Fundamentals of Implant Dentistry
Volume 1: Prosthodontic Principles
Second Edition

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Fundamentals of Implant Dentistry

VOLUME 1: *Prosthodontic Principles*

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DEDICATION

To Jan, for her unwavering love and support.
John Beumer III

To my wife, Terry, who continues to love, support, and believe in me as I continue my life's endeavors.
Robert F. Faulkner

To my entire family for their love and encouragement: to my parents, Chimanlal and Kusum, for always believing in me; to my siblings, Jigar and Hetal, for their unconditional support; to my son, Kiaan, and my daughter, Vachi, for their inspiration to keep trying no matter what; and last but definitely not least, to my wife, Shreya, for everything she does and her love and support.
Kumar C. Shah

To Betty, Chloe, and Sarah for making every moment a blessing, and to my teachers for shaping my students.
Benjamin M. Wu

PREFACE

A first edition is always a work in progress, and this is especially true in a field as dynamic as implant prosthodontics. Moreover, dentistry and dental education are in the midst of revolutionary change, primarily because of the refinement of CAD/CAM technologies. These changes are by no means confined to implant prosthodontics. For example, removable partial denture (RPD) metal frameworks designed digitally and printed using selective laser melting now achieve precision and strength equivalent to that produced by the most skilled laboratory technician using analog methods. Fabrication of complete dentures using digital technologies is now possible—although the best outcomes are achieved when time-tested analog impression techniques are combined with digital methods. The digital revolution has allowed us to explore the use of new restorative materials for our implant-borne restorations, to visualize the local anatomy of our patients in three dimensions prior to treatment, and to execute our surgical and prosthodontic treatments with improved precision and efficiency. One of the goals of this new edition is to illustrate when and how digital technologies can be combined with analog techniques to create workable and efficient prosthodontic workflows.

As in the first edition, the book is divided into sections. Several new topics and chapters have been added to the second edition. In chapter 3, a synopsis of biomechanics as it pertains to implant prosthodontics is presented along with our view of the proper approach to occlusal and component design. Where possible, clinical data are combined with engineering principles to illustrate practical application of biomechanical concepts. Mechanotransduction and tissue response to mechanical loading are included to emphasize the dynamic nature of the bone-implant interface. New chapters on digital technologies and contemporary materials used in implant dentistry have also been added. Issues pertinent to maintenance, implant and prosthodontic complications, and their treatment are combined in another new chapter. The chapter on the use of implants in irradiated tissues has been enhanced to include a section on the use of implants in patients treated with bisphosphonates. Another chapter has been added devoted to implant surgery and tailored for nonsurgically trained dentists.

The impetus for this supplement has been the recent mandate by CODA (Commission on Dental Accreditation of the American Dental Association) to train prosthodontic residents in the basic fundamentals of implant surgery. Furthermore, throughout the book, we have tried to present clinical follow-ups of patients displayed in the first edition, some over 30 years postdelivery.

We continue to emphasize the importance of considering conventional prosthodontic methods and presenting these to the patient. As in the first edition, we indicate when conventional approaches (tooth-supported fixed dental prostheses, RPDs, and restoring diseased teeth with endodontic therapy and conventional restorations) should be considered. Frequently, conventional treatments are just as effective in restoring form and function (and sometimes more so), are more time efficient, and more often than not are more cost effective than implant options.

We continue to believe that most patients are best served with an interdisciplinary effort. Some patients present with relatively simple problems and can be handled by a solo practitioner (hence, the addition of the chapter devoted to implant surgery for nonsurgically trained dentists). However, most patients present with significant prosthodontic complexities such as occlusal plane discrepancies, malposed teeth and unfavorable jaw relations, periodontal compromise of existing dentition, and significant bone and soft tissue defects associated with the potential implant sites, especially in the esthetic zone. Achieving sustainable outcomes for such patients requires the prosthodontist or restorative dentist to develop close professional interaction with oral and maxillofacial surgeons, periodontists, orthodontists, and endodontists as well as dental technicians and staff associated with biomedical modeling centers.

An important objective of this edition is to reinforce the basic principles of fixed and removable prosthodontics. In order to develop an appropriate level of expertise in implant prosthodontics, the clinician must have a firm foundation in conventional fixed and removable prosthodontics. Therefore, topics such as occlusal schemes used for the various types of implant prostheses, as well as designing proper resistance and retention form into customized abutments where the prosthesis is to be retained with cement, the principles of smile design and esthetics, and other topics pertinent to the fundamentals of prosthodontics are emphasized and discussed as needed.

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John Beumer III

As in the first edition, I would like to personally thank my mentors: Dr Sol Silverman Jr, Distinguished Professor of Oral Medicine, University of California, San Francisco (UCSF); Dr Thomas A. Curtis, Professor of Prosthodontics, UCSF, and one of the fathers of modern Maxillofacial Prosthetics; and Dr F. J. Kratochvil, Professor of Prosthodontics, University of California, Los Angeles (UCLA), and the developer of the RPI system of removable partial denture design. They were selfless individuals and wonderful role models who are rightly considered giants in their respective disciplines. Their personal integrity, commitment to excellence, and enthusiasm for education and research has been inspiring for me and many others in our profession. I would also like to thank Dr Henry Cherrick, Professor of Pathology and Dean Emeritus, UCLA School of Dentistry. His friendship and mentorship during my early years at UCLA were invaluable, and his leadership and vision as Dean led to the development of robust education and research programs in implant dentistry at UCLA. Also, his encouragement and support were indispensable to the development of the Jane and Jerry Weintraub Center for Reconstructive Biotechnology, Division of Advanced Prosthodontics, UCLA. Last, I would like to extend my thanks to Mr Hiroake Okabe, CTD, who for 20 years directed our Dental Laboratory and Dental Laboratory School devoted to Implant Prosthodontics. His knowledge of implant prosthodontics was astounding, and a substantial amount of his work and that of his students still survives in this edition. The quality of the implant program at UCLA was in large measure due to his expertise and commitment to excellence.

Robert F. Faulkner

First and foremost, I dedicate this book to my parents, Bob and Betty Faulkner. My mom's love and encouragement through the years of her life will remain with me and serve as a constant reminder to set goals and to reach for them with all of my being, and my dad has served as an incredible role model and is truly the man I have always admired and aspired to emulate the most. He has continued to believe in my abilities, even when I doubted myself. The completion of this second book was in no small part due to the work ethic that they have instilled in me. To my children, Lauren and Rob, with whom God blessed me, for their love and understanding; I continue to be amazed at the individuals they are becoming and I am honored to be their father. I would also like to acknowledge my coeditors. They dedicated themselves to a level of excellence in compiling this book and are a reflection of the level of commitment that we have strived to achieve in our profession of prosthodontics. There are several other individuals who have shaped my life's journey, and they, too, have given much to develop my path toward the culmination of these books. I would like to express my sincere gratitude to these mentors: Dr Wayne Payne, Professor Emeritus, Ball State University, Department of Health Science and Physiology, whose encouragement allowed the completion of my master's thesis and helped develop an interest in teaching; and Dr Julian Woelfel, Professor Emeritus in Prosthodontics, and Dr Wayne Campagni, Professor Emeritus, The Ohio State University, College of Dentistry, who both guided my early development in prosthodontics. These two individuals have helped shape many prosthodontists' careers, and it has been my honor to be influenced by their mentorship. Dr Theodore Berg Jr, Professor Emeritus, UCLA School of Dentistry, remains one of my most cherished mentors in prosthodontics. His careful way of teaching and encouraging students to excel was unparalleled, and he has remained an inspiration to me through my years in private practice and continues to be a constant reminder as to the true meaning of being a teacher. Finally, I would like to thank the countless friends and colleagues who have worked with me and have encouraged and been accommodating of my efforts throughout these many years. Without their support, these books would have

Kumar C. Shah

I would like to thank my coeditors for the opportunity to engage with them on this enormous task. Their friendship and support have been invaluable throughout this process. While receiving a strong foundation as a dental student at the National University of Singapore (NUS), Faculty of Dentistry, my initial interest in prosthodontics stemmed from two individuals: Dr Chew Chong Ling and Dr Keson Tan, both Professors at NUS. They both were extremely encouraging in the pursuit of graduate education. Two other individuals had a big impact on my professional life during my residency at The Ohio State University, College of Dentistry—Dr Wayne Campagni and Dr Ernest D. Svensson, Professors Emeritus, The Ohio State University. Their dedication to prosthodontic education and their passion had a great deal of influence on my early career. Their exemplary talents and patience have been a motivation for my career in education. I would also like to thank Dr Sreenivas Koka for his friendship and mentorship. He has been wonderful as a role model and someone to discuss ideas and concepts to challenge the status quo in dentistry.

Benjamin M. Wu

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CHAPTER 1

History and Biologic Foundations

John Beumer III | Robert F. Faulkner | Kumar C. Shah | Benjamin M. Wu

Introduction and Historical Perspectives

Osseointegration has had a greater impact on the practice of dentistry than any technology introduced during the last 60 years. Since the introduction of osseointegrated dental implants more than 30 years ago, significant advances have been achieved in implant surface bioreactivity, methods used in diagnosis and treatment planning—particularly 3D imaging, computer-aided design (CAD), computer-aided manufacturing (CAM), additive manufacturing, and surface engineering—enhancement of bone and soft tissues of potential implant sites, and prosthodontic approaches and techniques. A degree of predictability with implants has been achieved that is truly remarkable.

The concept of osseointegrated implants was first introduced by Brånemark.[1] These implants were made of titanium, and when placed in the jaws, bone was deposited on their surfaces, firmly anchoring the implants in the surrounding bone[1–3] (Fig 1-1). This phenomenon was discovered quite by accident. In a series of experiments designed to document bone healing in vivo, Brånemark used an optical chamber made of titanium placed in a rabbit tibia that was connected to a microscope. When he attempted to remove the chamber from its bone site, he noticed that the bone adhered to the titanium chamber with great tenacity. He recognized the importance of this discovery, and during the next several years, he experimented with various sizes and shapes of dental implants, testing more than fifty designs. He and his colleagues finally settled on a simple screw shape with a hex at the top.

Most of the previous implant systems were made of cobalt-chrome alloys and were subject to corrosion and release of metallic ions into the adjacent tissues. The presence of these ions in sufficient concentrations is thought to provoke acute and chronic inflammatory responses. When combined with insufficient primary fixation and the lack of stability during healing and function, fibrous encapsulation of the offending material is a common sequela (Fig 1-2a). Subsequently, epithelial migration along the interface between the implant and the fibrous capsule led to development of extended peri-implant pockets, and the chronic infections resulting from these pockets led to exposure of the implant framework and its eventual

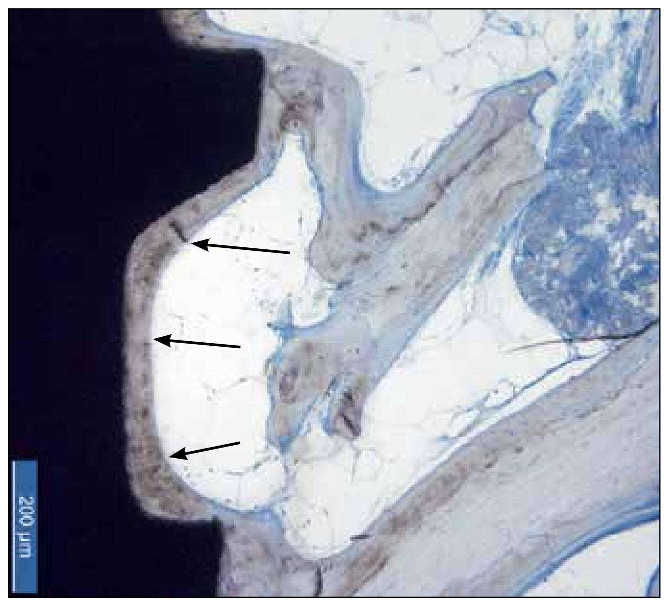

Fig 1-1 The gap between the wall of the osteotomy and the surface of the implant is filled with bone by means of contact *(arrows)* and distance osteogenesis. (Reprinted from Moy et al[3] with permission.)

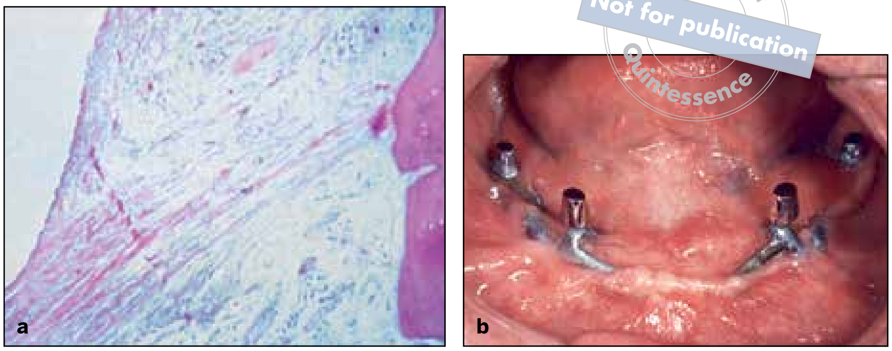

Fig 1-2 *(a)* Subperiosteal cobalt-chrome implants are enveloped by fibrous connective tissue slings. (Courtesy of Dr R. James.) *(b)* Epithelial migration led to the formation of extended peri-implant pockets, which in turn developed into chronic infections. The infections led to exposure of the implant struts and eventually loss of the implant.

Fig 1-3 Substantial portions of the hard palate were lost secondary to infections associated with a subperiosteal implant. (Courtesy of Dr J. Jayanetti.)

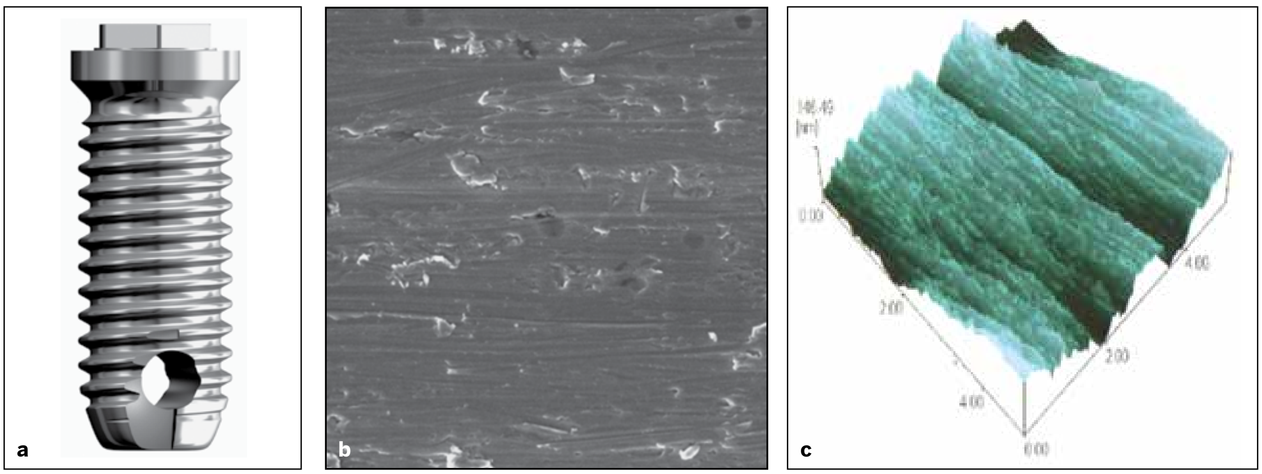

Fig 1-4 *(a)* The original Brånemark machined-surface implant. *(b and c)* Machined-surface topography.

loss (Fig 1-2b). In general, these implant systems survived for 5 to 7 years before the infections prompted their removal. The infections were particularly destructive of bone and soft tissue in the maxilla (Fig 1-3).

Titanium, however, spontaneously forms a coating of titanium dioxide (TiO_2), which is stable and biologically inert and promotes the deposition of a mineralized bone matrix on its surface. In addition, it is easily machined into precision geometries, and the oxide passivation layer provides corrosion resistance under most oral conditions. Following placement of the implant, a blood clot forms between the surface of the implant and the walls of the osteotomy site.[4] Plasma proteins are attracted to the area, accompanied by platelet activation and the release of cytokines and growth factors.[5–7] Some of these signaling molecules induce angiogenesis, and others orchestrate the cascade of wound healing response, which includes the recruitment of local stem cells. These and other repair cells migrate via the fibrin scaffold within the osteotomy site toward the implant surface. The stem cells differentiate into osteoblasts and begin to deposit bone on the surface of the implant and the walls of the osteotomy site, eventually leading to anchorage of the implant in bone (the result of contact and distance osteogenesis[8]; see Fig 1-1). The initial events of this process take anywhere from 8 weeks to 4 months depending on the biologic microenvironment and the osteoconductivity (the recruitment of osteogenic cells and their migration to the surface of the implant) of the implant surface.

The original dental implants developed by Professor Brånemark and his colleagues were prepared with a machined surface (Fig 1-4). These machined-surface implants were predictable in bone sites of favorable quantity and quality, such as the mandibular symphysis region, but were problematic when restoring posterior quadrants in partially edentulous patients. Since then, numerous surface treatments (eg, sandblasting, acid etching, titanium grit blasting, electrolytic processes) designed to change the microtopography of the implant surface have evolved that have significantly improved the osteoconductivity of titanium implants, making these implants highly predictable in less favorable sites, such as

Fig 1-5 *(a)* Semiguided surgical drill guide. Note the bushings (drill sleeves) incorporated within the drill guide. *(b)* Implants are being placed. *(c)* Implants in position.

when restoring the posterior quadrant of the maxilla in partially edentulous patients (see chapter 11).

Prerequisites for Achieving Osseointegration

Uncontaminated implant surfaces

The osteoconductivity of implant surfaces is impaired if they become contaminated with organic molecules; if this occurs, the surface charge is changed from positive to negative, the surface becomes less wettable, and upon implant placement, adsorption of plasma proteins is inhibited. However, implant surfaces can be decontaminated by exposure to ultraviolet light.[9,10] Decontaminating implant surfaces with ultraviolet light (photofunctionalization; see chapter 2) enhances adsorption of plasma proteins initially after implant placement and promotes more rapid differentiation of mesenchymal stem cells into osteoblasts once they reach the surface of the implant.

Creation of congruent, nontraumatized implant sites

Careful preparation of the implant site is important to obtaining osseointegration of a titanium implant in bone on a consistent basis (Fig 1-5). In an ideal situation, the gaps between the wall of the osteotomy and the implant are small, the amount of damaged bone created during surgical preparation of the bone site is minimal, and the implant remains immobilized during the period of bone repair. Under these circumstances, the implant becomes osseointegrated a very high percentage of the time (95% or greater with the modern microrough implant surfaces). During surgical preparation of the site, excessive bone temperatures (ie, above 47°C) should be avoided because they create a zone of necrotic bone in the wall of the osteotomy site, which leads to impaired healing and an increased likelihood of a connective tissue interface forming between the implant and the bone (see Fig 1-5).

A similar outcome is seen if excessive torque is employed to improve initial implant stability or if osteotomes are used to compress the bone adjacent to the osteotomy site in order to achieve a similar outcome (so-called "osteodensification"). Excessive compression of the bone adjacent the osteotomy site increases its density but does not improve initial implant anchorage. This practice results in cell death and increases the width of the zone of necrotic bone adjacent to the osteotomy site. Within 1 day of implant placement, the condensed bone interface exhibits microfractures and osteoclast activity. The subsequent resorption of this zone of necrotic bone around the circumference of the implant increases the dip in implant anchorage seen 7 to 10 days following initial implant placement and if the implant is loaded immediately, theoretically increases the likelihood of implant failure.[11,12] Finite element modeling, mechanical testing, and immunohistochemical data collected at various time intervals during the osseointegration period have shown that osteodensification results in excessive interfacial strains, marginal bone resorption, and no improvement in implant stability.[12]

Primary implant stability

Osseointegration is obtained more consistently when initial primary stability of the implant is achieved in the surrounding bone. This is particularly important when one-stage surgical procedures are employed, and is obviously necessary if the implant is to be immediately placed into function (ie, immediate loading or immediate provisionalization). In attempting to establish initial primary stability, often the implant site is underprepared when the bone is porous or soft. If the implant is not stable in its prepared osteotomy site, many clinicians prefer to replace it with an implant of a slightly larger diameter. This was particularly necessary when machined-surface implants were routinely employed. Today, implant surfaces are considerably more bioreactive, and unstable implants (so-called "spinners") have a reasonable chance of achieving osseointegration when the wound is closed primarily and as long as the clot remains undisturbed during the initial period of healing.

Appropriate initial implant stability is especially essential when considering immediate loading or immediate provisionalization (ie, inserting a prosthesis at the time of implant placement). Recently, an increasing number of implant companies are introducing thread designs with aggressive pitch and drill sequences that result in bone compression. Some of these systems require high insertion torque. However, as mentioned previously, excessive insertion torque appears to actually delay healing and may compromise the quality of implant bone anchorage ultimately achieved.[11,12] These studies have generated considerable debate because previously, many clinicians maintained that high torque values were beneficial and resulted in improved initial implant stability, which in turn led to better outcomes when implants were immediately loaded or immediately provisionalized with a prosthesis.[13,14] According to Cha et al[11] and Wang et al,[12] excessive compression of trabecular bone associated with higher torque levels leads to a relatively thick layer of damaged necrotic bone abutting the surface of the implant, and this layer must be resorbed before contact osteogenesis can begin. This is not surprising because it known that high compressive forces shut off angiogenesis and local microvascular blood flow, and the resultant biochemical cascades of cytokines and cellular reprograming leads to bone resorption. In fact, compressive stress on the leading edge of orthodontic tooth force vector is responsible for bone remodeling that is necessary for successful orthodontic movement. The data in this study is also consistent with the findings of many clinicians, who have recorded significant decreases in implant stability levels 7 to 10 days following implant placement.[15] The levels rebound, but the patient is instructed to avoid mastication for the first 6 weeks following implant placement, and restorative dentists are advised to avoid manipulations of the prosthesis for at least 12 weeks.[16]

Implant stability during the healing phase

It was thought that micromovement of the implant could disturb the tissue and vascular structures necessary for initial bone healing.[17] Furthermore, excessive micromovement of the implant during healing was thought to induce the detachment of the fibrin clot from the implant surface. Actually, it is well known that an optimal amount of strain is beneficial and necessary for most cellular function, from neurons to cardiac cells to osteoblasts and many more. Each cell type is known to respond to stress state (compression, tension, shear) and strain magnitude. The Frost model[18,19] describes a range of optimal microstrain that promotes osteoblast bone remodeling and homeostasis. When insufficient microstrain exists, the bone cells can actually stop producing bone, leading to an osteoblast/osteoclast imbalance. Furthermore, a slight increase above the optimal strain range can promote bone deposition. However, excessive microstrain can lead to necrosis and resorption. The healing processes are highly dependent on the microstrain status. Excessive micromovement tends to produce a connective tissue–implant interface (fibro-osseointegration), while appropriate microstrain can promote a healthy bone-implant interface. These phenomena have clinical significance. For example, immediate loading of dental implants provides a unique challenge. Implants placed into function immediately must be sufficiently stable so as to reduce micromovement to physiologic levels during healing. Otherwise, the implant may fail to osseointegrate.

Role of implant surfaces on implant stability

Any given implant geometry surfaces prepared with a microrough topography are considerably more osteoconductive compared with the original machined-surface implants[20,21] (see Fig 1-1). There are several reasons why these surfaces are such an improvement over the original machined surfaces. First, the modern implant surfaces with microrough surface topographies retain the fibrin blood clot more effectively than implants with machined surfaces.[22] As a result, the initial critical events (ie, plasma protein adsorption, clot formation, angiogenesis, local stem cell and repair cell migration and attachment, cell differentiation) associated with osseointegration are facilitated.

In addition, local stem cells differentiate more rapidly into functioning osteoblasts following attachment to the microrough surfaces as compared with machined surfaces. These surfaces also upregulate and accelerate the expression of genes of the differentiating osteoblasts associated with the osseointegration process.[23] This leads to a different combination of collagenous and noncollagenous proteins making up the bone deposited on the microrough surfaces as compared with the bone deposited on machined-surface topographies. As a result, bone that matures on implant surfaces with microrough surface topography is harder and stiffer than bone deposited on machined surfaces.[24,25]

An active and efficient remodeling apparatus is key to maintaining osseointegration during functional loading of the implants.[26] Osseointegration of the implant with bone continues to occur up to 1 year following delivery of either a provisional or definitive prosthesis.[27] Following initial healing and functional loading within physiologic limits, progressive osteogenesis continues to where the bone-implant contact area approaches almost 90% in favorable sites (Fig 1-6).

The Implant–Soft Tissue Interface

The peri-implant mucosa is similar to the mucosa circumscribing natural teeth. It is composed of nonkeratinizing epithelium in the sulcus, junctional epithelium, and a supracrestal zone of connective tissue. The connective tissue layer contains a dense zone of circumferential collagen fibers intermingled

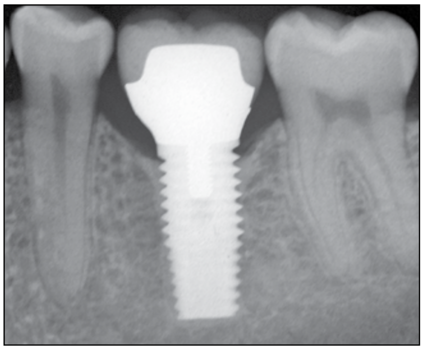

Fig 1-6 Following initial healing and when loading forces are favorable, the bone contact area on the surface of the implant continues to increase. Note the bone density of the peri-implant bone 7 years following delivery.

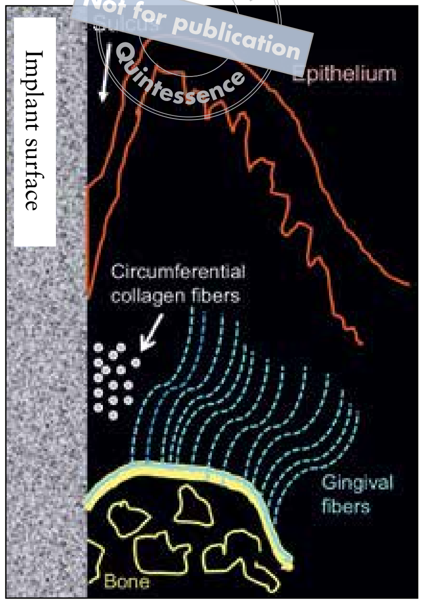

Fig 1-7 Soft tissue–implant interface.

Fig 1-8 Peri-implantitis triggered by excess cement beneath the peri-implant soft tissues. The bone loss has compromised the periodontal support of the adjacent teeth. (Reprinted from Moy et al[3] with permission.)

with fibers extending outward from the alveolar crest. These fibers run parallel to the long axis of the implant. The zone of connective tissue adjacent to the implant is relatively avascular and acelluar and similar to scar tissue histologically. The soft tissue barrier (interface) assumes a minimal dimension during the healing process. If this dimension is less than 2 to 3 mm, bone resorption occurs in order to establish an appropriate biologic dimension of the peri-implant soft tissue barrier.[28]

The titanium–soft tissue interface appears to be similar to but not exactly the same as that seen between gingiva and natural dentition (Fig 1-7). The epithelial-implant interface is based on the hemidesmosome basal lamina system, similar to that seen between gingiva and teeth. When implants emerge through attached keratinized mucosa, collagen fibers circumferentially configured around the neck of the implant are interwoven with collagen fibers running from the crest of the alveolus and the periosteum to the free gingiva and hold the epithelium in close proximity to the surface of the implant. The epithelial cells in the sulcus epithelium secrete a sticky substance (a protein network of glycoproteins) onto the surface of the implants, enabling the epithelial cells to adhere to the implant surface via hemidesmosomes. The epithelial cuffs that form as a result of the basal lamina hemidesmosomal system and the zone of connective tissue just apical to it effectively seal the bone from oral bacteria.[29] However, what differentiates the soft tissues around implants from the gingival tissues around natural teeth is the absence of gingival fibers inserting into a cementumlike tissue. Hence, the soft tissues around implants are more easily detached from the surfaces of the implant than are the soft tissues surrounding natural teeth. This difference is clinically significant for a number of reasons, including the manner in which these tissues respond to the oral microflora,[29] and especially when cement systems are used for retention of implant prostheses because of the risk of embedding cement subgingivally during cementation of the prosthesis[30] thereby increasing the risk of peri-implantitis[31] (Fig 1-8).

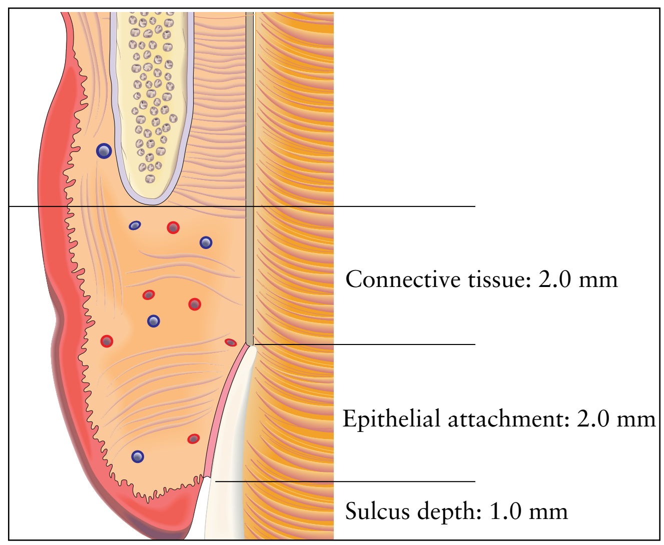

Fig 1-9 *Biologic width* is defined as the combined length of the supracrestal connective tissue and the zone of junctional epithelium associated with the epithelial attachment. (Redrawn from Spear[32] with permission.)

The phenomenon of biologic width applies not only to the natural dentition but also to the soft tissues around implants. *Biologic width* is defined as the combined length of the supracrestal connective tissue and the zone of junctional epithelium associated with the epithelial attachment[32] (Fig 1-9). This dimension averages approximately 3 mm around implants[28] and is slightly greater than that associated with the natural dentition. In general, the width of the epithelial component is

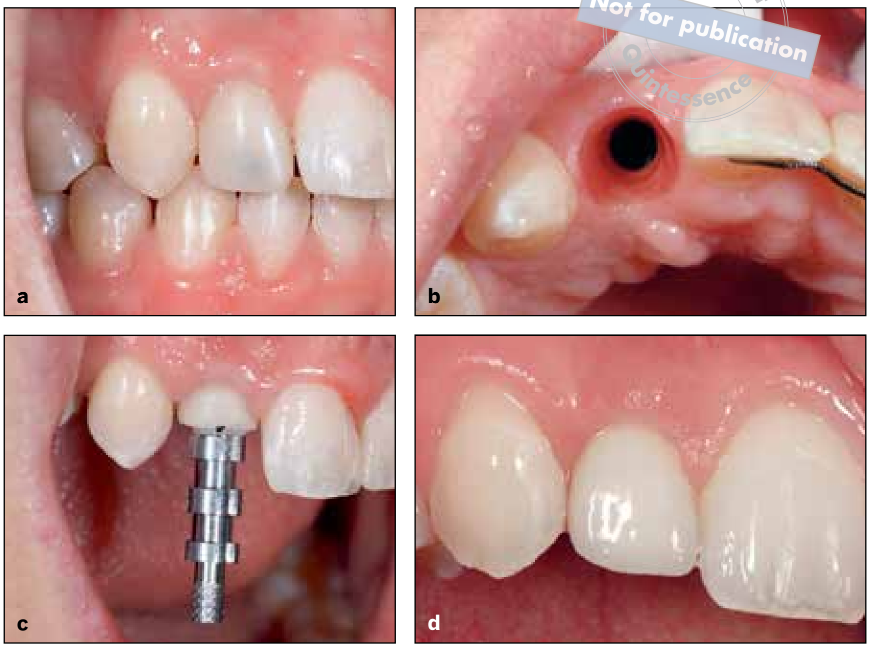

Fig 1-10 *(a and b)* A provisional implant crown was fabricated and altered as necessary to refine the peri-implant soft tissue contours. *(c)* A customized impression coping was used to make the definitive impression. *(d)* The definitive restoration.

greater and demonstrates more variability than the width of the connective tissue zone. This phenomenon has particular impact in the esthetic zone because, as with the natural dentition, the level and contours of the underlying bone primarily determine the contours and level of the overlying soft tissues. The zonal epithelium can be located on either the implant fixture or the abutment, depending whether the implant platform is supracrestal, crestal, or subcrestal. The dimension of the biologic width in relation to the nature and topography of the implant surface has been the subject of much debate in recent years. However, there is no clear consensus on whether differences in biologic width exist with respect to the varieties of surface topographies and surface treatments currently in use.[33] Also, the evidence appears to indicate that there are no significant differences in biologic width achieved between one-stage and two-stage surgical procedures.

However, it appears that the nature of the microgap between the abutment and the implant and its position in relation to the bone crest increases the biologic width. The deeper the implant-abutment connection in relation to the gingival crest, the greater the biologic width will be, particularly the epithelial component. It is unclear whether multiple abutment manipulations induce an apical migration of the connective tissue–epithelial attachment zone, resulting in marginal bone loss.[34,35] The lack of stability of the abutment-implant connection may also trigger an apical migration of the connective tissue–epithelial attachment zone accompanied by marginal bone loss around the neck of the implant, presumably as a result of increased levels of bacterial colonization. The long-term clinical consequences of these findings with respect to implant survival have yet to be determined.

In the esthetic zone, techniques have evolved that idealize the soft tissue contours around the implant prostheses. Provisional restorations are designed to support the soft tissues and develop ideal contours, and these contours can be recorded using customized impression techniques (Fig 1-10). In addition, surgical procedures have been developed that can be used to enhance bone and soft tissue contours.

Recent Innovations, Clinical Trends, and Impact

Several innovations have been introduced into clinical practice in recent years. The number of patients now considered suitable candidates for implant treatment has expanded dramatically because of the bioreactivity of modern implant surfaces and of our ability to enhance the bone and soft tissues of the potential implant sites. In addition, improved site evaluation with CBCT scans and the accompanying software, tilted implants, guided implant surgery, improved prosthodontic designs, the introduction of new materials, and a better understanding of the limitations of the prosthodontic materials previously used in conventional dentistry when used for implant prostheses have improved implant success rates and prosthesis predictability.

Impact of 3D imaging and CAD/CAM on diagnosis, treatment planning, surgical planning, surgical placement, and prosthesis fabrication

Initially, the workup of potential implant patients was surgically driven; that is, the suitability of a patient was determined primarily by the 3D volume and quality of the bone sites.

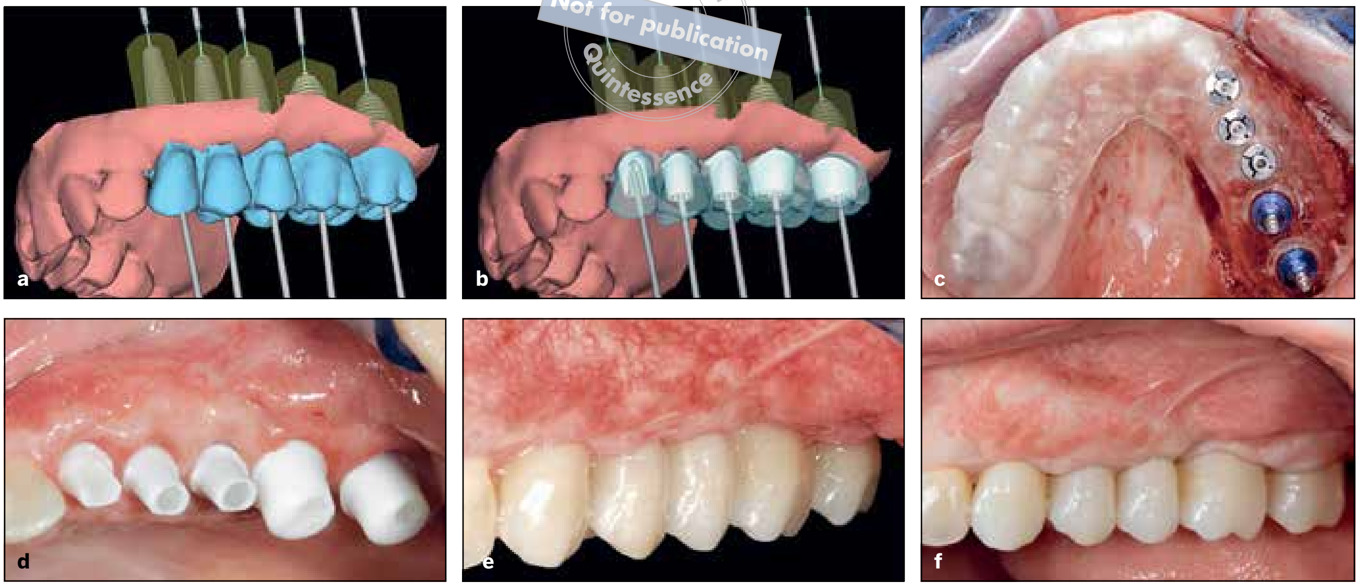

Fig 1-11 A computer-guided approach enables the implant team to *(a)* design a provisional prosthesis and determine the positions of the implants, *(b)* design and manufacture abutments and fabricate a provisional prosthesis, and *(c)* fabricate the surgical template prior to implant surgery. *(d)* The customized abutments. *(e)* The provisional prosthesis. *(f)* The definitive prosthesis. (Courtesy of Dr A. Pozzi.)

Fig 1-12 A variety of implant shapes, thread patterns, and implant platforms are available.

Today, the development and the improving sophistication of CBCT scans and CAD/CAM programs permits the workup to be driven by the needs of the prosthetic design. With these tools, clinicians are able to identify vital structures such as the inferior alveolar nerve, determine the 3D nature of the potential implant bone sites, predetermine implant position and angulation with great precision, and fabricate surgical stents and surgical drill guides that allow placement of implants into their intended positions via semiguided or fully guided surgery (Fig 1-11). In addition, CAD/CAM systems allow for the design and manufacture of customized implant connecting bars, custom abutments, provisional restorations, and now, definitive restorations with great precision (see Fig 1-11). All those who practice implant dentistry should become intimately familiar with these technologies.

Impact of changes in the design of the implant body and the implant platform (ie, interface between abutment and implant fixture)

Several new implant designs have been introduced, and the impact of these designs will be addressed in this new edition. For example, recently there has been increased use of self-tapping implant designs (Fig 1-12). These are used primarily in poor-quality bone sites (poor density), such as the posterior maxilla. Another innovation is the development of tapered implants designed specifically for immediate loading. With these two design changes, during insertion of the implant, the trabecular bone of the implant site is compressed around the implant, leading to improving primary stability of the implant. As a result, in select patients the improved initial anchorage allows for immediate loading or immediate provisionalization.

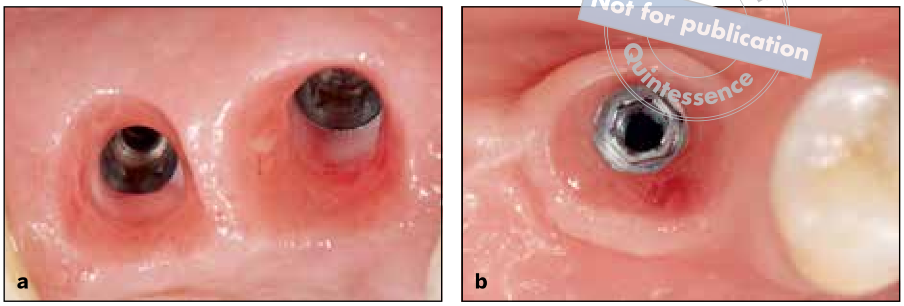

Fig 1-13 Implant platform designs. *(a)* Internal interlocking system. *(b)* External hex system.

Fig 1-14 Platform reduction. The diameter of the abutment as it emerges from the implant is less than the diameter of the neck of the implant.

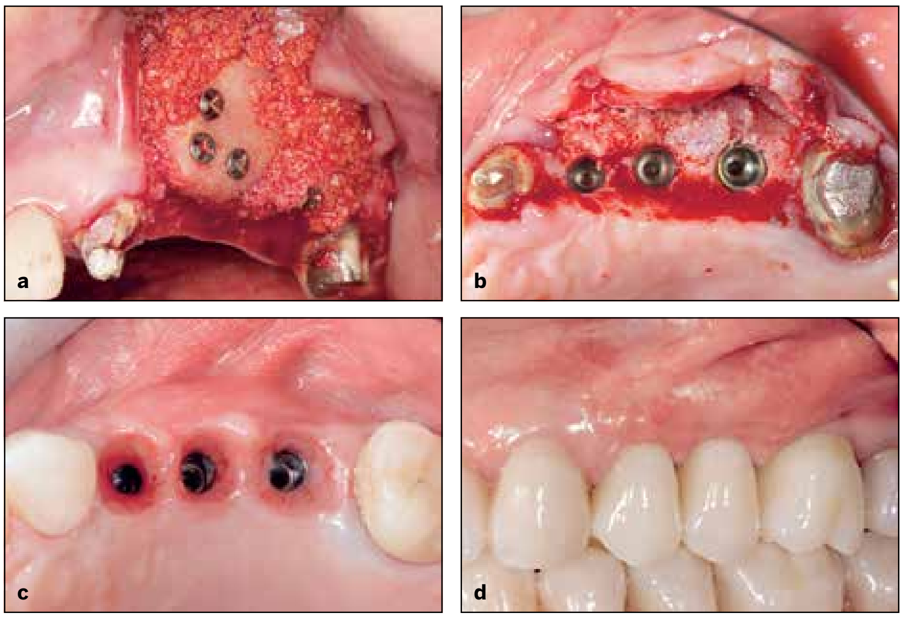

Fig 1-15 *(a)* Grafting defects lacking width has been predictable, and a number of different techniques have evolved (see Moy et al[3]). *(b and c)* The zone of attached keratinized mucosa around the implants can also be increased predictably. *(d)* Definitive prosthesis. (Courtesy of Dr A. Pozzi.)

Manufacturers continue to introduce new implant platform designs. However, the clinical impact of these design changes is rarely addressed. As a result, restorative dentists must increase their inventories of prosthetic components. A good example is the continuing debate regarding the use of external hex versus internal locking systems (Fig 1-13). The nature of the implant-abutment connection may be clinically significant when restoring single-tooth defects but probably not when restoring multiple-tooth defects. Single implants, especially in the posterior regions, are subjected to significant occlusal forces. The lateral component of these forces may be sufficient to widen the microgaps between the abutment and the implant during function in the external hex designs. Some have speculated that this may be detrimental to the long-term survivability of the implant and the restoration. However, clinical reports do not support this hypothesis.[36,37] These issues are probably not clinically significant when multiple implants are splinted together when restoring posterior quadrants or fabricating full-arch restorations where multiple implants are splinted together across the arch.[36]

Likewise, the impact of platform reduction is still far from settled. Some authors have hypothesized[38] that using designs where the diameter of the abutment is less than that of the head of the implant fixture horizontalizes the epithelial attachment[39] and may also redirect the stresses away from the crestal bone–implant interface,[40] and as a result of these phenomena, such designs will reduce the rate of crestal bone loss (Fig 1-14). The clinical evidence for this claim is not convincing,[41] and randomized clinical trials have failed to demonstrate a benefit of platform reduction with respect to maintenance of crestal bone levels.[42]

Impact of surgical innovations

Widening the alveolar ridge with bone grafts has become very predictable, and several new techniques have been introduced (Fig 1-15). The need to maximize the zone of keratinized tissue and retain or restore the interdental papilla has led to the development of many new grafting techniques and flap

Fig 1-16 Fully guided implant surgery enables flapless surgery in select patients with ample bone and keratinized attached tissue volume. *(a)* The tooth-borne fully guided surgical template in position. *(b)* A circular patch of tissue was removed from the implant site with a tissue punch before the osteotomy site was prepared. *(c)* The osteotomy site is prepared. *(d)* The implant is inserted. *(e)* A healing abutment has been secured to the implant.

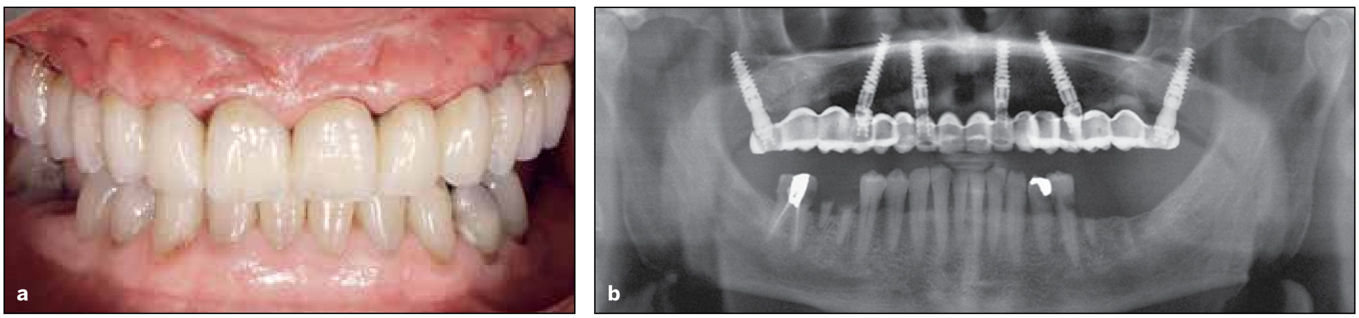

Fig 1-17 *(a and b)* Tilted implants have been placed to support this immediate load prosthesis. (Courtesy of Dr A. Pozzi.)

designs (see Figs 1-15b and 1-15c), particularly in the esthetic zone.[43] Furthermore, a one-stage technique can be used in select patients, as opposed to burying the implants beneath the mucosa during the healing period. Recent reports have also suggested that fully guided, flapless implant placement in select patients reduces the incidence of surgery-related bacteremia and may be beneficial for patients with medical risk factors that require prophylactic antibiotic coverage[44] (Fig 1-16). Many of these techniques are highlighted throughout the book, including in a newly added chapter 19 that discusses basic surgical techniques.

Implant manufacturers are increasingly introducing shorter and narrower-diameter implants with the promise of reducing the need for bone grafting. Despite short-term data, there is a lack of clinical evidence that these implants will enjoy the same long-term success as traditional-sized implants in properly grafted sites.

Impact of tilted implants

The use of tilted implants has emerged as a viable alternative to sinus augmentation,[45–48] especially in edentulous patients (Fig 1-17). This improves the biomechanical configuration in edentulous patients (see chapters 7 and 8) and recently has also been employed to restore extended edentulous areas in the posterior maxilla of partially edentulous patients (Fig 1-18). When this concept was first introduced, the anterior wall of the maxillary sinus was exposed in order to precisely postion and angle the implant. However, with the recent improvement in the precision of fully guided implant surgery, the use of tilted implants has become a less invasive and more attractive alternative. Tilted implants can also be used for immediate loading when cross-arch stabilization is possible. The use of this design concept will be discussed in several chapters.

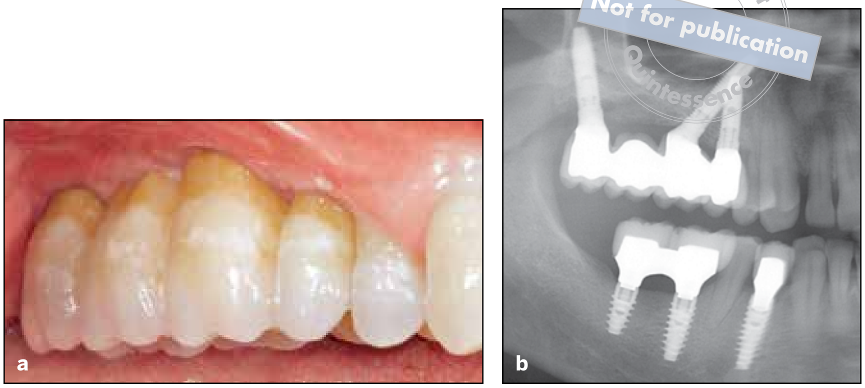

Fig 1-18 *(a and b)* Tilted implants have been used to restore an extended edentulous area in the posterior maxilla. (Courtesy of Dr A. Pozzi.)

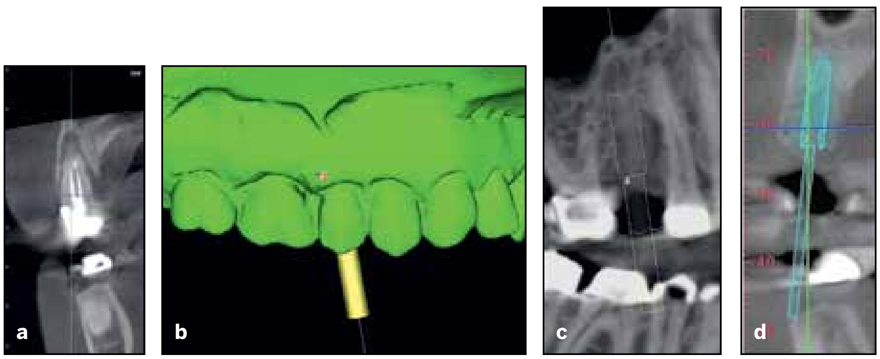

Fig 1-19 *(a)* The maxillary second premolar is to be extracted due to an endodontic failure. *(b to d)* CBCT scans are obtained, and the position, angulation, and size of the implant are selected. →

Impact of Loading Protocols

The original treatment protocols for using machined-surface implants required several months' delay after implant placement before the prosthesis could be delivered and placed into function. Most patients were required to use removable prostheses during this period. During the last several years, various immediate and early loading protocols have been proposed as implant macro shapes and implant surface textures have evolved (see Fig 1-17). Recent advances in CAD/CAM technologies have provided an additional stimulus to this trend. In this new edition, we offer guidelines regarding the various loading protocols currently in use, namely immediate loading, immediate provisionalization, early loading, and delayed (conventional) loading. The reader should understand that the immediate load prosthesis is a complex, technically demanding treatment and should be attempted only after the implant team has acquired the necessary experience. Mistakes in clinical judgment and execution can lead to a higher incidence of implant failure and loss of the prosthesis.

Impact of new prosthodontic materials

Several new materials and combinations of materials have been introduced to meet the unique demands placed upon implant-supported prostheses. Unfortunately, many materials used for tooth-supported prostheses have proven to be unsuitable for implant-supported prostheses. For example, the crazing and fracture of the resin-bonded systems used to restore extended edentulous areas with implant-supported fixed dental prostheses in the posterior quadrants was quite disappointing. In this edition, we have added an additional chapter (chapter 4) devoted to materials and, where possible, we provide the reader with evidence-based guidelines regarding selection of the appropriate materials for any given application.

Impact of digital technologies upon the role of the restorative dentist

As mentioned previously, digital technologies have had a dramatic impact upon the means of implant site evaluation and implant surgery. These new technologies—CBCT scans and the associated software for guided surgery, navigation systems, and 3D jaw movement recording and analysis systems (electronic pantograph)—allow prosthodontists and restorative dentists to virtually analyze the 3D characteristics of the potential implant bone site and design and fabricate accurate surgical drill guides (Fig 1-19). These new technologies also help prosthodontists and restorative dentists to better determine which patients are best served by referral to a periodontist or oral surgeon for implant placement as opposed to placing the implants themselves.

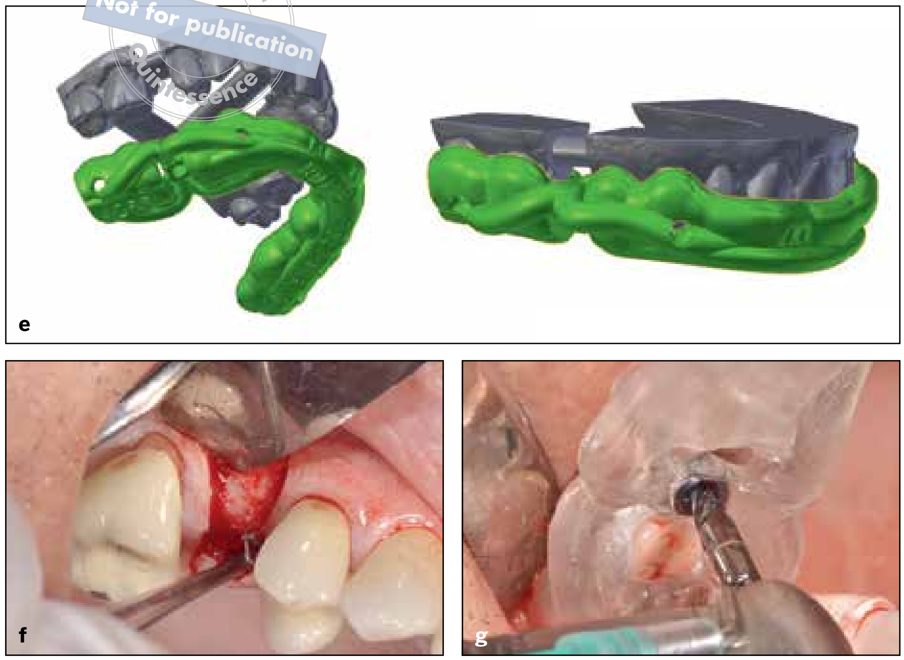

Fig 1-19 ***(cont)*** *(e)* The appropriate software permits the design and fabrication of a surgical template. *(f)* A flap is reflected. *(g)* The surgical drill guide is positioned, and the osteotomy site is prepared.

Fig 1-20 Three implants were used to restore the posterior teeth. A 20-year follow-up photograph. Note the significant mesial migration of the anterior teeth, resulting in a large space between the canine and the implant-supported fixed dental prosthesis *(black arrow)*. Note also the apical migration of bone and soft tissue around the two posterior implants *(white arrows)*.

Follow-up data analysis

In recent years, clinical study design has improved, and as a result, clinical decisions have become increasingly evidence based. However, still far too many studies rely on short follow-up times when assessing outcomes. Many current studies report data with only 1 or 2 years of follow-up data, which in most instances is quite insufficient. Even the traditional 5-year follow-up period may not enable clinicians to make truly evidence-based choices, especially when attempting to determine whether bone and soft tissue levels ever become stable. Even when implant treatment is executed properly and under ideal conditions, phenomena such as mesial migration and continued eruption of adjacent natural dentition and apical migration of bone and peri-implant soft tissues may render the outcome suboptimal. These phenomena are rarely recognized at 5-year follow-up and therefore have been largely ignored in the implant literature and by those presenting continuing education programs of instruction. However, these phenomena are often seen after 5 or more years of follow-up (Figs 1-20 and 1-21), and given their frequency, patients must be informed that it is likely that their implant-retained restoration may need to be remade at some future date. In addition, it is the clinician's responsibility to be aware of and plan for these eventualities and design prostheses that will mitigate their effects.

Fig 1-21 *(a)* Delivery; *(b)* 6-year follow-up; *(c)* 20-year follow-up. Note the continuous apical migration of bone and soft tissues around these implant-retained fixed dental prostheses. Also, note the progressive eruption and mesial migration of the adjacent natural dentition, and the numerous instances of chipping and fracture of the laminated porcelain. (Courtesy of Dr A. Davodi.)

Summary

Osseointegrated implants are highly predictable when used appropriately, and in many situations, implant treatment is as predictable or even more predictable than any of the conventional restorative procedures used to restore missing dentition. The key to predictable outcomes when implants are employed is accurate diagnosis and appropriate treatment planning, taking into account significant patient history findings such as parafunctional activities as well as implant biomechanics and the occlusal schemes to minimize undesirable occlusal forces. Successful outcomes are best accomplished in a multidisciplinary setting. The purpose of these volumes is to share with clinicians the approach to patient evaluation and treatment that has enabled the authors to provide these services with a very high degree of success. Indeed, when implant therapy is planned and executed properly, taking into account the basic principles of prosthodontics, it is the authors' expectation that once the implants are osseointegrated, while the prostheses that are retained by the implants may need to be replaced due to wear or breakage, the implants should last the lifetime of the patient. Recent innovations, including tilted implants, new and improved CAD/CAM systems, advances in implant body design, surgical enhancement of bone and soft tissues associated with the implant sites, and refinement of loading protocols, have improved implant and prosthesis success.

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