [25–28] (Figure 34.1). It is expected that whole-tooth replacement therapy will be established in the near future as a successful biological treatment that will provide the recovery of the essential functionalities of lost teeth to satisfy aesthetic and physiological requirements [26,27]. We first developed a fully functioning bioengineered tooth replacement with the correct whole-tooth structure, masticatory performance, responsiveness to mechanical stress, and perceptive potential following transplantation into a tooth loss region [29–31]. More recently, we reported a fully functional artificial tooth, designated as a bio-hybrid tooth dental implant that incorporated the correct periodontal tissue structures, including cementum, PDL, and alveolar bone, on to the implant surface [28]. In this chapter, we will describe new bioengineering technologies for whole-tooth replacement that have the great potential for providing functional recovery and entirely replacing traditional dental treatments.

(a) Organ Replacement Regenerative Therapy



(b) Bio-hybrid Artificial Organ Therapy

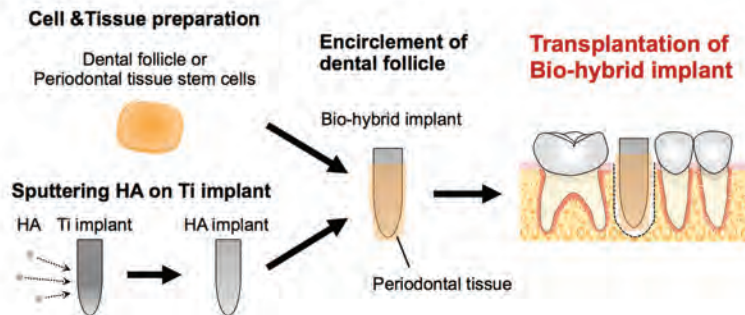


Figure 34.1 Strategies of dental regenerative therapy. (a) Fully functioning teeth can be regenerated *in vivo* by transplanting bioengineered tooth germs reconstituted from epithelial and mesenchymal cells via the organ germ method or by transplanting bioengineered tooth units with a periodontal ligament and alveolar bone that are developed from bioengineered tooth germs. (b) Fibrous connected tooth implants can be generated *in vivo* by transplanting a bio-hybrid implant using an HA-coated dental implant enveloped in dental follicle stem cells.

Strategy of tooth regenerative therapy by replicating tooth organogenesis

The ultimate goal of regenerative therapy in the future will be to develop organ replacement regenerative therapies that restore severely damaged tissues with a fully functioning bioengineered complex organ [13,22]. To achieve the reconstruction of bioengineered organs, one biological approach is based on recapitulating organogenesis by mimicking the reciprocal epithelial–mesenchymal interactions that occur in the organ developmental process [27,32].

In the developing embryo, tooth organogenesis is regulated by reciprocal epithelial and mesenchymal interactions, which are principal developmental mechanisms involving stem cells and signaling molecule pathways [33,34]. In early craniofacial development in mice at embryonic day (ED) 10–11, the dental lamina first thickens, followed by epithelial thickening at the sites of future teeth and subsequent epithelial budding to the neural crest-derived ectomesenchyme. At ED 11.5, the oral epithelium elongates into the mesenchymal region and then a tooth bud is formed by the condensation of neural crest-derived mesenchymal tissue. At ED

13.5–14.5, a transient epithelial signaling centre, known as the enamel knot, which expresses important signaling molecules such as Shh, Wnts, BMPs, and FGFs, is thought to regulate individual cell fates and to orchestrate epithelial morphogenesis through epithelial–mesenchymal interactions [33,34]. The epithelial and mesenchymal cells in the tooth germ terminally differentiate into tooth tissue progenitor cells, including ameloblasts, odontoblasts, and dental follicle cells, at ED 16.5–18.5. These progenitor cells accumulate the enamel or dentin matrix at the boundary surface between the epithelium and the mesenchyme [35]. Additionally, dental follicle cells differentiate into periodontal tissues, including cementum, the PDL, and alveolar bone [36]. After tooth crown formation, tooth eruption begins in the oral cavity and involves tooth-root elongation, and dental follicle cells form all of the periodontal tissues on the root-dentin surface [37,38]. It is therefore expected that a novel bioengineering technology will enable the creation of a fully functional bioengineered tooth by replicating the tooth developmental process via three-dimensional stem cell manipulation.

Whole-tooth replacement using a novel three-dimensional cell manipulation method

Current bioengineering technology for regenerating three-dimensional organs has progressed to the replication of organogenesis through epithelial–mesenchymal interactions that occur in the developing embryo, thereby enabling the development of fully functional bioengineered organs using bioengineered organ germs that are generated from immature stem cells via three-dimensional cell manipulation *in vitro* [32,39]. In the dental field, an attractive concept involves transplanting a bioengineered tooth germ into the tooth loss region that would develop into a functioning mature tooth [30] (Figure 34.1a, upper panel). It is also expected that it will be possible to transplant a bioengineered tooth unit, including a mature tooth, PDL, and alveolar bone, that can be integrated into the physiological bone of the recipient's jaw [31] (Figure 34.1a, lower panel).

Development of a novel three-dimensional cell-manipulation method for bioengineering tooth germs: the “organ germ method”

To realize whole-tooth replacement, the first major issue is the development of a three-dimensional cell-manipulation technology using completely dissociated epithelial and mesenchymal stem cells *in vitro*. To date, two conventional approaches, the biodegradable scaffold method [40–45] and the cell aggregation method [46–48], for generating bioengineered tooth germ have been attempted. These methods are able to partially replicate tooth organogenesis, although fundamental problems regarding the low frequency of tooth formation and the irregularity of the resulting tooth tissue structures have not been resolved.

To achieve precise replication of organogenesis, an *in vitro* three-dimensional novel cell manipulation method, designated the bioengineered organ germ method, has been recently established [29,49]. This method incorporates a three-dimensional cell compartmentalization of epithelial and mesenchymal cells at a high cell density in a collagen gel (Figure 34.2a). Bioengineering tooth germs using this method replicate the multicellular assembly, including the ameloblasts, odontoblasts, pulp cells, and dental follicle cells, based on epithelial–mesenchymal interactions and natural tooth development in an *in vitro* organ culture [29] (Figure 34.2a). The bioengineered tooth germ generates a structurally correct tooth composed of a mature tooth, PDL, and alveolar bone, which is designated as a bioengineered tooth unit that can be transplanted into a subrenal capsule *in vivo* [29,31] (Figure 34.2b and c). Multiple bioengineered tooth units surrounded by alveolar bone have also been generated by transplanting several tooth germs, and each generated bioengineered tooth exhibited the correct tooth structure, including the pulp and the partitioned periodontal tissue [31] (Figure 34.2b and c). These technologies have the potential to be adapted for functional tooth regeneration and also represent a substantial advance in bioengineered organ replacement regenerative therapy [29,31].

Successful transplantation of a bioengineered tooth germ or a bioengineered mature tooth unit for whole-tooth replacement therapy

The critical issue regarding the successful tooth regenerative therapy via the transplantation of a bioengineered tooth germ into the tooth loss region is whether the germ can erupt and occlude

correctly with the opposing tooth in an adult oral environment. Natural tooth eruption is regulated by an autonomic mechanism that involves the tooth germ cell components and the surrounding alveolar/jawbone [50,51]. It has been reported that a transplanted natural tooth germ can erupt in a murine toothless diastema region [39,52]. Recently, we demonstrated that a bioengineered tooth germ can develop the correct tooth structure in an oral cavity and erupt completely 49 days after transplantation [29,30] (Figure 34.3a). Subsequently, the erupted bioengineered tooth not only reached the occlusal plane but also maintained occlusal function with the opposing natural tooth [30] (Figure 34.3b).

Transplantation of a bioengineered mature organ would lead to immediate performance of its full functions *in vivo* [53]. In dental therapy, the most critical consideration is whether a bioengineered tooth unit composed of mature tooth, PDL, and alveolar bone can be engrafted into the tooth loss region, which involves natural bone remodelling in the recipient. We have previously demonstrated the successful engraftment of a bioengineered tooth unit with bone integration between the alveolar bone of the tooth unit and that of the recipient 40 days after transplantation [31] (Figure 34.3b and c). The hardness of the enamel and dentin components in the bioengineered teeth were equivalent to those of natural teeth based on the Knoop hardness test [30,31]. These tooth regenerative approaches demonstrated the potential for successfully restoring masticatory performance.

Biological functions of bioengineered teeth

The cooperation between teeth and the maxillofacial region via the biological connection of periodontal ligaments is essential for full oral functions. The structural properties of periodontal tissue contribute to the physiological functions of teeth, including the absorption of occlusal loading, the maintenance of alveolar bone height and orthodontic tooth movement involving bone remodelling [37]. Therefore, the coordination of the tooth and the maxillofacial components through biological connections of the PDL is a requirement for bioengineered teeth [2,5,54]. We have demonstrated that bioengineered teeth are able to successfully undergo functional tooth movement equivalent to that of natural teeth based on the proper localization of osteoclasts and osteoblasts in response to mechanical stress [30,31]. These findings indicate that a bioengineered tooth can replicate a periodontal ligament function and lead to the re-establishment of functional teeth within the maxillofacial region [30,31].

Teeth are the peripheral organs of the sensory trigeminal and sympathetic nerves, and the afferent nervous system in the maxillofacial region plays essential roles regarding the regulation of tooth physiological functions and the perception of noxious stimuli [55]. It is thought that neuronal regeneration, including the re-entry of nerve fibres after the transplantation of tooth germs or tooth units, is required for the functional recovery of noxious stimuli perception in future tooth regenerative therapy [53]. Our studies have demonstrated that sensory and sympathetic nerve fibres can innervate both the pulp and the PDL region of an engrafted bioengineered tooth [30,31] (Figure 34.3e). Bioengineered teeth offer the potential for pain stimuli perception, including the perception of stimuli due to pulp injury and orthodontic movement, and the potential to properly transduce these peripheral stimulations to the central nervous system through c-Fos immunoreactive neurons [30,31]. These findings indicate that bioengineered teeth can restore the proprioceptive responses to noxious stimuli within the maxillofacial region.

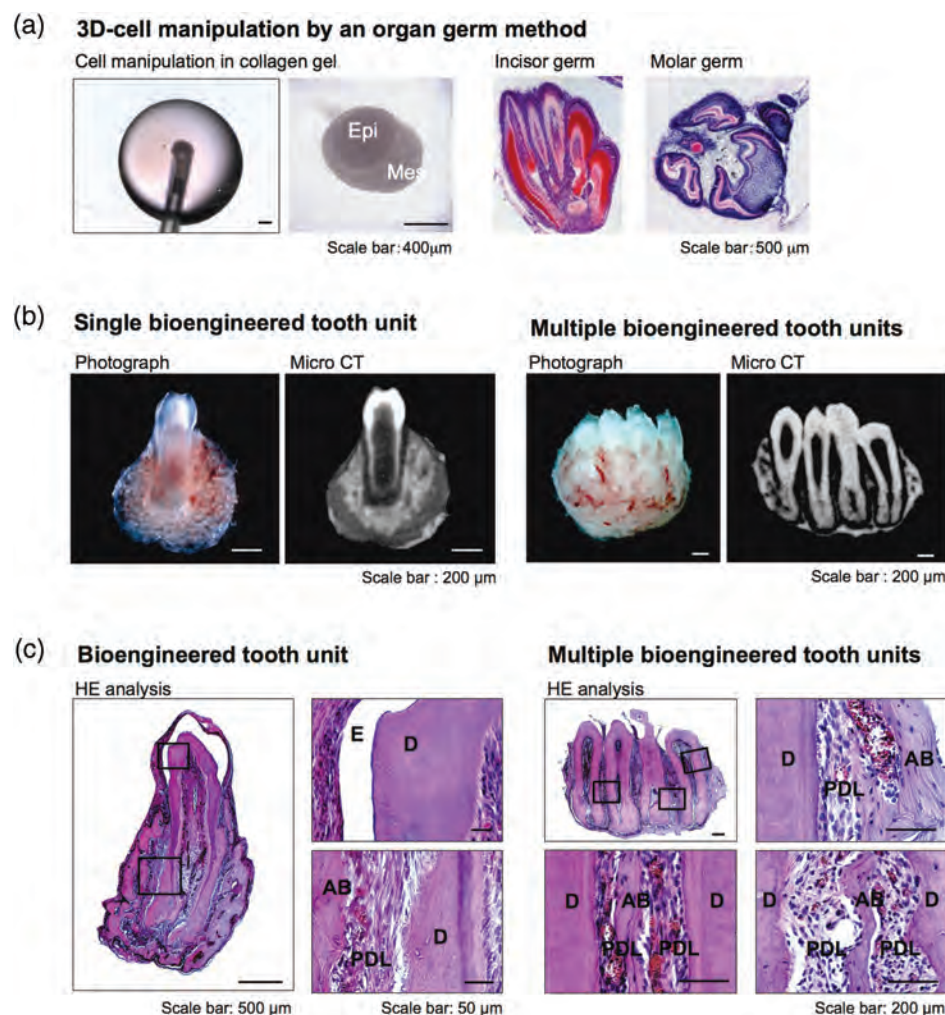


Figure 34.2 The organ germ method: a three-dimensional cell-processing system. (a) A high density of dissociated mesenchymal cells is injected into the centre of a collagen drop. Tooth-germ-derived epithelial cells and mesenchymal cells are injected into the collagen drop at a high density (left). At organ culture day 1, the bioengineered tooth germ with the appropriate compartmentalization between the epithelial and mesenchymal cells and cell-to-cell compaction was formed (centre-left). Bioengineered molar tooth germs, which were reconstituted using dissociated cells isolated from incisor and molar tooth germs, developed in an *in vitro* organ culture for 14 days (centre-right and right). (b) Transplantation of the bioengineered tooth germ into a subrenal capsule for 30 days. Multiple bioengineered tooth units surrounded by alveolar bone can also be generated by transplanting several tooth germs. (c) A bioengineered tooth unit composed of a mature tooth, periodontal ligament, and alveolar bone was generated with natural tooth structures, such as enamel (E), dentin (D), the periodontal ligament (PDL), and alveolar bone (AB).

Regenerated teeth developed from bioengineered germs or transplanted bioengineered mature tooth units have successfully demonstrated the physiological functions of teeth, including sufficient masticatory performance, biological cooperation via periodontal tissues, and afferent responsiveness to noxious stimuli. Our bioengineering technology for fully functional tooth regeneration could contribute to the realization of whole-tooth replacement regenerative therapy in the future [29–31].

Functional tooth restoration by transplantation of a bio-hybrid implant

To restore occlusal function after tooth loss, osseointegrated dental implants that are able to stand alone in the jawbone without invading adjacent teeth have been widely used to treat

tooth loss [6,7]. However, due to the absence of natural periodontal tissue, the currently used dental implants that are directly connected to the surrounding alveolar bone do not provide the same function as physiological teeth, such as the ability to alleviate excessive occlusal force, to undergo orthodontic movement via bone remodeling, and to perceive noxious stimuli [6,7,56]. Although dental implants are an available treatment that represents a paradigm shift from traditional dental therapies, such as dental bridges and dentures, fundamental problems must be overcome before implants can be clinically used in young patients who are still undergoing jawbone growth [7,56]. It is therefore necessary to develop a functional dental implant that cooperates with the maxillofacial region and satisfies physiological functions through a biological connection with bioengineered PDL (Figure 34.1b).

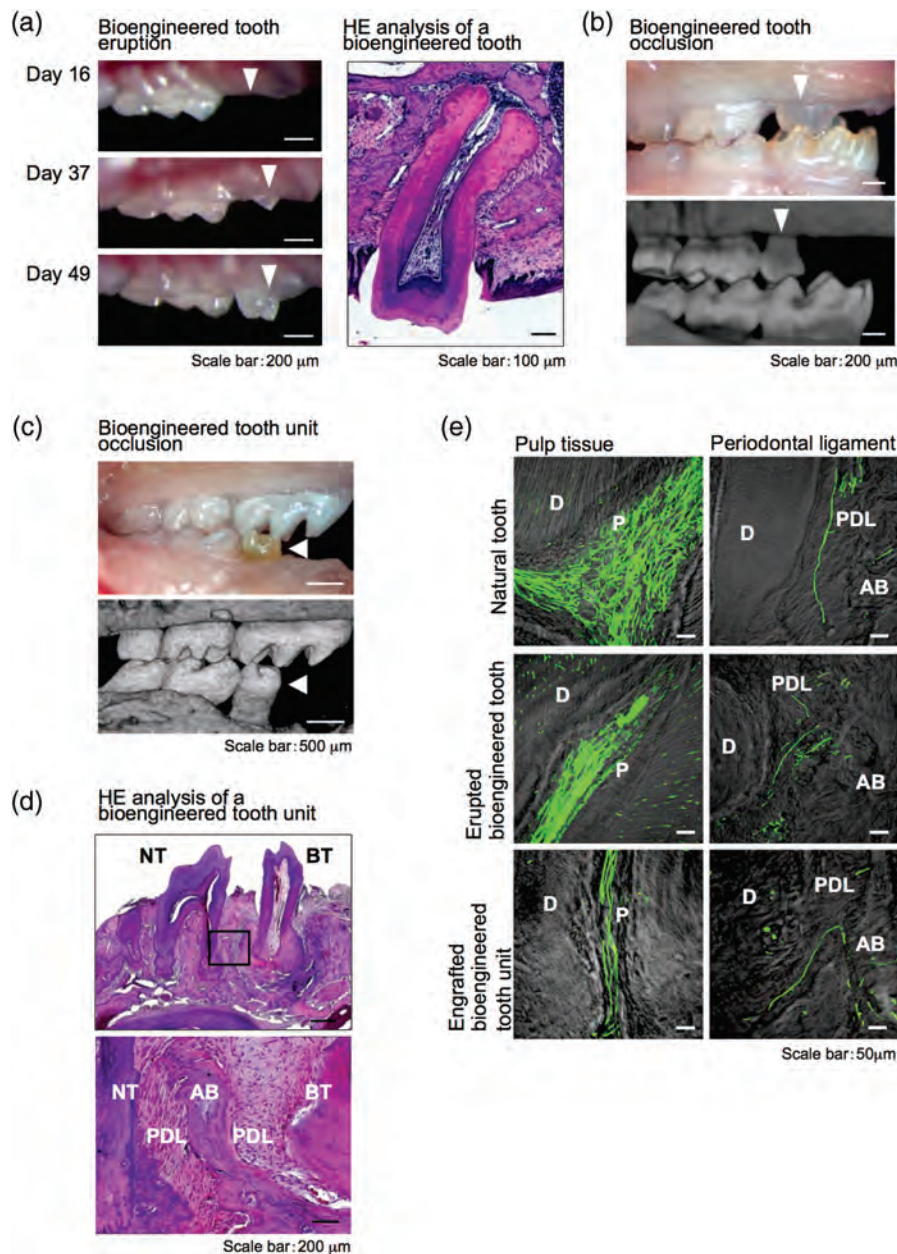


Figure 34.3 Functional tooth regeneration via the transplantation of a bioengineered tooth germ or a bioengineered tooth unit. (a) The transplanted bioengineered tooth germ erupted 49 days after transplantation (left). The bioengineered tooth formed a correct structure composed of enamel, dentin, dental pulp, and alveolar bone (right). (b) The bioengineered tooth reached the occlusal plane with the opposing lower first molar 49 days after transplantation (arrowheads, bioengineered tooth unit). (c) The bioengineered tooth unit was engrafted through bone integration and reached the occlusal plane with the opposing upper first molar 40 days after transplantation (arrowheads, bioengineered tooth unit). (d) The engrafted bioengineered tooth unit also exhibited the correct structure. NT, natural tooth; BT, bioengineered tooth; AB, alveolar bone; PDL, periodontal ligament. (e) Nerve innervation of the dental pulp and periodontal ligament in natural (upper) and bioengineered teeth (middle and lower) detected via immunostaining for neurofilament H. D, dentin; P, pulp; PDL, periodontal ligament; AB, alveolar bone.

Successful development of a bio-hybrid implant using a dental implant and dental follicle stem cells as a bio-hybrid artificial organ

The critical goal regarding the successful development of a bio-hybrid implant is to identify cell sources that can regenerate periodontal tissue on an artificial material. In the tooth developmental stages, the dental follicle tissue, which is formed around the tooth germ, differentiates into all periodontal tissues, including cementum, PDL, and alveolar bone. We have previously demonstrated that our bioengineered tooth was composed of the correct periodontal tissue derived from the dental follicle tissue that formed around the bioengineered tooth germ [31]. Thus, we hypothesize that a bio-hybrid implant could be developed by applying dental follicle tissue to the bioengineering technology of bioengineered teeth [28].

Recently, we reported that the only ED 18.5 tooth germ-derived dental follicle tissue (ED 18.5-DF) was able to form the completely authentic periodontal tissue on hydroxyapatite (HA) surfaces (Figure 34.4a). We next investigated whether HA-coated dental implants in combination with ED 18.5-DF could serve as a bio-hybrid implant with periodontal tissue after transplantation into a tooth loss region in the adult mouse oral environment. The bio-hybrid implant was engrafted into the tooth loss region through the correct formation of periodontal tissue structures consisting of cementum, PDL, and alveolar bone on the HA-coated implant (Figure 34.4b and c). The PDL fibre structure of the engrafted bio-hybrid implant was equivalent to that of a natural molar tooth, and an invasion of Sharpey's fibre into the cementum of the bio-hybrid implant was also observed (Figure 34.4d). These results demonstrated that the engrafted bio-hybrid implant formed the correct

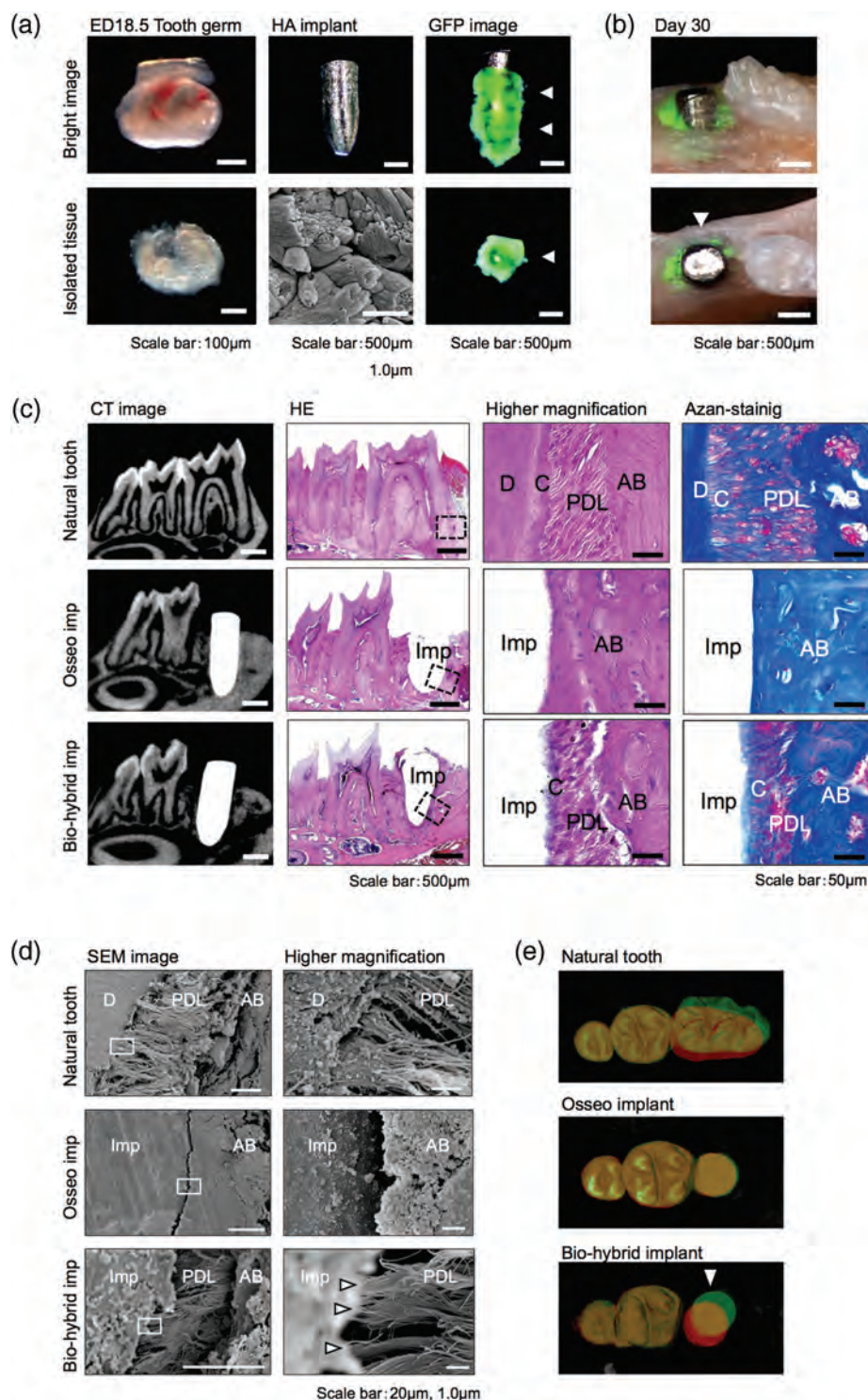


Figure 34.4 Functional tooth restoration of a bio-hybrid implant. (a) Photographs of ED 18.5 tooth germ (left-upper) and isolated dental follicle tissue (left lower). Photograph (centre-upper) and surface analysis (centre-lower) of HA implants using SEM. Merged images of a bio-hybrid dental implant using dental follicles isolated from GFP transgenic mice (right). (b) Photograph of a bio-hybrid implant using ED 18.5 dental follicles isolated from GFP transgenic mice at 30 days post-transplantation. Arrowhead, bio-hybrid implant. (c) Micro-CT images and histological analysis of a natural tooth (upper), an engrafted osseointegrated implant (middle), and an engrafted bio-hybrid implant (lower) at 30 days post-transplantation. Micro-CT image, HE, and Azan staining are shown. D, dentin; C, cementum; AB, alveolar bone; PDL, periodontal ligament; Imp, implant. (d) Scanning electron microscopic (SEM) images of a natural tooth (upper), an engrafted osseointegrated implant (middle), and an engrafted bio-hybrid implant (lower) at 30 days post-transplantation. D, dentin; AB, alveolar bone; PDL, periodontal ligament; Imp, implant. (e) Horizontal superposition of micro-CT images of a natural tooth (upper), an osseointegrated implant (middle), and a bio-hybrid implant (lower) at days 0 (red) and 14 days (green) of experimental orthodontic treatment.

periodontal tissue architecture on the implant surface and that the proper fibrous structural connections were formed [28].

Biological response of bio-hybrid implants to mechanical stress

The PDL can cooperate with the maxillofacial region through fibrous connections with the cementum and the alveolar bone, and it plays important roles in the biological functions of teeth, including the absorption of occlusal forces and tooth movement via bone remodelling [2]. It has been postulated that a fibrous connective bio-hybrid implant could be achieved by fulfilling critical functions in the oral environment, such as the cooperation of the bio-hybrid implant with the oral and maxillofacial regions, specifically the response to mechanical stress and the ability to perceive noxious stimuli *in vivo* [28]. Recently, we demonstrated that the PDL of a bio-hybrid implant successfully mediated bone remodeling via the proper localization of osteoclasts and osteoblasts in response to mechanical stress (Figure 34.4e). Furthermore, the engrafted bio-hybrid implant not only was detected by the peripheral nerves in the PDL surrounding the bio-hybrid implant but also responded to external stimulation and transduced signals to the central nervous system. These results indicate that the engrafted bio-hybrid implant was able to restore the essential physiological functions of teeth, including the response to mechanical stress and the perceptive potential to noxious stimuli in cooperation with the maxillofacial region [28].

Three-dimensional bone regeneration via the transplantation of bioengineered tooth units and bio-hybrid implants

The PDL plays an important role in maintaining the height and volume of the surrounding alveolar bone. Tooth root fracture or tooth loss causes a large amount of vertical and horizontal alveolar bone resorption [57,58]. Alveolar bone resorption resulting from dental diseases, which is often the most drastic in the buccal alveolar bone, is difficult to rectify based on standard dental therapies, such as dental implants and autologous tooth transplantation, without bone regenerative approaches [57,58]. Although bone regenerative therapies have been attempted for many years, which have included various utilizations of guided bone regeneration methods, autologous bone or cell transplantation, and cytokine therapies [59], a clinical protocol for bone regeneration is not yet available [60].

We previously reported that a bioengineered tooth unit was successfully engrafted and integrated via recipient bone remodelling after transplantation into an extensive bone defect model (Figure 34.5a and b). The recipient alveolar bone of the vertical dimension was observed to maintain the height of the PDL in the bioengineered tooth unit [31] (Figure 34.5b). We also demonstrated that a bio-hybrid implant induced vertical bone regeneration in a murine three-wall bone defect model (Figure 34.5c and d). The regenerative bone area after transplantation of the bio-hybrid implant significantly increased compared to a no-transplant control and compared to the transplantation of an osseointegrated implant [28] (Figure 34.5d). These findings indicate that our bioengineering technology, including the transplantation of bioengineered teeth or bio-hybrid implants, has great potential for not only future whole-tooth replacement therapy but also for the treatment of clinical cases where tooth loss is accompanied by a serious alveolar bone defect [28].

Conclusions and future directions

Regenerative technology has progressed remarkably and many patients await whole-tooth replacement therapy in the near future. However, there are several problems regarding suitable cell sources that must be solved for the feasibility of this bioengineering technology [32]. The cell source should be optimized using the patient's own cells for regenerative therapy to avoid immunological rejection. In the dental field, recent studies of stem cell biology have led to the identification of candidate cell sources based on tooth organogenesis for tooth tissue regeneration and tooth replacement therapy [25,26]. For whole-tooth replacement therapy that involves reconstructing bioengineered tooth germs, tooth inductive potential cells that can replicate an epithelial-mesenchymal interaction for whole-tooth regeneration have not yet been identified. In the future, cell sources that are able to reproduce the epithelial and mesenchymal interactions for tooth organogenesis must be identified from the various tissue-derived stem cell populations isolated from patients [32]. Pluripotent stem cells including ES cells and iPS cells are also candidate cell sources that are capable of differentiating into endodermal, ectodermal, and mesodermal cell types [61]. Recently, iPS cells have been established from several oral tissues, and these cells have shown the ability to differentiate into dental epithelial and mesenchymal cells [62–64].

To realize future clinical applications of bio-hybrid implants, stem cells derived from wisdom tooth (impacted third molar) germs of young patients, which correspond to the ED 18.5 dental follicle stem cells, discussed here, are thought to be a potential candidate for periodontal tissue regeneration in bio-hybrid implants [65,66]. The identification and engineering optimization of adult tissue stem cells, such as PDLSCs and dental follicle stem cells, for periodontal tissue regeneration could also contribute to the development of a clinically relevant next-generation bio-hybrid implant therapy for treating tooth loss [65,66]. This bio-hybrid technology may underlie novel medical technologies that integrate stem-cell-mediated tissue regeneration strategies, engineered structural materials, and conventional dental therapeutic methods. This bio-hybrid implant concept also holds great promise for clinical applications that precede whole-tooth regeneration [28].

Whole-tooth replacement and bio-hybrid implant therapies have a great potential for future tooth regenerative technologies. Further pre-clinical studies in large animal models or human clinical trials using patient tissue-derived cells are needed to realize human clinical applications. Tooth regenerative therapy is now regarded as a viable model for studying future organ replacement regenerative therapies that can be applied to several complex organs, and it will contribute substantially to the knowledge and technology of organ regeneration [26,32].

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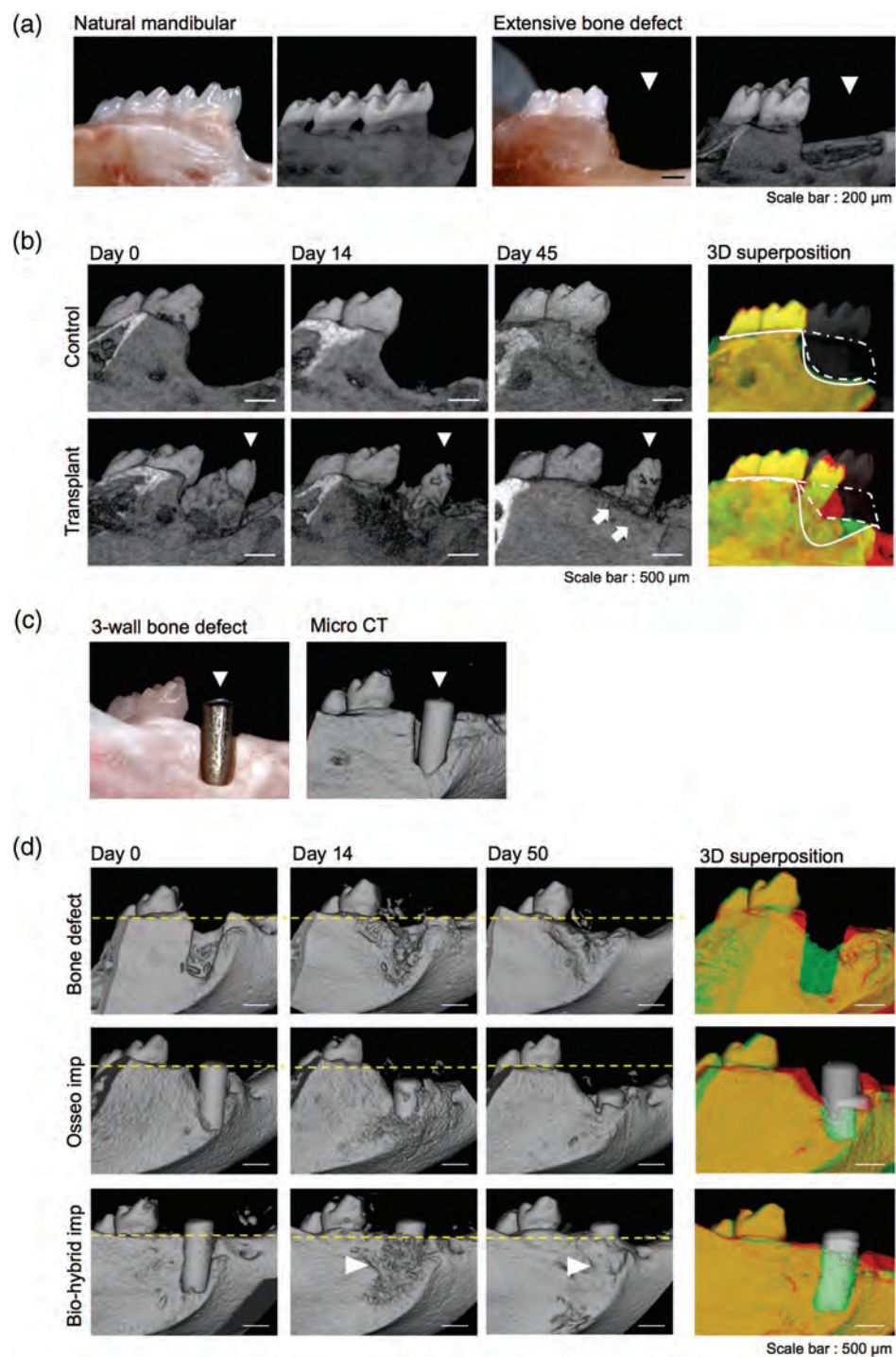


Figure 34.5 Vertical bone regeneration following the transplantation of a bioengineered tooth unit and a bio-hybrid implant. **(a)** Photographs (left) and micro-CT images (right) of the natural mandibular and the extensive bone defect model (arrowheads). **(b)** Three-dimensional superpositions of micro-CT images of natural dentition (grey, double dotted line), a transplanted bioengineered tooth unit (lower) and a no-transplantation control (upper) on day 0 of an extensive bone defect (red, straight line) and 45 days after transplantation (green, dotted line) are represented. The superior edges of the recipient's alveolar bone are indicated by each line. **(c)** Photographic representation of a murine three-wall bone defect model and transplantation of the implant (arrowhead, transplanted implant). **(d)** Micro-CT images of the vertical alveolar bone regeneration processes in a no-transplantation bone defect model (upper), transplantation of an osseointegrated implant in a bone defect model (middle), and transplantation of a bio-hybrid implant in a bone defect model (lower). Vertical bone formation after transplantation of the bio-hybrid implant was observed, and the bone recovered almost completely by 50 days after transplantation. The superior edges of the recipient alveolar bone are indicated by the dotted line. Three-dimensional superposition of micro-CT images of the no-transplantation control (upper-right), the transplanted osseointegrated implant (middle-right), and the transplanted bio-hybrid implant (lower-right) in a three-wall bone defect at day 0 (red) and day 50 (green) after transplantation.

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