Implantology

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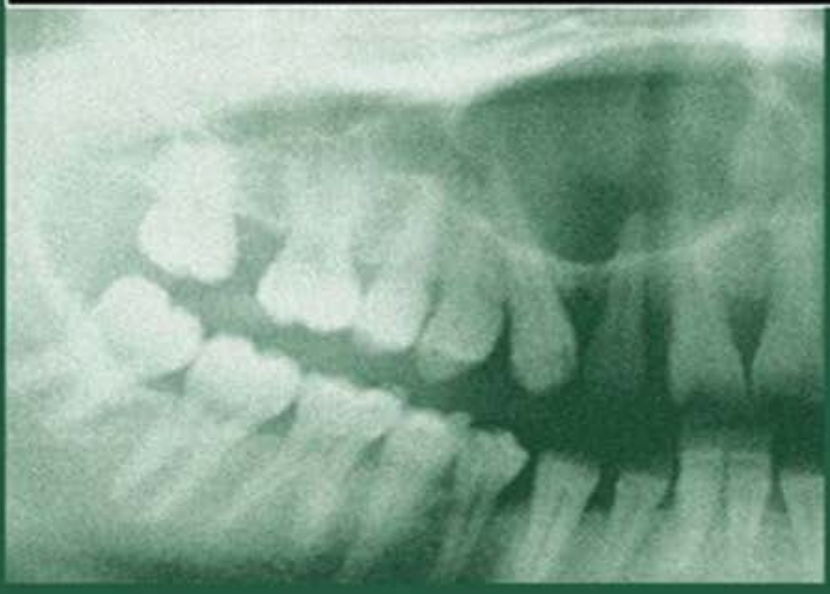

Guest Editor

Mark V. Thomas

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Preface

Implantology

Mark V. Thomas, DMD
Guest Editor

The pioneering work of Brånemark ushered in a new era in dentistry—the era of implant dentistry. Brånemark and his colleagues created a new field of study from a serendipitous research observation, thus exemplifying Pasteur's dictum that ''chance favors the prepared mind.'' Through further research, these investigators transformed the field of implantology from an unpredictable art to a well-grounded clinical science. This research provided the scientific basis for a set of strict clinical protocols. Although some of the early protocols proved to be overly conservative, such as the requirement that all implant surgery be performed in an operating room environment, the growth of implantology was well served by this emphasis on predictability and outcomes.

From those early beginnings, much has changed in implantology. As new knowledge has accumulated, old paradigms have been revised or replaced with new ones. What began as a hyper-specialized treatment modality has now become a commonplace method of tooth replacement. Some of these new paradigms are summarized in this volume. Drs. Puleo and Thomas discuss the impact of implant surfaces and the role of surface enhancements in improving outcomes and shortening treatment time. Drs. Jones and Cochran revisit the literature regarding one- versus two-stage implants. Drs. Paquette, Brodala, and Williams review risk factors for implant failure, a topic that is likely to be of increasing importance. Dr. Jay Beagle discusses immediate implant placement, while Dr. Mohanad Al-Sabbagh examines the placement of implants in the esthetic zone, another topic of increasing importance. Drs. Tiwana, Kushner, and Haug discuss sinus augmentation

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surgery and make suggestions for improved outcomes, while Drs. Thomas, Daniel, and Kluemper review applications of the palatal orthodontic implant. Drs. Haubenreich and Robinson review simplified posterior implant impression techniques, while Ms. Humphrey examines the literature regarding implant maintenance (a topic neglected in the early implant literature). Most of these topics clearly fall outside of the original Brånemark protocols. At that time, the concept of immediate placement, roughened titanium surfaces, or orthodontic implant anchorage would have been outside of the mainstream. But times have changed and the discipline has evolved.

Implantology has, indeed, matured. Many clinicians initially were skeptical of Brånemark's work, because many earlier implants were neither well researched nor predictable. As a result of this early skepticism, implantology has been preoccupied with outcomes research and survival analysis. Indeed, dental implantology has made greater use of such methodology than most other areas of dentistry, with the result that it is often difficult to make evidence-based treatment decisions involving implants versus traditional dental treatment.

All too often, the clinician finds that the predictability of the implant may be, to a greater or lesser extent, quantifiable, but similar data for the so-called "traditional" therapies is lacking. This must change as dentistry enters the new millennium. The profession desperately needs better outcomes research that can guide clinical decision-making. In this issue, the article by Drs. Thomas and Beagle compares implant outcomes with some conventional dental treatments, such as endodontic therapy and conventional mandibular dentures. The authors suggest some clinical decision-making guidelines. However, these issues are far from resolved. All disciplines in dentistry must scrutinize their procedures and find out what works well and how well it works. Such outcomes research often is difficult and time consuming to execute. But the work must be done if we are to serve our patients well.

Last, dental education must ensure that graduates are well versed in the responsible use of implants in routine dental care. At the University of Kentucky College of Dentistry, a comprehensive predoctoral implant program was begun in the late 1990s. The program was spearheaded by then-Dean Leon Assael. The result is a program in which all dental students are required to restore several implants in the setting of the predoctoral clinic.

This emphasis on performing the restorative phase in the predoctoral clinic is intentional and serves to underscore the fact that dental implantology is no longer a "black-box" quasi-specialty that must be learned in a special implant clinic and performed on special implant patients. Rather, the intent is to dispel the aura of mystery that formerly surrounded implant restorations by making implant treatment a banal, routine component of the clinical experience. The program has been very successful in terms of outcomes and student satisfaction. Part of this success is the result of strict adherence to evidence-based treatment protocols, use of a single implant

system, and careful case-selection criteria. This sort of mainstream experience is the type of implant education that all dental students should be receiving.

This preface opened with a reference to one medical pioneer and shall end with reference to another, Sir William Osler, who admonished his colleagues that "to study the phenomenon of disease without books is to sail an uncharted sea, while to study books without patients is not to go to sea at all." It is hoped that this volume will provide some navigational aid for the dentist who must daily navigate the clinical sea, while suggesting some areas for future research. I pray that those engaged in clinical teaching are like Osler, in that they often take up the heavy yoke of personal responsibility that comes with caring for patients.

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Implant Surfaces

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The use of implants in the oral and maxillofacial skeleton continues to expand. In the United States alone, an estimated 300,000 dental implants are placed each year [1]. Implants are used to replace missing teeth, rebuild the craniofacial skeleton, provide anchorage during orthodontic treatments, and even to help form new bone in the process of distraction osteogenesis.

Although oral implants have improved the lives of millions of patients, fundamental information relating implant characteristics and clinical performance is often lacking. More than 220 implant brands, produced by 80 different manufacturers, have been identified [2]. Considering the variety of materials, surface treatments, shapes, lengths, and widths available, clinicians can choose from more than 2000 implants during treatment planning. This wide range of options is good. However, it complicates the clinician's task of selecting the correct device based on sound evidence. In many instances, new companies have entered the dental implant market using a "copycat" strategy of simply mimicking or making minor, incremental changes to a competitor's products. By seeking only 510(k) approval in the United States or CE marking in Europe, a company can easily demonstrate "substantial equivalence," often without extensive preclinical and clinical testing. Even without documentation of significantly better performance of new implants, existing systems may be abandoned in favor of devices that have not been thoroughly tested. As stated by Jokstad and colleagues [2], "A substantial number of claims made by different manufacturers on alleged superiority due to design characteristics are not based on sound and long-term clinical scientific research." Although many longitudinal studies of

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implant survival have been published, only a few have employed formal statistical methodology, and those few have not compared implant surfaces [3,4]. Thus, there is little rigorous evidence to guide the clinician in selecting the optimal surface for a given situation.

With so many variables affecting oral implants, it is sometimes difficult to reliably predict the chances for an implant's success. In light of the continuing development of new dental implants, this article focuses primarily on important surface characteristics and their potential effects on the performance of dental implants.

The tissue–implant interface

A goal of implantology research is to design devices that induce controlled, guided, and rapid integration into surrounding tissues. Events leading to integration of an implant, and ultimately to success or failure of the device, take place largely at the tissue–implant interface. Development of this interface is complex and involves numerous factors. These include not only implant-related factors, such as material, shape, topography, and surface chemistry, but also mechanical loading, surgical technique, and patient variables, such as bone quantity and quality. In contrast to orthopedic prostheses, which are designed to interact with only bone, dental implants also must interact with epithelium and submucosal soft connective tissue. Certain basic events, however, are common to all tissue–biomaterial interactions.

Following implantation, events take place both on the biological side and on the materials side. According to the "interface scenario" of Kasemo and Lausmaa [5], primary molecular events lead to secondary events that ultimately result in particular cell and tissue responses. On the implant side, studies indicate that electrochemical events take place on the surface of the implant and cause the oxide to double or triple in thickness [6–8]. The electrochemical reactions also lead to the incorporation of biological ions, such as calcium, phosphorus, and sulfur ions [6,7]. During these events, metal ions are released [9]. Reports about metal released from dental implants are sparse compared with reports related to orthopedic devices. The orthopedic literature indicates significantly elevated metal content both in periprosthetic tissues [10,11] and in serum and urine [12–14]. In one report, analysis of tissues around dental implants showed titanium at levels up to tens of ppm immediately adjacent to devices, but background levels were found within 0.4 mm [15]. Long-term effects of the metal remain unknown. Even though trace metals are essential for health, they can be toxic [16] or cause hypersensitivity reactions [17].

On the biological side, water molecules and hydrated ions associate with the implant surface within nanoseconds [18]. The presence of the substrate locally alters the organization of water molecules, and this may subsequently affect adsorption of biomolecules, which occurs within milliseconds. Hundreds

of biomolecules are available in body fluids to interact with the surface. A complex, time-dependent cascade of events involving adsorption, displacement, and exchange then takes place, during which smaller, lower-affinity molecules can be replaced with larger species having greater affinity for the biomaterial. Interaction with the surface may also alter the orientation and conformation of the biomolecules [19]. A further level of complexity is added in that inhomogeneities in "real" implant surfaces will likely result in a distribution of biomolecules and their properties on the surface. With time, cells encounter an implant surface that has been preconditioned with a variety of biomolecules. Cells do not interact with a "bare" biomaterial surface.

As mentioned, the success of dental implants depends on the interaction with both soft and hard tissues. Formation of a peri-implant soft tissue barrier is important for protecting the bone-implant interface from microbiological challenge. Lack of a perimucosal seal also can lead to apical migration of epithelium and possibly to encapsulation of the root of the implant. Successful implants exhibit a peri-implant mucosa that forms a cuff-like barrier and adheres to the implant [20,21]. Between the epithelium and bone is a collagenous connective tissue. The fibers of this tissue are aligned parallel to the implant surface. This interaction between the implant and soft tissue is analogous to the epithelial and supra-alveolar connective tissue attachment that exists between the tooth and the periodontal tissues. Hermann and colleagues have determined that the total dimension of the sulcus depth, epithelial attachment, and connective tissue dimension remains stable over time, although the individual components may change slightly [22].

Apically, the successful implant will be surrounded by bone. Bone can be formed on the adjacent bone surfaces in a phenomenon called distance osteogenesis, or on the implant surface itself in a phenomenon called contact osteogenesis [23,24]. In the case of distance osteogenesis, osteogenesis occurs from the bone toward the implant as the bone surfaces provide a population of osteogenic cells that deposit a new matrix that approaches the implant. In the case of contact osteogenesis, osteogenesis occurs in a direction away from the implant as osteogenic cells are recruited to the implant surface and begin secreting bone matrix. While both these processes are likely to occur with implants, their relative significance may depend on the specific type of implant and its surface characteristics.

Osseointegration versus osseocoalescence

The term *osseointegration* is commonly used in conjunction with dental implants. Unfortunately, investigators frequently use the term differently. The term stems from Brånemark's work with titanium bone chambers for intravital microscopy in the 1950s [25]. Observations of good interaction between bone and metal led to the crafting of dental implants using titanium. Osseointegration was originally defined as a relationship where "bone is in direct contact with the implant, without any intermediate

connective tissue'' [26]. A revised definition describes the interaction as a ''direct structural and functional connection between ordered living bone and the surface of a load-carrying implant'' [27]. In effect, osseointegration means that there is no relative movement between the implant and the surrounding bone.

Although some investigators believe there is chemical interaction between bone and the surface of titanium implants, osseointegration largely refers to the physical integration or mechanical fixation of an implant in bone. By having bone intimately apposed to the surface, whether macroscopically at the level of screw threads or microscopically at the level of machine marks and surface defects, the interlocking provides mechanical resistance to mechanical forces, such as shear experienced in ''pull-out'' and ''torque-out'' testing (Fig. 1). With purely physical interaction, however, the interface would not be able to withstand even moderate tensile forces (see Fig. 1).

The term *osseocoalescence* has been proposed to refer specifically to chemical integration of implants in bone tissue [28]. The term applies to surface reactive materials, such as calcium phosphates and bioactive glasses, which undergo reactions that lead to chemical bonding between bone and biomaterial. With these materials, the tissues effectively coalesce with the implant. An example of qualitative evidence for chemical bonding is when fracture lines propagate through either the implant or the tissue but not along the interface. With respect to Fig. 1, osseocoalesced implants would exhibit resistance to both shear and tensile loads. Unfortunately, the term has not found widespread use, and osseointegration still is often used when describing interactions between bioactive materials and bone.

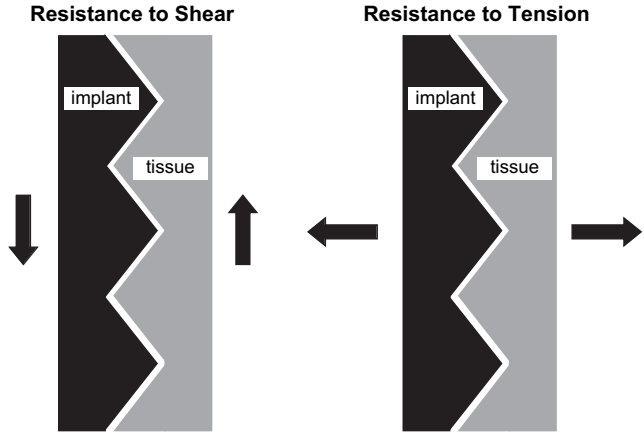

Fig. 1. Mechanical integration (ie, osseointegration) of an implant in bone provides good resistance to shear forces but poor resistance to tension. Chemical integration (ie, osseocoalescence) provides good resistance to both shear and tensile forces. Arrows indicate direction of force. (*From* Kasemo B, Gold J. Implant surfaces and interface processes. Adv Dent Res 1999; 13:11; with permission.)

Important surface characteristics

Two categories of surface characteristics commonly are cited as being important for determining tissue responses. One category includes the topographic or morphological characteristics. The other category includes the chemical properties. As will be discussed, independent study of topographic and chemical properties is confounded because methods used to alter surface morphology frequently lead to changes in surface chemistry. Some investigators include surface mechanical properties as being important. This differs from interfacial mechanics, which are known to affect integration of dental implants. For example, the adverse effect of excessive micromotion is understood [29]. However, the role of mechanical properties of the implant's surface is largely unknown. Poor wear resistance may generate particulate debris and high residual stresses may cause metal ion release. Both can affect cell and tissue behavior.

In the search for methods for altering surface characteristics to improve implant performance, much attention has been focused on changes in surface roughness and chemistry. Such changes can, for example, improve interaction with hard and soft tissues and strengthen characteristics for bearing loads. As indicated, mechanical interaction between bone and surfaces with texture can lead to osseointegration, and chemical interactions can lead to osseocoalescence. Macroscopic mechanical interlocking can provide initial fixation of the implant, allowing time for surface reactions that lead to chemical bonding.

Surface topography

Simply describing surfaces as "rough" or "smooth" is not sufficient. Quantitative evaluation is important for comparing surfaces prepared using different methods. As reviewed by Wennerberg and Albrektsson [30], several methods are available for measuring surface roughness, and more than 150 parameters can be calculated to characterize surface topography. The parameters may reflect vertical height of surface features, horizontal space between features, or a combination of height and spatial information (ie, hybrid parameters). Many reports provide only one quantitative parameter [30]. The most commonly reported parameter is R_a, the arithmetic mean of deviations in the roughness profile from the mean line. Other parameters that can be found with some frequency are R_q, which is the root mean square average, and R_{max} (or R_y), which is the maximum peak-to-valley height encountered during a scan. Three-dimensional parameters can also be calculated. For example, S_a represents the arithmetic mean of deviations in roughness from the mean plane of analysis. The three-dimensional nature of implants yields another difficulty in evaluating topography; many profilometric techniques were developed for planar surfaces, but not for threaded dental implants. Wennerberg and Albrektsson recommend evaluation at the

tops, valleys, and flanks of threads [30]. Reporting only one parameter following examination of only one region of an implant is unlikely to adequately characterize the device.

The scale of surface features also should be considered. The common, threaded root-form implant serves as a good example. The thread pitch may be on the order of 1000 μm, and the thread depth on the order of 300 μm. Cells, however, are 1 to 100 μm, and proteins are around 0.001 to 0.01 μm. These differences in scale are illustrated in Fig. 2. Because relevant surface features span six orders of magnitude in size, from the macro-, to micro-, to nano-scales, comprehensive assessment of the topography requires different methods, ranging from optical light microscopy to scanning probe techniques. The literature contains abundant evidence for the effects of macro- and micro-scale surface features on cells and tissues [31–33]. For example, microtopography causes osteoblastic cells to secrete factors that enhance differentiation and alters their responses to osteogenic factors, while decreasing osteoclast formation and activity [34,35]. Even though in vitro studies show that nanomaterials can affect cell responses [36,37], the influence of nanostructured materials on tissue behavior in vivo remains unknown.

Terms such as *contact guidance* and *rugophilia* have been used to describe the interaction of cells and tissues with textured surfaces. The former refers to the directional guidance provided by a substrate [31]. This phenomenon has been extensively studied in cell cultures by exposing cells to microfabricated substrata having grooves of various dimensions, but it also has practical, clinical implications. The best example is placement of circumferential grooves on a dental implant to prevent epithelial downgrowth. *Rugophilia* literally means "rough-loving." Whereas some types of cells will accumulate on smooth surfaces, others, such as macrophages, prefer roughened surfaces [38].

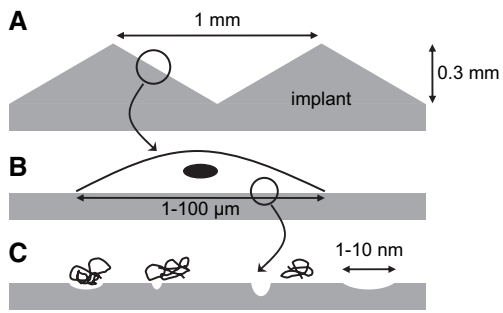

Fig. 2. Size and scale of surface features relevant to the tissue–implant interface. Screw threads (*A*) are on the macro-level; cells and surface topography (*B*) are on the micro-level; and proteins and surface defects (*C*) are on the nano-level. (*Adapted from* Kasemo B, Gold J. Implant surfaces and interface processes. Adv Dent Res 1999;13:11; with permission.)

Porous materials are examples of extreme surface roughness. Such materials have been used to allow growth of tissues into implants to enhance integration, particularly in orthopedics for total joint replacements. Early work with bioinert ceramics showed that pore sizes greater than 100 μm were needed for ingrowth of mineralized tissue [39]. Pores in the range of 40 to 100 μm allowed formation of osteoid, and only fibrous tissue was present in 5 to 15 μm pores. The importance of pores exceeding 100 μm was also shown for metallic implants [40]. More recent work with bioactive materials indicates that bone may grow into smaller pores and that the size and volume density of interconnections is important because of the need for blood circulation and extracellular liquid exchange [41]. Interconnections measuring 20 μm supported cell ingrowth and formation of chondroid tissue, but bone formed when interconnections were greater than 50 μm. A recent electron microscopic examination of implants retrieved from humans appears to show bone in small surface pores having diameters of around 2 μm [42]. These apparent discrepancies confirm the complex, multifactorial nature of tissue–implant interactions.

Surface chemistry

Commercially pure titanium (cpTi) and Ti-6Al-4V alloy are the most commonly used dental implant materials, although new alloys containing niobium, iron, molybdenum, manganese, and zirconium are being developed [43,44]. These materials dominate because of their combination of mechanical properties and biocompatibility. Biocompatibility is attributed to the stable oxide layer, primarily titanium dioxide (TiO_2), that spontaneously forms when titanium is exposed to oxygen. This reaction converts the base metal into a ceramic material that electrically and chemically passivates the implant. Manufacturers may also immerse implants in acidic solutions to enhance formation of the passivating oxide film. Depending on the method of preparation and sterilization, cpTi implants have an oxide thickness of 2 to 6 nm [45]. As described earlier, this biomaterial surface interacts with water, ions, and numerous biomolecules after implantation. The nature of these interactions, such as hydroxylation of the oxide surface by dissociative adsorption of water, formation of an electrical double layer, and protein adsorption and denaturation, determine how cells and tissue respond to the implant.

Surface energy, surface charge, and surface composition are among the physicochemical characteristics that can be manipulated to affect the interaction of implants with cells and tissues. Glow discharge treatment is a process in which materials are exposed to ionized inert gas, such as argon. During collisions with the substrate, high-energy species ''scrub'' contaminants from the surface, thereby unsaturating surface bonds and increasing surface energy. This higher surface energy will then influence adsorption of biomolecules, which in turn affects subsequent cell and tissue behavior. Some

speculate that high-energy surfaces increase tissue adhesion [46]. However improved interactions with bone have not been demonstrated [47,48].

Considering the role of electrostatic interactions in many biological events, charged surfaces have been proposed as being conducive to tissue integration. Conflicting findings have been reported, however, as both positively [49] and negatively [50] charged surfaces were found to facilitate bone formation. Calcium phosphate coatings have been extensively investigated because of their chemical similarity to bone mineral [51]. While their popularity has increased, their use has remained controversial. Concerns have arisen because of instances of such problems as dissolution and cracking of coatings as well as separation of coatings from metallic substrates, a phenomenon referred to as delamination [52,53].

Common implant systems

Implants with smooth surfaces (ie, $S_a < 0.2$ μm) are not used mainly because such implants show poor interaction with tissues, both soft and hard. Smooth, polished surfaces show poor mechanical integration with bone because, without surface irregularities, such surfaces provide no resistance to mechanical forces at the bone-implant interface (see Fig. 1). Furthermore, very smooth surfaces can allow epithelial downgrowth and are associated with deeper peri-implant pockets [54].

Machine-finished (ie, turned) implants, such as the Brånemark System implants (Nobel Biocare, Zurich, Switzerland), have a substantial history of use in the clinic. Whereas they may appear macroscopically smooth, the implants have a low roughness, in the range of 0.5 to 1 μm [30]. With careful selection of patients and anatomical sites, meticulous surgical technique, and delayed loading, this system has shown excellent survival rates [55,56]. In the mandible, success at 5 to 8 years exceeded 99% and was approximately 85% in the maxilla.

Even though Brånemark implants have been documented to perform well in humans, implants with different surface characteristics continue to be developed in attempts to increase the degree and rate of osseointegration, to allow early and immediate loading, and to promote integration in anatomic sites with poor bone quality or insufficient bone quantity for conventional implants. Because of experimental and clinical evidence of better integration with tissues, implants having rougher surfaces now receive the most attention. ''Moderately rough'' surfaces are described as having S_a between 1 and 2 μm, while ''rough'' surfaces have an S_a greater than 2 μm [30]. The methods used to increase roughness, however, frequently tend to change the surface chemistry as well as texture.

Roughened surfaces are associated with increased interfacial strength as measured, for example, by reverse (or removal) torque testing [57–59]. Experiments have also indicated a faster rate and higher degree of bone

formation for rougher implants than for implants with turned surfaces [60]. Rougher surfaces, however, are not necessarily better. This applies to both hard and soft tissue responses. Surfaces with intermediate roughness (ie, $S_a \sim 1.5$ μm) have higher bone–implant contact indices [58,61,62]. Furthermore, rough surfaces favor accumulation of plaque, which can lead to peri-implantitis and implant failure if that portion of the implant surface becomes exposed to the oral environment [63].

Methods for altering surface texture can be classified as either ablative or additive. Ablative methods remove material from the surface. Common methods for ablating dental implant surfaces include grit blasting, acid etching, and grit blasting followed by acid etching. The primary method used to deposit material on implant surfaces is plasma-spraying.

The TiUnite (Nobel Biocare, Zurich, Switzerland) surface is formed by anodically oxidizing titanium in a proprietary electrolytic solution. Treatment results in an increased thickness of the oxide layer and a porous surface topography [64]. In the coronal region, the oxide grows to 1 to 2 μm, whereas it approaches 10 μm in the apical region. In conjunction with oxide growth, surface roughness continuously increases from top to bottom, with an average R_a of 1.2 μm. The apical end also has numerous 1 to 2 μm pores. Although the composition of the electrolyte is not published, studies on anodic oxidation have shown that use of sulfuric or phosphoric acid in the bath results in incorporation of sulfur or phosphorus ions, respectively, in the oxide [65]. Furthermore, crystal structure of the oxide film can be altered during electrochemical oxidation [66]. Thus, there is the possibility for roughness-related as well as chemistry-related effects on integration of the implant [67]. A recent publication reported essentially 100% success of TiUnite implants at 18 months, even with early or immediate loading [68]. Four-year results indicate 97% success in an immediate loading protocol, even when implants were placed in soft bone [69].

Dual acid-etching (DAE) of titanium in a solution of hydrochloric acid and sulfuric acid results in microrough surfaces. This technique is used with the Osseotite Implant System (Implant Innovations, Inc. (3i), Palm Beach Gardens, Florida). However, the texture is not uniform over the entire screw surface. S_a is about 1.8 to 2 μm at the tops of the threads, but roughness decreases to 0.5 to 0.7 μm in the valleys and on the flanks [30,70]. Animal studies have demonstrated improved removal torque values, presumably because of greater mechanical interlocking [71,72]. Compared with machined implants, DAE surfaces showed significantly greater bone–implant contact, even in sites of poor bone quality [73]. The apparently accelerated integration of the implants enables loading to begin at 1 month instead of after 2 months of healing [74]. Davies describes de novo bone formation, a key part of contact osteogenesis, on acid-etched surfaces [24]. In clinical use, cumulative success rates approach 97% at 5 [75] and 6 [76] years. Even with immediate occlusal loading, excellent success rates are observed, 99% at a mean follow-up of 28 months [77].

The sandblasted (large grit) and acid-etched (SLA) surface of implants from Institut Straumann (Basel, Switzerland) has also received significant attention. Implants are blasted with 250 to 500 μm corundum grit followed by acid etching in a hot solution of hydrochloric acid and sulfuric acid. Sandblasting produces macroroughness onto which acid etching superimposes microroughness [78]. The S_a for SLA surfaces is around 1.8 μm [30,70]. The increased roughness compared with turned implants combined with possible microstructural changes in the oxide resulting from the acid treatment produces good cell and tissue responses, such as greater bone–implant contact [78] and increased removal torque values [79]. In clinical studies, SLA implants were loaded after 6 weeks when in class I, II, or III bone or after 12 weeks if in class IV bone [80]. At both 1- and 2-year follow-up, 99% of the implants were successful. An identical success rate (ie, 99%), was also reported at 3 years [81].

More recently, Salvi and colleagues [82] conducted a study using SLA implants in the mandible. A split-mouth design was employed, with the one side serving as the test site and the contralateral serving as the control. Control implants had abutments connected at 5 weeks followed by crown cementation (post-implant placement) at 6 weeks. The test implants received abutments at 1 week and crowns at 2 weeks. At 1 year, implant survival was 100% for both arms of the study, and no significant differences were noted between the arms. Even though these implants were placed in bone of good quality, this study underscores the affinity of osteoblasts for this surface.

Some of the roughest dental implant surfaces are titanium plasma-sprayed (TPS). The S_a depends on the manufacturer, but can be up to 6 μm [70]. To prepare these surfaces, titanium particles are heated to a nearly molten state and sprayed at the substrate via an inert gas plasma. The softened particles "splat" on the surface and rapidly solidify. The resultant surface is quite irregular and rough. This increased surface texture, with relatively greater void volume into which bone can grow, results in higher removal torque values [83,84]. Several studies, however, have shown cause for concern with TPS implants. For example, titanium particles have been detected in peri-implant tissues [85]. The authors speculate that friction during surgical insertion may have sheared off the particles. TPS surfaces have also been associated with increased mobility and higher incidence of peri-implant inflammation and recession [86,87].

By coating implants with hydroxyapatite (HA), such as by plasma spraying, both the roughness and surface chemistry are altered. The roughness increases to $S_a \sim 5.8$ μm [70], and the surface chemistry is dramatically changed from TiO_2 to a bone-like ceramic with the potential for chemically bonding to bone. Unfortunately, the properties of commercial coatings can be quite variable. During plasma spraying, HA can be transformed to other forms of calcium phosphate, with different crystalline structures, such as β-tricalcium phosphate. Because the chemical properties depend on the microstructure [88], dissolution characteristics may be quite different for various

coated implant preparations. However, reports documenting clinical use of dental implants coated with calcium phosphate show good success of the prostheses. Periodontal measurements were comparable for HA-coated and uncoated implants through 3 years [89], and survival rates were 95% to 99% at up to 7 years [90–92].

Other studies have observed "late" failures with HA-coated implants. Wheeler reported the results of an 8-year retrospective study that compared implant survival of TPS implants versus HA-coated implants [93]. A total of 1202 press-fit cylindrical implants were placed in 479 patients. Of these, 889 had TPS surfaces, and 313 were HA-coated. Cumulative survival rates based on life table analysis were 92.7% and 77.8% for TPS and HA-coated systems, respectively. Many of the HA-coated implants were lost after being in service for some years, and their failure was often accompanied by a good deal of bone loss.

Summary

Dental implants are valuable devices for restoring lost teeth. Implants are available in many shapes, sizes, and lengths, using a variety of materials with different surface properties. Among the most desired characteristics of an implant are those that ensure that the tissue-implant interface will be established quickly and then will be firmly maintained. Because many variables affect oral implants, it is sometimes difficult to reliably predict the likelihood of an implant's success. It is especially difficult to assess whether the various modifications in the latest implants deliver improved performance. Thus far, metanalysis of randomized clinical trials finds no evidence of any particular type of implant having better long-term success [94]. There is limited evidence, however, for decreased incidence of peri-implantitis around smooth (ie, machined) implants compared to implants with rougher surfaces.

The continuing search for "osseoattractive" implants is leading to surface modifications involving biological molecules. By attaching or releasing powerful cytokines and growth factors [23], desired cell and tissue responses may be obtained. Using even a simple delivery system, introduction of bone morphogenetic protein at the tissue–implant interface was shown to enhance the rate of periprosthetic bone formation [95]. In the future, similar approaches may also be used to promote interaction of mucosal and submucosal tissues with dental implants.

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Consequences of Implant Design

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The use of dental implants to replace missing teeth is becoming a preferred alternative for restorative dentists and their patients. Patients who previously did not seek dental replacements now present to dental practitioners and request information and replacement care. Furthermore, patients have gained such awareness of these new options that they increasingly request modification or replacement of existing dental restorations (eg, dentures, fixed partial dentures, and removable partial dentures). Quality of life analyses indicate that patients perceive their oral health status as improved by their experience with dental implants [1]. Root-form dental implants now comprise the most widely used form of treatment and often have success rates of 90% to 100%. Success and survival rates continue to improve as the physical design, surface technology, and clinician experience evolve.

Currently, two basic types of root-form implants are used. The first category of implants was introduced and developed by Branemark and colleagues [2] and the implants are referred to as two-piece implants. The two pieces consist of an implant body and a separate abutment. The implant is placed during a surgical procedure; the top of the implant is at the level of the bone crest or some distance apical to it (Fig. 1). The gingival tissues are re-approximated for primary closure over the top of the implant, which is then left undisturbed for a period of time, usually 3 to 6 months, for osseointegration. This surgical placement technique is referred to as submerged placement.

After successful integration in the bone, a second surgery is performed and a healing or restorative abutment is connected to the implant (Fig. 2). This is referred to as second-stage surgery. The gingival tissues are re-approximated around the abutment as they would be around a tooth.

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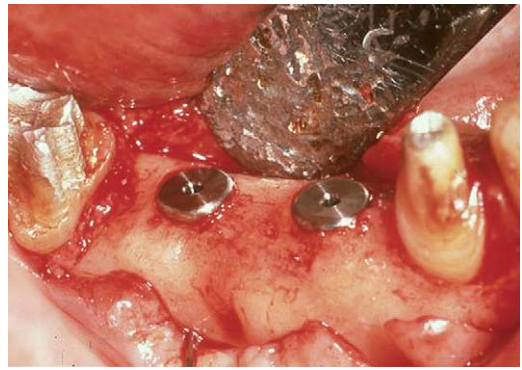

Fig. 1. Clinical photograph of two submerged (two-piece) dental implants in the posterior mandible after flaps were reflected at second-stage surgery. Note that the tops of the implants are placed slightly apical to the alveolar crest and only the thin cover screws can be seen.

A second healing period is allowed for the gingival tissues before restorative procedures are continued.

The second category of implants is referred to as one-piece implants. This concept was introduced and developed by Schroeder [3–5]. A one-piece implant comprises the implant body and the soft tissue healing abutment manufactured as one piece. The implant is surgically placed; the top is positioned coronal to the crest of the alveolar bone and the gingival tissues are reapproximated around the now transgingival implant, rather than over the top of the implant, at the time of implant placement surgery (Figs. 3 and 4). This surgical approach is referred to as non-submerged placement. Another term used to describe this implant category is single-stage implants because no

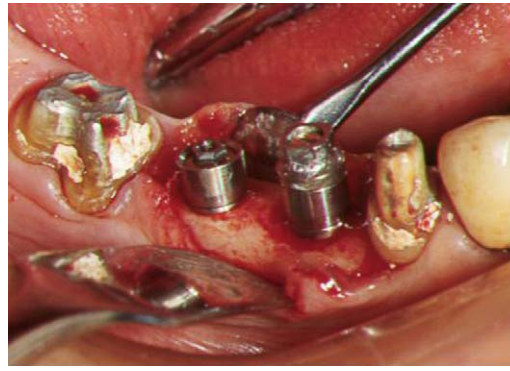

Fig. 2. Clinical photograph of two submerged (two-piece) dental implants in the posterior mandible at second-stage surgery. The thin cover screws are replaced with transgingival abutments. An interface or microgap now exists at the bone crest level where a butt-joint connection exists between the top of the implants and the apical ends of the abutments.

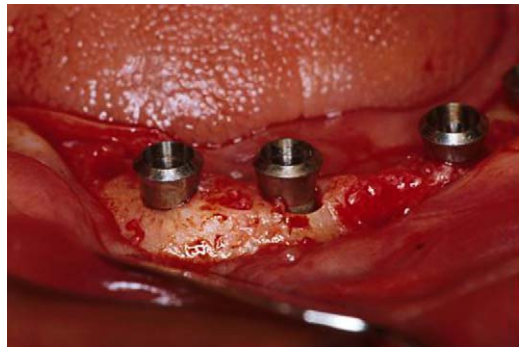

Fig. 3. Clinical photograph of non-submerged (one-piece) dental implants placed in the anterior mandible of an edentulous patient. The surgical flaps reveal the alveolar crest and the implants in the osteotomy preparations. In the middle implant a defect exists and the rough-smooth border of the implant can be seen slightly apical to the bone crest.

second-stage surgery is required. Restorative procedures may commence as soon as healing has occurred.

The discussion in this paper will reflect the terminology of one-piece implants placed using a non-submerged technique, and two-piece implants placed using a submerged technique. These techniques reflect the development and descriptive analysis of implant therapy in the literature. Currently used clinical techniques, however, also include placement of the two-piece implant and abutment components simultaneously in one surgical procedure, during which the gingival tissues are re-approximated around the abutment (ie, two-piece implants placed in a non-submerged approach). Additionally, one-piece implants may be placed subjacent to the buccal portion of the surgical flap for esthetic advantage. This is referred to as semi-submerged placement. Or, the one-piece implant can be completely submerged

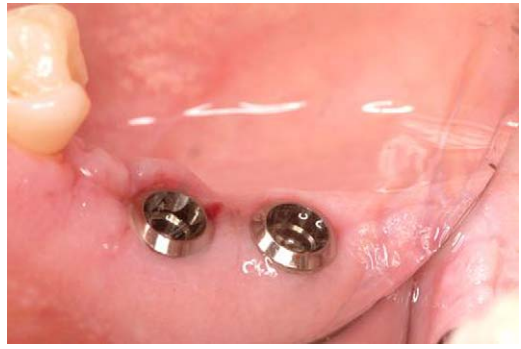

Fig. 4. Clinical photograph of two non-submerged (one-piece) dental implants placed in the posterior mandible. This is a 1-week postoperative view after the sutures have been removed. The healing caps placed in the tops of the implants have been removed to reveal the internal aspect of the implants. Note the healthy condition of the peri-implant soft tissues.

at the time of surgical placement (ie, a one-piece implant placed in a submerged or two-stage approach). This might be preferred if bone augmentation procedures are to be combined with implant placement surgery.

The healed bone and gingival tissue-to-implant and gingival tissue-to-abutment relationships are analogous to, but different from the dentogingival interface of natural teeth. These relationships depend on the physical design of the implant, the location of the implant components relative to the bone, the surface technology of the implant, and the soft and hard tissue dimensions existent at the time of placement. The long-term stability of these relationships depends on the restorative and occlusal demands placed on the implant, as well as the bacterial colonization of the components and spaces created (Fig. 5).

The connection of restorative components (abutments and crowns) to the restorative interface of the implant creates a space, which can be colonized by oral bacteria. This space is sometimes referred to as the microgap. Research has shown that the creation of the microgap can have a direct influence on bacterial colonization, recruitment and localization of inflammatory cells, and the soft and hard tissue anatomical relationships around the implant complex. Long-term stability depends on the healthy attachment of epithelium, connective tissue, and bone to titanium as well as the subsequent maintenance of bone levels.

Both one- and two-piece implants are surgically placed with similar drill sizes, sequences, and methods. Although there are some variations in manufacturers' recommendations based on design features and materials, the

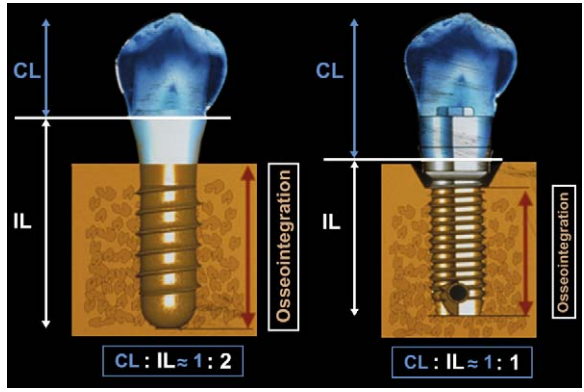

Fig. 5. Schematic diagram of a non-submerged (one-piece) dental implant on the left, and a submerged (two-piece) implant on the right. The one-piece implant has its interface above the bone level; the two-piece implant has its interface at the original bone crest level. After this interface is created at the bone crest, bone resorption occurs mesial and distal (in the schematic) but actually all around the implant, down to the first or second thread level. The crown length (CL) to implant length (IL) is less in the non-submerged (one-piece) design compared with the submerged (two-piece) design. (Courtesy of Institut Straumann AG, Basel, Switzerland, with permission.)

various protocols have become progressively more similar. In most implant systems, a screw-shaped implant macrostructure is used. The implant is screwed into the prepared bony walls of the osteotomy and, in some cases, after the osteotomy has been prepared ("tapped") for the screw threads. A cover screw is attached to the implant and then the flaps are re-approximated.

Marginal bone levels

Successful dental implant therapy requires long-term maintenance of the soft and hard tissues that surround the implant. This is particularly true for the bone-to-implant contact because osseointegration provides resistance to the forces exerted on the implant restoration. Osseointegration is a histological outcome and cannot be clinically ascertained in patients. Therefore, surrogate clinical variables must be used to determine tissue stability around the implant over time. One such surrogate variable that has been used is the level of the osseous tissue mesial and distal of the implant as determined by radiographic evaluation. One convenient aspect of the radiographic evaluation is the level of the bone adjacent to the implant as measured from a predetermined location on the implant restoration. This location is usually at the top of the implant and can also be used before implant restoration to assess the bone level around the implant. This is commonly referred to as the marginal bone level (Figs. 6 and 7). The implant macro-structure is relatively fixed and so provides a constant point from which measurements can be made, in a manner similar to the use of a stent to determine relative attachment levels in periodontal trials.

The predictability of dental implants has been established through longitudinal studies of implant survival or success (the latter being a function of some pre-specified criteria). Parameters that have been followed include detection of mobility, pain, infection, inflammation, and marginal level of bone (also referred to as crestal bone). Particular emphasis was placed on monitoring the marginal bone level over time, because some implants lost a significant amount of marginal bone and the implants failed after becoming mobile. Implant mobility turned out not to be a very sensitive indicator for implant failure because large amounts of bone loss could occur, yet the remaining bone prevented movement of the implant. Thus, when mobility of a previously osseointegrated implant is clinically detected, implant failure invariably occurs. Therefore, evaluating the marginal bone level over time allowed the clinician to better assess the status of the peri-implant tissues and facilitated earlier therapeutic intervention.

Early reports on implants in patients indicated that marginal bone loss occurred in the 1–2 mm range in the first year after restoration and after the first year generally very small amounts of bone loss occurred or the level stabilized. In these studies, the baseline radiograph was made at the time the prosthesis was placed on the implant and the studies generally included a submerged implant that had a machined surface and a butt joint

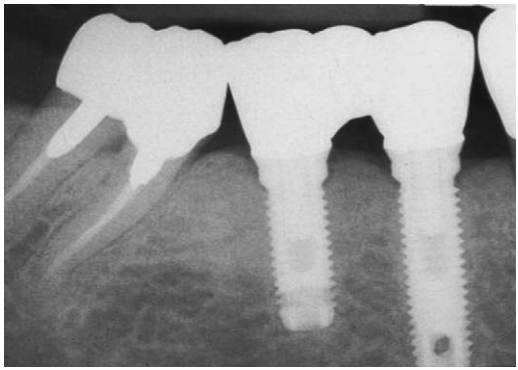

Fig. 6. Periapical radiograph of two submerged (two-piece) dental implants placed in the posterior mandible. The final crowns are connected together. Note the angular bone loss mesial and distal of each implant down to the level of the first thread of the implants. This bone loss is characteristic for this type of two-piece implant.

connection in which an external hex with a screw joint was used to connect the abutment to the implant. The bone levels were not evaluated before the prosthesis was connected because in early studies, the technique prohibited taking radiographs at the time of implant placement. At that time there was a fear of critically damaging the cells that lined the implant preparation which contribute to making the bone-to-implant contact. Therefore, in the early studies, the baseline or first radiograph was taken at the time the prosthesis was inserted and was used to evaluate changes in the marginal bone level over time.

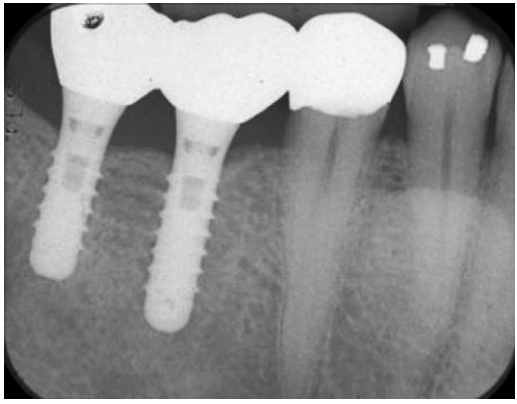

Fig. 7. Periapical radiograph of two non-submerged (one-piece) dental implants placed in the posterior mandible. The final crowns are connected together. The crowns contact the tops of the implants approximately three millimeters above the alveolar crest. This means that the interface or microgap is located coronal to the bone level.

Later studies and experiences clinically indicated that baseline radiographs could be taken at implant placement and could then be used to evaluate the changes in the marginal bone levels beginning with implant surgery. Hermann and colleagues [6,7] performed a series of studies that evaluated radiographic marginal bone changes over time around both submerged and non-submerged implants. A radiograph taken at the time of placement was used to establish a baseline from which changes would be measured. This facilitated evaluation of the marginal bone changes before prosthesis insertion and the biological events that occurred during the soft tissue remodeling as the implant or implant component parts passed through the gingival, and a peri-implant mucosal seal was created. It became evident from these studies that differences occurred in the marginal bone area if the top of the implant stopped at the bone crest level and the implant was first submerged and a second surgery was used to connect a secondary implant component. This was in contrast to a one-piece implant that was made to extend beyond the crest through the soft tissues initially (non-submerged) at the first surgery.

In one set of studies, two-piece implants (originally referred to as submerged-type implants) were placed either at the bone crest level (recommended position), 1 mm above the crest of bone, or 1 mm below the crest of bone and then closure screws were attached and the tissues closed over the top to submerge the implants [7]. In addition, one implant, placed at the crest of bone, had the abutment connected to the implant at the time of implant placement and was, therefore, a two-piece implant placed in a non-submerged surgical approach. These implant configurations were compared with a one-piece implant (originally referred to as a non-submerged type implant) placed with the border of the roughened endosseous portion of the implant at the crest of the bone and the smooth transgingival portion of the implant in the soft tissues. One last configuration was examined that used the one-piece implant with its rough-smooth border placed 1 mm below the alveolar crest. The results demonstrated that minimal amounts of bone loss occurred around the one-piece, non-submerged implant when it is placed as recommended, with its rough-smooth border at the crestal bone level. If this non-submerged implant was placed 1 mm apically, so that 1 mm of smooth collar was within osseous tissue, a small amount of bone loss occurred. If an abutment was connected at the time of first-stage surgery to a typically submerged implant and placed as a non-submerged but two-piece implant, approximately 1.5 mm of bone loss occurred after 1 month in the canine model. After that, minimal bone loss was observed.

No crestal bone changes were observed around the three submerged implants for the 3 months that they were covered with the alveolar mucosa. However, once the second- stage surgery was performed and an abutment was connected to the implant, bone loss was observed within a month around all three designs. Approximately 1.5 mm of bone loss occurred around the implant that was placed with the top of the implant at the

alveolar crest. This was identical to the same design (two-piece) that was placed in a non-submerged approach as described above. In other words, a two-piece design implant that had an interface (called a microgap) between the top of the implant and the abutment, located at the alveolar crest, was associated with about 1.5 mm of bone loss once the connection of the components took place. If these components were connected at the time of first-stage surgery, the bone loss occurred within the first month after implant placement. If however, the implant was first submerged for 3 months and then the abutment was connected, the same amount of bone loss occurred within the first month after the connection was made at second-stage surgery. The investigators suggested the bone loss observed was associated with the microgap (a two-piece implant configuration). Submerging the implant (ie, no microgap) was not associated with bone loss; however, once the abutment was connected and a microgap was created, bone loss occurred identical to the bone loss that occurred if the abutment was connected at the time of first-stage surgery (ie, a two-piece implant configuration placed in a non-submerged approach). Thus, the actual surgical technique of submerging or not submerging the implant does not have marginal bone consequences. However, once the abutment is connected to a submerged implant, bone loss occurs. The bone loss is simply delayed until the abutment is connected and the microgap is created. This association was confirmed by the fact that a one-piece, non-submerged implant was not associated with this bone loss. Thus, marginal bone loss was strongly correlated with microgap creation.

Another confirmation that marginal bone loss is associated with the presence of the microgap was that as the microgap was moved apically, more bone loss was observed. When the microgap was located 1 mm above the bone crest (ie, the top of the implant was placed 1 mm above the bone crest at the time of first-stage surgery), only a small amount of bone loss was observed. If however, the microgap was located at the bone crest level (ie, the top of the implant was placed at the bone crest level at first-stage surgery), more bone loss was observed. Finally, if the microgap was located 1 mm apical to the bone crest (ie, the top of the implant was placed 1 mm apical to the bone crest level at first-stage surgery), the greatest amount of bone loss was observed in these two-piece configurations. Thus, marginal bone loss strongly correlated with microgap location.

In the experiments described, the bone loss observed in all cases occurred within the first month after microgap creation. After that, no further significant loss of marginal bone occurred. This again suggests that the observed loss is associated with the creation of the microgap and that afterwards the driving force for further bone loss is no longer present. Therefore, the etiology of the marginal bone loss associated with the creation and location of the microgap appears limited to this structure.

In summary, radiographic marginal bone levels have been used as a clinical outcome to determine the status of the implant restoration. Depending

on implant design, marginal bone loss is observed after implant placement and the abutment is connected. Thus, the creation and location of the microgap is associated with marginal bone loss. This bone loss occurs relatively rapidly and then stabilizes. The presence of ongoing bone loss is a clinical sign of instability and likely, pathology. Based on the loading conditions, some bone loss may be observed, but equilibrium tends to be reached in the bone level. Progressive bone loss suggests that a problem exists and the clinician needs to take therapeutic action.

Biologic width around dental implants

Natural teeth are surrounded by gingival soft tissues that provide a biologic seal between the oral cavity and the inside of the body. This unique structure is composed of epithelium and soft connective tissues that are continually bathed in a transudate called gingival fluid. The linear dimensions of this structure have been described and the epithelial and connective tissue dimensions were referred to as the biologic width by Gargiulo and coworkers [8]. Cadaver specimens were measured and mean values determined for the space occupied by the sulcus depth, the junctional epithelium, and the gingival connective tissues. Questions arose about whether the soft tissues around implants had similar structures. A pioneer in endosseous dental implants, Andre Schroeder [3], used histologic specimens that showed both the titanium implant and the surrounding tissues to describe the epithelium and connective tissues around the implant. Buser and colleagues [9] further explored these tissues and described the existence of a junctional epithelium similar to that found around teeth and a surrounding connective tissue, which appeared to encircle the implant. This connective tissue was a 50 to 100 μm avascular zone that ran perpendicular to the implant long axis. Peripheral to this scar-like tissue was a vascular zone and large connective tissue fiber bundles that ran parallel to the long axis of the implant. Although the epithelial attachment to an implant surface was similar to the natural dentition, the connective tissue contact was completely different.

The marginal bone tissue around an implant is directly influenced by the presence or absence of a microgap and its location. Bone loss is associated with the two-piece implant design and is generally not observed with one-piece dental implant designs. Based on these observations, investigators questioned whether a biologic width existed around implants analogous to that seen around teeth. Additional questions concerned the influence of implant design on the biologic width. Weber and coworkers [10] had described histological differences in the location of the apical extension of the junctional epithelium between one-piece and two-piece implant designs. These investigators had observed that around two-piece implant designs the epithelium was always located apical to the microgap, and that the epithelium around two-piece implants was always located more apically than around one-piece implants. Cochran and colleagues [11] measured the linear

soft tissue dimensions around implants and demonstrated that a biologic width existed around endosseous dental implants. In addition, these dimensions were different between one- and two-piece implant designs. The biologic width dimension around one-piece dental implants was similar to the biologic width dimension described by Gargiulo and coworkers [8] for natural teeth. This finding was significant for esthetic reasons and has implications for the surgical placement of the implant. The biologic width dimension for two-piece implants was different (larger) compared with one-piece implants and natural teeth. These findings suggested that the concept of biologic width is valid in both teeth and implants, despite the obvious differences between these two structures. In addition, the presence of the microgap and its location influences the epithelial dimension and location. Thus, a microgap in two-piece dental implant designs influences marginal bone levels and also influences the biologic width of the surrounding soft tissues. The epithelial structure around teeth and implants is similar but the soft connective tissue structure is completely different. In spite of these differences, the biologic width around one-piece implants and natural teeth is similar. These physiologic similarities make it possible for a clinician to create esthetic tooth replacement with implant restorations.

It is not known why the biologic width dimension is similar between one-piece implants and natural teeth in spite of different gingival connective tissue structures. Because the epithelial structure is similar between teeth and implants, it is not surprising that these linear dimensions are similar. What is remarkable is that a junctional epithelium forms around the implant from the existing keratinized oral epithelium similar to what happens around the natural tooth after periodontal surgery. This suggests that the physiologic conditions that govern junctional epithelium formation are independent of the adjacent non-vascular hard structure (an implant or tooth root). In fact, it may be that anytime a nonvascular solid structure is placed into oral epithelium, the host reaction is a physiologic structure (ie, the nonkeratinized junctional epithelium). This likely relates to an acquired pellicle formation, microbial plaque accumulation, and corresponding oxygen tension changes. A remarkable finding is that a hemidesmosomal attachment is formed on the titanium oxide surface similar to that which is formed on the tooth root surface. This again suggests a physiologic structure that forms regardless of the nature of the substrate and again may reflect a host reaction to a nonvascular solid structure in the oral cavity. In regard to the gingival connective tissues, the linear biologic width dimension is similar between the one-piece implant and the natural tooth in spite of completely different structures. This counter-intuitive finding suggests that in spite of dramatic structural differences (in the case of the connective tissues) an overall physiologic phenomenon drives the apico-coronal dimension of the connective tissues and epithelium, which finds expression in the literature as the concept of biologic width. This physiology is unknown but may be related to the location and functional demands of the tissues within

the oral cavity. Thus, the oral cavity demands determine the oral soft tissue dimensions in spite of actual structural differences in the connective tissue contact between teeth and one-piece implants.

It has been shown that around natural teeth, the epithelial component is more variable than is the connective tissue component. That is, the connective tissue dimension remains more stable over time. Hermann and colleagues [12] evaluated the changes over time in the biologic width dimensions around one-piece implants and determined that the connective tissue dimension around implants was more stable than the epithelial dimension, a phenomenon also observed in the natural dentogingival interface. Interestingly, this study included implants that were not loaded (ie, the implants did not have restorations) and implants that were loaded (with restorations) for 3 months and for 1 year. The biologic width dimension did not vary significantly regardless of whether the implant was unloaded, loaded for a short time, or loaded for a long time. This suggests again that the formation of a biologic width is a physiologic response in the oral cavity and is not dependent on the presence or absence of loading, or the length of loading time. This is reinforced by analogy with the natural dentition where a biologic width is formed around teeth that may not be in occlusion, such as around third molar teeth or teeth that have lost the antagonist tooth in the opposing arch. The fact that the connective tissue dimension is more stable over time than the epithelium dimension, both around teeth and one-piece implants, may be related to the fact that the connective tissues once formed are predominated by the protein collagen, and as collagen matures, more cross linkages occur which stabilizes this tissue. This highly cross-linked connective tissue structure would then be more resistant to dimensional change over time. In the case of the junctional epithelium however, this structure is constantly being challenged by microbial growth and pathologic microbial products. The host reacts by changes in the inflammatory immune system including widening of the intercellular epithelial spaces and the recruitment of polymorphonuclear leukocytes. The host response would be expected to fluctuate greatly over time depending on the challenge, which varies daily based on host stress, home oral hygiene, professional hygiene etc. Thus, it would not be unexpected to see more changes in the epithelial dimension compared with the connective tissue dimension around both teeth and implants. Another point regarding the biologic width is that the epithelium is always found below the microgap on a histological basis.

Bacterial challenges around implants

The natural dentition is continuously challenged by microbial plaque, which consists of hundreds of species of bacteria. These bacteria and their products elicit a host inflammatory–immune reaction. Dental implant restorations face the same microbial challenge but, unlike the natural tooth,

consist of multiple component parts. The connection of these multiple component parts has changed over the years but screw connections are most common. This often results in the creation of an interface between components located within the tissues surrounding the implant. For example, two-piece implants by design have an interface at the crestal bone level where the top of the implant contacts the abutment that fits on top of the implant. Further coronally, an interface is found where the crown meets the abutment. One-piece implant designs result in only one interface between the top of the implant (which by design extends coronal to the crestal bone) and the crown. As noted above, these interfaces or microgaps are associated with marginal bone loss when they are located close to or within the bone tissue. The question then becomes why bone loss is associated with the interfaces (microgap).

Experimental research and investigation of implant components from patients indicates that the interfaces become contaminated with bacteria and their products. Experimental studies have connected the components together on the bench top under ideal conditions of asepsis, not likely to be attained in the mouth because of the presence of bacteria. These implants were then incubated in solutions that contained various bacterial species. Under these scenarios (which are much more favorable than would actually exist in the mouth), bacterial contamination is found in all the interfaces examined. In addition, implant components taken from patients also reveal bacterial contamination of the internal aspects of the components. Thus, bacteria are able to penetrate the interface and create microbial niches in the interfaces [13–19].

Studies examining the soft tissues that surround the implant have demonstrated that inflammatory cells are present in variable amounts adjacent to the implant depending on the implant configuration [19]. These studies have examined the inflammatory cells in the soft tissues adjacent to both one- and two-piece implant designs with varying relations between the microgap and the alveolar crest. In addition, a two-piece implant placed in a non-submerged approach (the abutment was connected to the implant at the time of first-stage surgery) was also examined for the presence of inflammatory cells in the soft tissues around the implant. The analysis was performed 6 months after implant surgery and two-piece implants had abutments connected at a second-stage surgery 3 months after implant placement. The results revealed that two-piece implants placed at the alveolar crest resulted in identical inflammatory cell accumulation patterns regardless if the abutment was connected at first or second-stage surgery. In these cases, the most inflammatory cells were located at the level of the interface (where the original bone crest was located) and the number of cells decreased as one moved away from the interface both in an apical and in a coronal direction (Fig. 8). The predominant inflammatory cell was the polymorphonuclear leukocyte, which is normally associated with a more acute reaction. This peak of inflammatory cells correlated with the interface whether the

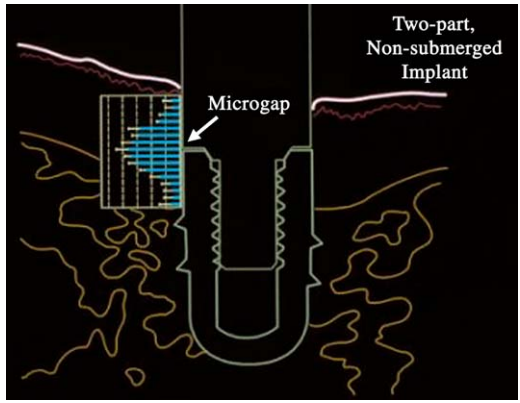

Fig. 8. Schematic drawing of a submerged (two-piece) dental implant design with abutment attached at the time of first-stage surgery (implant placement surgery), which results in a two-piece implant placed in a non-submerged surgical approach. This shows the result after 6 months of healing where the alveolar bone crest has moved from the abutment or implant interface down the implant after bone loss has occurred. If the inflammatory cells are counted along the side of the implant soft tissues, the greatest number of cells (represented in the inset graph as the longest bars) is located at the microgap or interface between the implant and abutment. The literature demonstrates that bacteria are found in the microgap and likely cause recruitment of the inflammatory cells.

interface was moved apically or coronally. Furthermore, this accumulation of inflammatory cells (and hence inflammatory reaction) was not observed when no interface was present (ie, adjacent to a one-piece implant). The one-piece implant design had many fewer inflammatory cells around the implant: the majority of the cells were located coronally near the junctional epithelium. The predominant cell type around this implant configuration was the mononuclear cell, the number of which diminished in an apical direction. These studies also demonstrated that the amount of bone loss was positively correlated with the accumulation of inflammatory cells apical to the microgap around the two-piece implants. Such bone loss (or inflammatory cells) was not observed around the one-piece implant design.

These inflammatory cell findings are suggestive of mechanisms that may relate to the tissue changes that occur around the different implant designs. One possibility is that the interfaces become colonized with a biofilm after being exposed to the oral environment (ie, during abutment connection and second-stage surgery). The growth of the bacteria and subsequent release of pathological products provide a continual stimulus to the host, which reacts by sending inflammatory cells to the site (in this case the adjacent interface soft tissues). These cells in turn, if located adjacent to or within a certain dimension to the alveolar crest, stimulate the recruitment and differentiation of osteoclast cells which then start resorption of the bone. This bone resorption continues until there is a certain distance between the site of infection (the interface or microgap) and the alveolar

bone, essentially walling off the source of the infection. This might be considered the effective range of the biofilm and is analogous to a similar plaque–bone distance observed by Waerhaug around periodontally involved teeth [20]. Further significant bone loss would not be observed because the infection is now a set dimension away from the bone crest. This scenario is exactly consistent with the marginal bone changes described above. Recall, for example, that two-piece implants placed in a non-submerged approach (ie, the abutment was connected at the time of implant placement) resulted in bone loss in the first month and then little loss occurred afterwards (ie, the host reacted to the infection and once bone was a set distance away from the infection, no further bone loss occurred). Similarly, submerged two-piece implants did not experience bone loss until the second-stage surgery when an abutment was added and an interface (microgap) was created (ie, an infected interface was created). In all these cases, bone loss occurred again within the first month and little loss occurred after that (ie, the host reacted by resorbing bone to a set dimension away from the infection). Also, the bone loss increased as the interface was moved apically but then after one month, the bone level stabilized (ie, the infection was placed more closely to the bone so more bone loss occurred but once a set distance occurred away from the infection, the bone loss stopped). These findings are all consistent with bacterial contamination of the interface, an inflammatory reaction by the host to that contamination, and bone changes associated when the inflammation approached the bone within a certain dimension. Further support comes from the observation that there were no such bone changes around one-piece implants and no peak of inflammatory cells. These findings are reinforced in clinical studies of two-piece machined implants where bone loss occurred to the level of the first thread when an abutment was connected at second-stage surgery. This was such a consistent finding that a mean 1.5 mm of bone loss was accepted as one of the success criteria in the first year of loading for this design of implant [21].

The quality of the inflammatory reaction adjacent to the interface of two-piece designs after six months in the canine proved to be interesting. Predominantly polymorphonuclear leukocytes and some monocytes were observed. This suggests that the host reacts with a chronic acute type reaction to the interface. It also suggests that this reaction is persistent and that new pathogenic substances are being released over time from the interface. This again is consistent with the scenario described above whereby bacteria occupy the interface, they grow and flourish within the interface, and continually release substances that the host must deal with yet the host cannot eliminate. This is consistent with plaque formation on the tooth root surface that stimulates an inflammatory reaction in the tissues (gingivitis), and if the inflammation approaches the alveolar crest within a certain dimension, bone loss is initiated (periodontitis). This is an effective strategy for the host to try to isolate an infection which it cannot effectively eliminate. The body similarly tries to isolate an endodontic infection at the apex of the tooth by

resorbing the periapical bone and forming an epithelial lined cavity which results in a radiolucent periapical lesion. These implant findings are also consistent with descriptions of the inflammatory reaction around teeth and its correlation to periodontal bone loss. Several investigators have described an extended arm of inflammation or radius of infection. Although the names differ, the concept is the same (ie, when inflammation reaches a certain distance from the alveolar crest, bone loss results around the tooth) [20]. This discussion suggests that the same phenomenon occurs around implants that have contaminated interfaces (ie, when the interface is located at or near bone, bone loss is initiated until a certain distance is reached so that the infection and associated inflammation is no longer within reach of the bone tissue).

These results, taken together, reveal that interfaces between implant components that become contaminated should be avoided near alveolar bone and in the more apical area of the soft tissues around the implant (Fig. 9). Some implant systems have attempted to either eliminate the infection from the interface or move the infected interface away from the bone level. For example, one solution has been to place an anti-infective material at the interface to help with the infection and subsequent inflammatory reaction. However, this approach has not been widely adopted. Another, more elegant solution has been to shift the interface away from the bone by having the abutment fit within the inside of the two-piece implant so that the interface is separated from the bone horizontally by the thickness of the implant outer wall to the inner wall, which mates with the abutment. Another approach would be to effectively seal the interface against bacterial contamination. This latter approach seems unlikely using butt joints on components but may be possible if cold welds (such as can be created

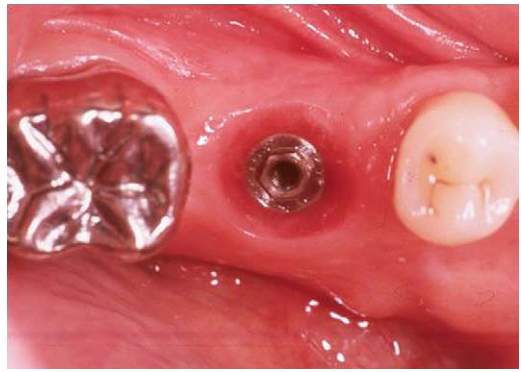

Fig. 9. Clinical photograph of the top of a submerged (two-piece) dental implant after the temporary restoration has been removed. With this implant design, an external hexagonal piece extends coronally and the abutment fits over the top. The abutment (or in some cases, the crown) extends to the top of the implant which was placed at the alveolar crest (thus creating an interface or microgap at the bone level).

with some Morse tapers) could be created between the implant and the abutment (presumably with internal connections of the abutment in the implant). These are attractive possibilities but need to be proven with data and histological evaluations. Without such data, they remain only as attractive possibilities.

Restoration of one-piece implants

When using one-piece implants, the coronal aspect of the implant is visible and more accessible clinically; seating the abutments is straight forward. The practitioner can visually confirm that components are fully seated. Therefore, confirmatory radiographs to verify seating may not be required (Figs. 4 and 10). This can facilitate quick placement as well as replacement of abutments and cover screws. Also, access to the top of the implant facilitates seating and verification of impression components and thus can save time during this process.

Simplified impression techniques have been developed to take advantage of the clinically accessible top of the implant. For example, in some systems, self-retained plastic components are used to record and transfer the exact clinical position of the implant as well as the restorative margin and the position of the abutment to the alveolar crest. These plastic components can be picked up in a closed tray final impression. An appropriate analog is then securely placed in each implant site in the impression and the working cast is poured. The process is similar, if not less complicated, than conventional crown and bridge restoration. This technique is described in some detail elsewhere in this issue (see Haubenreich and Robinson). Cementation of such implant-supported restorations can routinely be accomplished (Fig. 11).

One-piece implants make cementation of restorations practical. Cement-retained restorations are increasingly used because of the overall ease of use, the lower costs involved, and the minimal maintenance required.

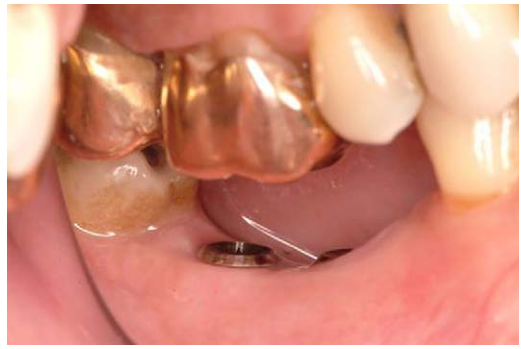

Fig. 10. Buccal view of two one-piece implants placed in the posterior mandible before abutment placement. Note the healthy condition of the peri-implant soft tissues.

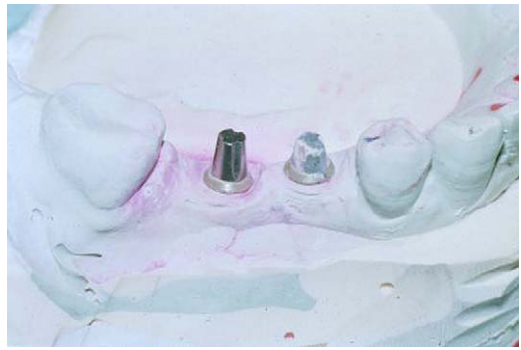

Fig. 11. Stone model of a non-submerged (one-piece) dental implant and cemental abutment placed in the mandibular posterior sextant. Once this model has been created, crown fabrication can occur using conventional crown-and-bridge techniques.

Furthermore, the similarity to conventional crown and bridge restorations is comfortable for most dentists. At the time of cementation with a one-piece system, residual cement can be eliminated more thoroughly when the top of the implant is exposed rather than situated at the bone level. Apically placed subgingival one- or two-piece implants may, however, make it difficult to remove cement and it may be preferable to retain the screw in those cases.

The use of one-piece solid abutments has simplified the restoration of one-piece implants. One-piece abutments consist of both the abutment and the screw portion for connection to the implant as one manufactured part. The entire abutment is screwed into the implant (Fig. 12). Anti-rotation for this abutment can be ensured by a minimally tapered cone-in-socket fit of the abutment into the implant rather than an external hex connection. This connection design, referred to as a Morse taper configuration, is a reliable, stable, non-loosening attachment mechanism which prevents further rotation of the abutment and eliminates the necessity of an additional abutment

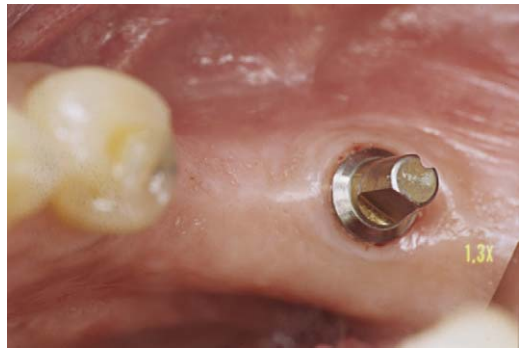

Fig. 12. Solid abutment screwed into a one-piece (non-submerged) implant.

screw. The problem of screw loosening—as seen in two-piece abutments—is eliminated or greatly reduced by this design for one-piece implants. Abutment screw fracture secondary to screw loosening and subsequent metal fatigue is also avoided as the force on the abutment is transmitted to the mating walls of the Morse taper and not the screw threads. One-piece abutments do not have a screw junction at the level of the alveolar crest and the cone arrangement of the connection helps distribute forces favorably [22].

Some implant designs also incorporate flat surfaces within the implant that facilitate exact transfer of the position of the implant to the working model (ie, an implant level impression). An array of abutment designs has been introduced to manage multiple restorative challenges. These abutment options include custom-cast and custom-milled technologies. Abutment connection via screw-retained components is also practical on one-piece implants. This approach is indicated in some circumstances. For example, when restorative space is minimal (the space available between the top of the implant and the opposing occlusion), abutment and crown retention can be accomplished without the abutment surface length necessary for cement retention. Additionally, the Morse taper type of connection stabilizes the screw joint and distributes forces away from the screw. This design element greatly minimizes problems with screw loosening.

Another circumstance that favors screw retained abutments occurs when the top of the implant is located significantly apical to the soft tissue margin. When the margin is placed apically, the removal of excess cement is quite difficult and tissue trauma may result. Residual cement is likely and will prove harmful to all tissue components in its presence. Bone loss and continued inflammation are likely. These potential problems may be avoided with cement-retained restorations which use an internal Morse taper to prevent screw loosening.

As with screwed-in abutments on one-piece implants, the microgap, which is created between the screw-retained abutment and the top of the one piece implant, is located away from the bone crest. This has the same effect of minimizing the inflammatory reaction on the bone and the adjacent soft tissue at the bone level. Screw-retained abutments allow a selection of angled abutments which can be used to overcome angulation problems following implant placement. Custom abutments and computer-designed, computer-generated abutments also are available. The final restoration can be retained by cement or screw to the screw-retained abutment.

Restoration of two-piece implants

The restoration of two-piece implant systems can be considered as part of the two-stage surgical placement. After implant healing in the bone, a full-thickness flap is typically used to gain access to the implant with a mid-crestal incision. A soft tissue healing abutment, in most cases, is placed onto the top of the implant. Sometimes, a non-crestal incision is used to remove

the planned healing incision line from directly over the implants to retain keratinized tissue and gain access to the top of the submerged implant. A further healing period is then required for the gingival tissues to mature around the now transgingival, or transmucosal, component on top of the two-piece implant.

After the healing component is placed at the time of the second-stage surgery, a radiograph may be required to ascertain whether the components involved are fully seated, particularly if the top of the implant is obscured by gingival tissue or fluids. Prosthetic components can be difficult to connect to the implant when the components join at a level that is apical to the bone crest, especially if bone has grown adjacent to or over the top of the implant during healing.

In some techniques, the second-stage placement of the healing or prosthetic component is accomplished without a flap by using a punch technique. In this technique, or at anytime an abutment must be placed or replaced, soft tissue interference with full seating can be problematic. Radiographic verification of component seating is usually necessary. Also, radiographic verification is necessary when impression components must be seated subgingivally; the mating components must be completely in contact. Similar problems are encountered when one-piece implants are placed in two-stage techniques and the top of the implant is intentionally positioned subgingivally (eg, in some esthetic situations).

Following impression procedures, the final restoration is attached to the abutment by way of screw retention or—more commonly now—cementation. Depending on the thickness of the tissue, the subgingival location of the abutment again may make complete removal of residual cement problematic. In some instances, the final restoration can be fabricated such that the restoration mates with the top of the two-piece implant located at or below the alveolar crest.

The restorative options for one-piece and two-piece implants continue to evolve. Most options for abutment design and abutment materials are available for both implant types. The two basic modes of treatment are differentiated by the connection design facilitated by one-piece implants, supra-crestal placement of the top of the implant, and the resulting location of the prosthetic connection relative to the bone. An understanding of the prosthetic components available as well as the healing characteristics of the implant system involved is essential for successful implant restorations.

Esthetic implications

The stability of the peri-implant tissues over time is critical to implant success and patient satisfaction. Biologic principles govern the relationships of these tissues and have physiologically established dimensions. Tooth esthetics is dependent on the dimensions of the teeth, and their positions and lengths relative to adjacent soft tissues and teeth. As with natural teeth,

implant restorations should ideally have non-inflamed, keratinized gingival margins coronal to the perceived level of the cemento-enamel junction. The relative positions of the height of the gingival margins are just as important on implant restorations as they are on teeth and tooth restorations. And, just as with natural teeth, inflammation can cause alterations of soft tissues and their anatomic relationships.

Fundamental to the dimensions and anatomy of the soft tissues is the position and anatomy of the underlying bone. Unfavorable alterations of bony anatomy and levels thus have esthetic consequences in the supported soft tissues. The degree and localization of inflammation, and consequent changes in crestal bone are clearly related to the presence, location, and sizes of interfaces (microgaps). The marginal bone levels around one-piece implants with a rough-smooth border have been shown to be stable at that border position [6,23,24]. The interface with one-piece implants is most often placed sufficiently above the crestal bone and apical to the gingival margin so that long-term anatomic relationships of bone and soft tissues, and thus esthetics, are preserved. Two-piece designs often result in bone loss of approximately 2 mm and soft tissue loss of 1 mm [6,25]. These dimensions and changes must therefore be taken into account in the surgical placement of esthetic implant restorations. Together the implant design, as well as the accuracy of the surgical placement, become especially important for implants and supported restorations placed in the esthetic zone.

Summary

There are two general surgical approaches for the placement and restoration of missing teeth using endosseous dental implants. One approach places the top of the implant at the alveolar crest and the mucosa is sutured over the implant, which results in a submerged surgical approach. An alternative approach places the coronal aspect of the implant coronal to the alveolar crest and the mucosa is sutured around the transmucosal aspect of the implant. This results in a non-submerged surgical approach. Different implant designs are generally used for submerged and non-submerged approaches and these designs have biological implications. When a submerged implant design is used, secondary implant components are added that extend through the mucosa to place the implant restoration. The connection of these components requires a second surgical procedure for the patient and results in interfaces in close proximity to the alveolar crest. These connections typically are flat connections maintained by screws within the secondary components. Data demonstrate that such connections become contaminated with bacteria and that the host reacts by creating an inflammatory immune reaction. This host response results in bone loss and soft tissue changes including an enlarged biologic width dimension and recession. With non-submerged implant designs, only one surgical procedure is required and no interfaces are created at the alveolar crest. Consequently, the host inflammatory immune

response is negated and the hard and soft tissue changes are minimized. The restoration of both implant designs can be achieved with either cemented restorations or restorations retained by screws. Screw-retained restorations offer the advantage of retrievability. However, in single teeth and short-span implant restorations, removal is not usually indicated. In these situations, cemented restorations offer simplicity, similarity to conventional crown and bridge techniques, and low maintenance. Regardless of implant design, surgical technique, or final restoration retention, endosseous dental implants have revolutionized restorative dentistry and made a significant impact on improved patient care.

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Risk Factors for Endosseous Dental Implant Failure

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A recent report published by the American Dental Association Council on Scientific Affairs recognized the consistently high rate of endosseous dental implant success or survival in human clinical trials [1]. For example, in 14 trials spanning follow-up periods of 2 to 16 years and involving over 10,000 dental implants placed in edentulous, partially edentulous, or single-tooth replacement cases, the overall mean survival rate was 94.4% with a range between 76% and 98.7% [2–15]. Implant survival rates also remain high for grafted bone (86.8%) [16–24] and for immediate loading protocols (94.0%) [25–27]. Still, these figures indicate a small but relevant implant failure rate of less than 10% overall, in which the implant is lost, fractured, or mobile; is a source of irreversible pain or infection; or coincides with peri-implant radiolucency or critical crestal bone loss [28]. Implant failures are usually classified either as early, when osseointegration fails to occur, or as late, when the achieved osseointegration is lost after a period of function. Implant failures may also be categorized as biological (eg, due to infection) or mechanical (eg, fracture). This article examines the available evidence on risk factors for implant failure. This should provide the basis for clinicians to better understand the role of device, procedural, anatomic, systemic, occlusal, microbial, immuno-inflammatory, and genetic factors that may indicate or cause an implant loss. With this understanding, clinicians can select appropriate cases or interventions that may enhance dental implant success.

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Device and procedural factors

Esposito and coworkers [29] conducted a recent systematic review and meta-analysis to determine whether different dental implant materials, shapes, and surface properties affect success rates. Twelve randomized clinical trials spanning at least 1 year were identified and included in the review. Overall, these trials represented 512 patients and constituted 12 implant types, all commercially pure titanium but with different shapes and surface preparations. On a per-patient basis, rather than a per-implant basis, no significant differences were observed between various implant types for implant failures. There were statistically significant differences for peri-implant bone-level changes on intraoral radiographs in three comparisons in two trials. However, these differences disappeared in the meta-analysis. More implants with rough surfaces were affected by peri-implantitis (relative risk = 0.80; 95% CI 0.67–0.96). This meta-analysis of the available evidence indicates that titanium implants with different shapes and surface preparations have similar success rates, but that smooth implants, compared to rough implants, appear to be less prone to peri-implantitis.

Several recent trials suggest that different implant dimensions are associated with different failure rates (Fig. 1). In a secondary analysis of 2,917 implants, Winkler and coworkers [30] reported a significantly lower mean 3-year survival for implants <4 mm in diameter (90.7%) versus survival for implants ≥ 4 mm in diameter (94.6%). Survival also significantly differed for 7-mm long (66.7%) implants versus 16-mm implants (96.4%). These outcomes did not change when clustering was considered, although the *P* values increased slightly. Chuang and coworkers [31] similarly conducted a multivariate analysis of clinical data on 677 patients and 2,349 implants. These investigators also found a significant association between short implants and implant failure. Shin and coworkers [32] compared survival rates for 64 wide-bodied implants placed consecutively in the posterior jaws of 43 patients and those for 64 regular-diameter implants (3.75 mm or 4 mm in

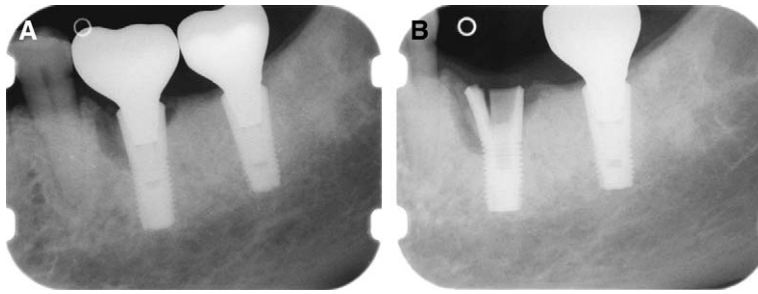

Fig. 1. Periapical radiograph of endosseous implant indicating peri-implant bone loss (*A*) and following removal of the prosthesis and abutment (*B*). The case was diagnosed with a fractured implant (technical failure) most likely due to short implant length and occlusal load.

diameter) placed in the posterior jaws of 25 of the same patients plus 14 others. The investigators observed 10 failures among the wide-bodied implants versus 2 for regular-diameter implants Multivariate analysis demonstrated a significant predictive relationship between overall cumulative survival rates and the ratio of implant volume to remaining-bone volume. The investigators postulated that the increased failure susceptibility for wide-bodied fixtures may relate to either implant design or the relative relationship of implant to host-bone dimensions. Hence, implant length and diameter, while selected on the basis of bone volume, present differences in risk for implant failure.

Degini and coworkers [33] recently assessed the relationship between implant dimension and survival in the context of immediate functional loading of the edentulous maxilla. For 388 implants in 43 patients, the crude 5-year survival rate was 98% with all failures occurring within 6 months from loading. Significant factors determining survival included implant diameter (99.37% for diameter $\leq$5.25 mm versus 93.8% for diameter $>$5.25 mm), the number of implants placed (99.3% for $\leq$10 implants versus 96.3% for $>$10) and gender (97.1% for males versus 99.5% for females). Cox regression analysis showed that diameter of implants adjusted for patient age and gender was associated to an average risk of failure (hazard rate) of 3.13 (95% CI 1.04–9.43) per mm (from 3 to 6.5). These findings indicate that wider diameter implants are associated with a higher risk of failure in maxillary edentulous cases with immediate functional loading.

In contrast, different surgical techniques in placing dental implants do not appear to be associated with different survival rates. Coulthard and coworkers [34] tested this hypothesis in a systematic review and analysis that included four randomized controlled trials (six publications). Two different aspects of implant surgical technique were reported in these trials. These were (1) two versus four implants to support a mandibular overdenture, and (2) crestal versus vestibular incision for implant placement. At the patient level, the investigators found no statistically significant differences for any of these alternative techniques with respect to implant failures, marginal bone levels, morbidity, or patient satisfaction.

Anatomic and osseous factors

Clinical studies consistently demonstrate patient anatomy and bone quality as important determinants of dental implant survival. For example, Herrmann and coworkers [35] recently analyzed an extant database involving 487 implants followed for 5 years. Significant determinants for implant failure were poor bone quality (type 4), a resorbed jaw, short implant length (7 mm), overdenture treatment protocol, and combination jawbone-related characteristics. Accordingly, 65% of the patients with a combination of poor bone quality and resorbed jaw (3% of the total study population) experienced implant failure (Fig. 2). These data indicate that patient

anatomic and bone characteristics independently or simultaneously can affect implant success.

Naert and coworkers [36] collected outcomes on 1,956 dental implants in 660 partially edentulous patients to identify anatomic and other factors predictive of implant success. The estimated cumulative survival rates were 91.4% for all implants and 95.8% for all restorations over a period of 16 years. Neither jaw site (maxilla versus mandible) nor implant position (anterior versus posterior) had any significant effect on implant survival. The investigators also reported that short implant length, high number of implants per patient, low number of implants per prosthesis, implants loaded by acrylic-veneered restorations, and implants combined with bone grafting present a higher risk for implant failure.

Clinicians should recognize peri-implant bone resorption occurring in the interval between first- and second-stage surgeries (for two-stage implant systems) as predictive of implant failure. In a retrospective cohort study, Strietzel and coworkers [37] assessed treatment outcomes for 504 patients constituting 1,554 implants followed for approximately 6 years on average. Overall, the implant survival rate of 92.6% in the maxilla remained constant after 68 months of observation. In the mandible, the implant survival rate of 96.7% showed no changes after 76 months. Statistically significant correlations were found between the incidence of implant failure and vertical bone loss adjacent to the implant at the time of second-stage surgery. In addition,

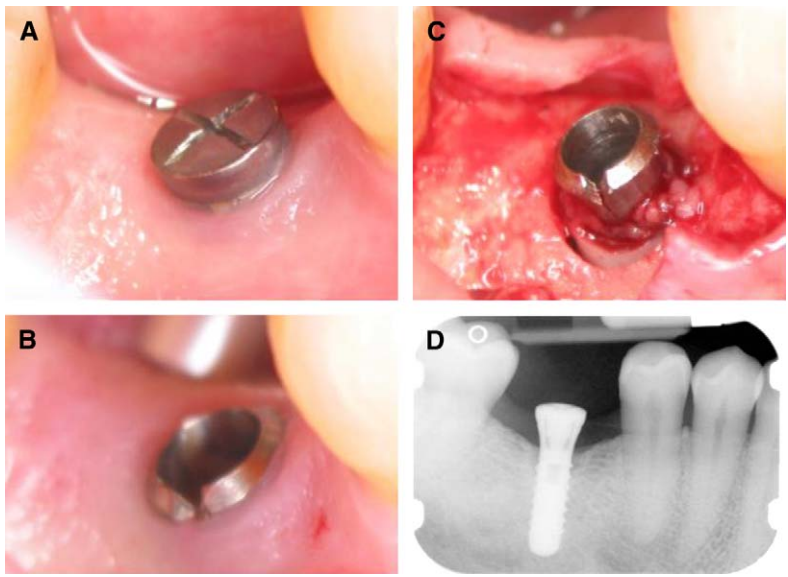

Fig. 2. (*A*) Implant with soft tissue inflammation and suppuration. (*B*) Implant fracture revealed after healing abutment removed. (*C*) Flap elevation and trephining to remove the fractured fixture. (*D*) Preoperative periapical radiograph indicates peri-implant bone loss.

a multivariate Cox regression showed that subject gender (male), jaw (maxilla) and the occurrence of postoperative complications were factors that increased the risk of implant loss. Hence, peri-implant bone resorption before loading along with other factors may compromise implant success.

In a recent, small clinical trial, Widmark and coworkers [38] randomized 43 subjects with resorbed maxillae to one of three treatment groups: (1) bone grafting and implant placement, (2) modified implant placement but no bone grafting (nongrafted control), or (3) optimized complete dentures (negative control). At the 1-year follow-up, 10% (22 of 221) of the implants had been lost, and at the 2-year follow-up, 18% of the implants had been lost (40 of 221 with 25% in the grafted versus 13% in the nongrafted control group). Following years 2 to 5, no further losses occurred. Life-table analysis showed cumulative success rates of 82% in the grafted group and 96% in the nongrafted control group after 1 year, and 74% in the grafted group and 87% in the nongrafted control group at the final examination after 3 to 5 years. Woo and coworkers [39] conducted a larger cohort study involving 677 patients, each with one implant, randomly selected for analysis. The overall implant survival rates were 95.2% after 1 year and 90.2% after 5 years. In the multivariate model, patients with osseous grafting (ie, dento-alveolar reconstructive procedures including sinus augmentation, onlay bone grafting and guided bone regeneration with autogenous bone or substitutes) did not have a statistically significant increased risk for implant failure (odds ratio = 1.4, 95% CI 0.7–2.9). Bivariate analyses revealed that only four factors were statistically or nearly statistically associated with implant failure. These included current tobacco use, implant length, implant staging, and type of prosthesis. The results of this comprehensive study indicate that the use of bone-grafting procedures to reconstruct deficient implant recipient sites is not an independent risk factor for implant failure.

Factors related to occlusion or loading

While restoration of occlusal function is a principal objective of implant therapy, parafunctional and excessive loading may present different risks for failure, including implant fracture [40]. Bragger and coworkers [41] compared the frequency of technical or occlusal complications occurring for implant-supported fixed partial dentures (FPDs), tooth-supported FPDs and mixed (implant- and tooth-supported) FPDs. Eighty-eight partially edentulous subjects were treated and followed for 4 to 5 years with FPDs in function. Complete failures resulted in the loss of one FPD per group. Significantly more technical complications were found for implant-supported FPDs and for cases with bruxism. Of the 10 bruxers, 6 (60%) exhibited a technical complication whereas 13 of the 75 (17%) nonbruxers exhibited a complication. Extensions (cantilevers) were associated with more technical complications (37% with extensions versus 11%

without). These data indicate that bruxism and extensions were associated with more technical failures for implants loaded under a conventional protocol.

Glauser and coworkers [42] reported on treatment outcomes for 41 patients receiving 127 immediately loaded implants (76 maxillary and 51 mandibular). Of these patients, 71% received their prosthetic restoration the same day and the others within 11 days [43]. All prosthetic constructions were in full contact in centric occlusion. At 1 year, 21 implants (17.3%) were lost in 13 patients (including 7 maxillary implants lost in 1 patient). Implants in patients with a parafunctional habit (bruxers) were lost more frequently than those placed in patients with no parafunction (41% versus 12%, respectively). Of the immediately loaded implants placed in regions other than the posterior maxilla, 91% were successful, compared with 66% of immediately loaded implants placed in the posterior maxilla. Immediately loaded implants subjected to guided bone regeneration were more successful compared with those not subjected to regeneration procedures (90% versus 67%). Therefore, patient bruxism, clenching, and the posterior maxilla may reduce the likelihood of implant success under an immediate-loading protocol.

The opposing occlusion or dentition may also be a relevant determinant of implant success. Becktor and coworkers [43] retrospectively analyzed data obtained from 90 consecutive patients with edentulous maxillae autogenous bone grafting and endosseous implants (mean patient follow-up of 64.2 months). Accordingly, the investigators recorded the presence and distribution of the opposing mandibular teeth as a dependent variable. Of 643 maxillary implants placed, 118 (18.4%) were lost between implant placement and definitive prosthesis delivery. The type of mandibular dentition was significantly associated with implant failure during this time interval. In particular, patients with implants opposing unilateral occlusal support showed the highest rate of implant failure (43.8%). Implants that opposed a mandibular implant-supported fixed prosthesis demonstrated an implant failure rate of 14.3%, and in patients with a removable mandibular denture, the implant failure rate was 6.2%. Thus, unfavorable concentration of forces on the maxilla may contribute to increased risk of implant failure.

Esposito and coworkers [44] recently presented results from another systematic review and meta-analysis demonstrating no differences in implant survival with different times of loading. Five randomized control trials constituting 124 patients met study inclusion criteria. Within these studies, implants were immediately loaded after insertion (2 to 3 days), early loaded (6 weeks), or conventionally loaded (3 to 8 months) in edentulous mandibles of adequate bone quality and shape. On a per-patient basis, rather than per-implant basis, the investigators failed to detect any statistically significant differences for prosthesis failures, implant failures, and marginal bone loss on intra-oral radiographs among the three loading strategies.

While it is possible to successfully load oral implants immediately after their placement in carefully selected patients with mandibles of adequate bone density and height, it is yet unknown how predictable this approach is in other cases.

Systemic risk factors

Smoking, a prevalent behavior in our population, constitutes a systemic exposure or risk factor for several adverse health outcomes, including tooth and implant loss [45,46]. The rationale for poorer oral health among smokers is related to vasoconstriction and tissue hypoxia, reduced polymorphonuclear cell function, enhanced inflammatory mediator secretion, and persistence of the pathogenic biofilm [47]. Cohort and clinical trials of endosseous implants consistently rate smoking as a primary patient-centered risk factor for implant loss. In one retrospective cohort study, McDermott and coworkers [48] identified predictor variables (eg, demographic, medical history, implant-specific, anatomic, prosthetic, and reconstructive variables) for 677 patients receiving implant therapy and followed for 13 months on average. These investigators observed an overall frequency of implant complications of 13.9% (10.2% inflammatory, 2.7% prosthetic, and 1.0% operative). A multivariate Cox model revealed that smoking was statistically associated with an increased risk for overall complications or failure. Similarly, Vehemente and coworkers [49] conducted a retrospective study of predictor variables for implant success versus failure involving 677 patients. After adjusting for other covariates in a multivariate model, tobacco use was statistically associated with an increased risk for failure (hazard ratio = 4.36, 95% CI 1.94–9.77). These cumulative findings indicate that subjects who smoke are over four times more likely than nonsmokers to experience implant loss.

Endocrine disease, particularly diabetes, may also pose a systemic risk for implant failure among patients. Morris and coworkers [50] compared treatment outcomes for 255 implants placed in type-2 diabetic patients and 2,632 implants in nondiabetic controls. The primary model assuming independence showed that type-2 diabetic patients exhibited significantly more failures. Although surgeon experience did not affect implant survival overall, the use of adjunctive antimicrobials (eg, preoperative antibiotics or postoperative chlorhexidine mouth rinses) improved implant survival in type-2 diabetics relative to nondiabetics. This association between implant loss and diabetes is likely related to the formation of advanced glycation endproducts, exaggerated production of inflammatory mediators, and impairment in leukocyte function [51]. A recent report by Attard and Zarb [52] documents no differences in implant success rates for hypothyroid patients with replacement therapy versus matched controls.

Postmenopausal women may constitute another at-risk patient group because of decreased estrogen and progesterone levels and altered bone

metabolism. Indeed, this patient group does exhibit reduced alveolar bone density and mass [53]. August and coworkers [54] conducted a retrospective study to test the hypothesis that postmenopausal women have lower rates of osseointegration of endosseous dental implants than premenopausal women and male controls. Five hundred and twenty-six participants were grouped in five categories: (1) postmenopausal women without estrogen replacement therapy (ERT), (2) postmenopausal women with ERT, (3) premenopausal women, (4) men younger than 50, and (5) men older than 50. Successful osseointegration was defined as stability at uncovering using a manual torque wrench plus radiographic confirmation. Postmenopausal women without ERT exhibited the highest maxillary failure rate (13.6%), which was significantly greater than the rate for premenopausal women (6.3%) and for men over 50 (7.6%). Other comparisons in success rates for maxillary and mandibular fixture failed to reach statistical significance. These results suggest that estrogen deficiency and the resultant bony changes associated with menopause may be systemic risk factors for dental implant failure in the maxilla.

Microbial and host immuno-inflammatory factors

Peri-implantitis, defined as infection and inflammation affecting implant-supporting tissues, is a leading cause of late implant failures (Fig. 3). This prompts the question as to whether certain microbial exposures or inflammatory biomarkers may indicate increased risk for subsequent implant failure or loss. Rutar and coworkers [55] conducted a retrospective study to explore the relationship between the clinical and microbiological peri-implant conditions in 45 partially edentulous patients (64 implants). During 5 to 10 years between implant installation and final examination, 9 implants experienced one episode and an additional 6 implants two episodes of peri-implantitis (23% overall). Of the peri-implantitis sites, 4 implants showed cultural evidence for presence of *Porphyromonas gingivalis*, and 2 implants were positive for *Actinobacillus actinomycetemcomitans*. Statistical analysis also revealed a significant relationship between peri-implant probing depth

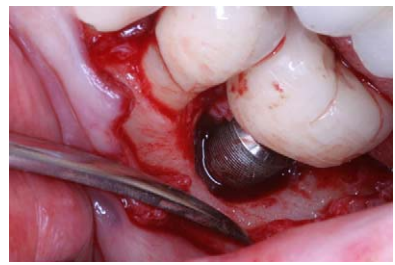

Fig. 3. Peri-implantitis and bony defect formation upon flap elevation and debridement (biological complication).

and the total anaerobic cultivable microbiota, as well as the frequency of detection of *P gingivalis*. These data implicate two putative pathogens of periodontitis with peri-implantitis and implant failure.

Salcetti and coworkers [56] conducted a case-control study comparing levels of bacterial pathogens, inflammatory mediators, and growth factors for failing (eg, evidence of peri-implant radiolucency or vertical bone loss >2 mm after 1 year of function) versus healthy implants. Twenty-one patients with failing implant sites (experimental group) and 8 patients with only healthy implants (control group) were included. Fifteen of the 21 failing-implant patients also presented with at least one stable nondiseased implant. Plaque samples were examined, using checkerboard DNA–DNA hybridization techniques. Peri-implant sulcus fluid samples were collected and analyzed for prostaglandin E_2 (PGE_2), interleukin-1β (IL-1β), IL-6, transforming growth factor-β (TGF-β), and platelet-derived growth factor (PDGF). Although positive trends were noted, there were no significant differences in any of the microbial factors, inflammatory mediators, or growth factors comparing failing to stable implants within the experimental group. In contrast, the investigators detected higher frequencies of *Prevotella nigrescens, Peptostreptococcus micros, Fusobacterium nucleatum ss vincentii,* and *F nucleatum ss nucleatum*, as well as significant elevations in sulcus fluid levels of PGE_2, IL-1β, and PDGF in mouths with failing-implant sites as compared with mouths with healthy control implants. The investigators concluded that risk appears to be primarily at a patient level and secondarily at a site or implant level from a clinical, microbial (*P micros and P nigrescens*), and biochemical (PGE_2 and IL-1β,) perspective. Furthermore, the counts of *P nigrescens* and *P micros* correlated with concentrations of PGE_2 at a site level. These data indicate that specific microbial exposures (orange complex) and the ensuing host inflammatory response are predictive of early implant disease [57].

Specific microbial exposures as assessed with serum antibody levels may also indicate elevated risk for implant failure. Kronstrom and coworkers [58] measured serum IgG antibody titers and avidity in 40 subjects with implant failure (nonosseointegration) and 40 age- and gender-matched control subjects with successful implants. The investigators noted significant elevations in serum IgG antibody titers to *Staphylococcus aureus* subjects with implant failures as compared with control subjects. They also observed significantly higher serum IgG antibody avidity to *P gingivalis* and *Tannerella forsythensis* in subjects with implant failures versus controls. Further analysis failed to demonstrate antibody titer or avidity differences for any of the other pathogens studied. The investigators concluded that serum IgG antibodies or exposure to *T forsythensis, P gingivalis*, and *S aureus* may be associated with the poor implant outcomes.

At least three clinical studies indicate that local elevations in matrix metalloproteinases (MMPs) accompany implant inflammatory and destructive tissue changes occurring around dental implants. Kivela-Rajamaki and

coworkers [59] analyzed peri-implant sulci fluid sampled from healthy versus untreated diseased implant sites for MMP concentrations using immunologic techniques. Accordingly, levels of active MMP-8 and MMP-7 were significantly elevated in diseased peri-implant sulcus fluid as compared with healthy controls. Furthermore, MMP-8 and MMP-7 levels correlated significantly to each other and to gingival index scores. Other cross-sectional studies have documented elevated peri-implant sulcular fluid levels for laminin-5 and gelatinase B at diseased sites relative to healthy sites [60,61]. Cumulatively, these findings demonstrate that host inflammatory biomarkers are up-regulated secondary to infection and that these biomarkers may be predictive of peri-implant tissue changes and ultimately implant failure.

Evidence on genetic risk markers for implant failure

To date, there is inconsistent evidence on any genetic risk factors for implant therapy. Studies in general have focused on genetic variations or polymorphisms for cytokines, such as IL-1, that are involved in bone turnover and resorption. Independent research has demonstrated that these cytokine polymorphisms indicate increased risk for advanced periodontitis or tooth loss in human populations [62,63]. Gruica and coworkers [64] demonstrated a positive association for the combination of IL-1 genotype plus heavy smoking with implant complications. These investigators conducted a retrospective analysis of 180 consecutive Swiss subjects followed for at least 8 years following implant and prosthetic treatments. Biological complications (Fig. 3) were defined as suppuration, fistula, and peri-implantitis with radiographic bone loss. Subjects were further classified on the basis of smoking status. Overall, 36% of subjects tested positive for the IL-1 genotype, and 17% of fixtures presented with a biological complication. Failures in general clustered in heavy smokers with the IL-1 genotype (50%). Jansson and coworkers [65] conducted a similar clinical study involving 22 partially edentulous Swedish patients who were treated with implants and who consented to genetic testing. For this cohort, the implant failure rate was 30.1%. Of these, 45% were smokers and 27% were IL-1 genotype positive. Patients positive for IL-1 genotype were more prone to implant loss, however, a synergistic effect between IL-1 genotype and smoking was noted. At least two other clinical studies report no detected association between the IL-1 genotype and implant failures in nonsmoking populations [66,67]. In addition, Campos and coworkers [68] report no association for TNF-α polymorphism and implant failure among a cohort of 66 Brazilian nonsmoking subjects. The limited data suggest that genetic polymorphisms related to cytokines may confer increased risk for dental implant failure at least among patients who smoke.

Summary

Clinical trials document a consistently high success rate for endosseous dental implants in partially and completely edentulous patients. Failures occur at a low rate but tend to cluster in those with common profiles or risk factors. These risk factors may be categorized as related to implant devices, procedures, anatomy, systemic health or exposures, occlusion, microbial biofilm, host immuno-inflammtory responses, and genetics. In general, factors related to the patient appear to be more critical than those related to the implant in determining the likelihood of implant failure [69]. Several of these risk factors can be modified. For example, the patient can modify smoking habits and the clinician can modify implant selection, site preparation, and loading strategy. Both the patient and clinician are important for long-term oral biofilm management and maintenance. In identifying these factors and making appropriate interventions, clinicians can enhance dental implant success rates for better oral function, esthetics, and patient well-being.

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The Immediate Placement of Endosseous Dental Implants in Fresh Extraction Sites

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Nearly 40 years ago, the advent of implant dentistry changed our ideas about tooth replacement therapy for our patients. Brånemark discovered that fully edentulous patients could be dentally rehabilitated using machined screws made of commercially pure titanium, which osseointegrated to the jawbone, enabling the attachment of a fixed prosthesis [1]. Since then, endosseous dental implants of various shapes and surface textures have been used in partially edentulous patients, achieving a measured rate of success of 96.7% at 8 years [2]. To achieve this safe, predictable, and cost-effective mechanism of rehabilitation, Brånemark and coworkers developed a list of clinical recommendations regarding treatment protocols. According to one of the recommendations, a waiting time of 12 months was necessary following tooth extraction before an endosseous dental implant could be installed [3]. The rationale for this reasoning was to allow resolution of any hard or soft tissue pathology in a proposed recipient site.

Several investigations have evaluated the effects of tooth extraction on the dimensional changes observed with both the hard and soft tissue. These changes in the healing extraction sockets have been evaluated by means of cephalometric analysis [4,5], study cast assessments [6–8], subtraction radiography [9], and direct measurements made at surgical reentry [10–13]. Diagnostic casts have the ability to evaluate morphologic changes in the bone and overlying mucosa in a noninvasive fashion. During the first 4 months of healing, according to observations and measurements, the buccal-lingual ridge undergoes a reduction of approximately 5 to 7 mm [5,10] with a 2- to 4.5-mm loss of vertical bone height [9,11]. Several studies have observed greater apico-coronal changes when comparing multiple adjacent

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extraction sites to single sites [7,10,11]. Most recently, Schroop and colleagues measured dimensional changes intraoperatively in 46 healing sockets in 46 patients, confined to only the premolars and molars in both arches. They reported a reduction in buccolingual width of nearly 50% over an observation period of 12 months. They noted that two thirds of the change occurred within the first 3 months following tooth extraction, with greatest changes observed in the molar sites.

Noting that this postextraction resorption could adversely affect the availability of bone for implant placement, clinicians began to insert dental implants immediately following tooth extraction. The first reported case was described by Schulte in 1976 using a polycrystalline aluminum surface [14]. Since then, numerous clinical case reports have been published, and, at various times, review papers have appeared to update this surgical technique with contemporary findings [15–18].

Advantages and disadvantages

In nearly all cases, investigators report many advantages for immediate placement. These include a reduction of surgical procedures [19], a reduction in treatment time [20], preservation of alveolar bone [21–23], maintenance of ideal soft tissue contours [24], better implant placement [25], simplification of the prosthetic design [19], and an improvement in the patients' psychological outlook for dental treatment [26].

Potential disadvantages of immediate placement include the possibility of infection [27–29], lack of soft tissue closure [30], thin tissue biotypes with consequent risk of recession [31], and an incongruity between the socket wall and the endosseous implant shape [32].

Site classification

To assist the clinician in properly evaluating patients for immediate dental implant placement, several investigators have developed a classification system for the timing of implant placement following tooth extraction [7,17,18,30,33]. Terms such as *immediate*, *recent*, *delayed*, *late*, and *mature* have been used in the literature in describing timing for implant placement following an extraction. Wilson and Weber's description concerns soft tissue healing and the predictability of guided bone regeneration. Mayfield's classification focuses on intervals expressed as time before installation of an implant. Most recently, Chen and colleagues [18] published a report classifying implant placement based on morphological, dimensional, and histologic changes that occur following tooth loss with regards to the term *immediate* (Table 1). Several papers defined *immediate* as occurring on the day when the tooth was extracted, while others include the time frame of 0 to 15 days and 0 to 7 days.

Table 1
Protocols for implant placement in extraction sockets and their advantages and disadvantages

Classification	Definition	Advantages	Disadvantages
Type 1	Implant placement immediately following tooth extraction and as part of the same surgical procedure	Reduced number of surgical procedures Reduced overall treatment time Optimal availability of existing bone	Site morphology may complicate optimal placement and anchorage Thin tissue biotype may compromise optimal outcome Potential lack of keratinized mucosa for flap adaptation Adjunctive surgical procedures may be required Procedure is technique-sensitive
Type 2	Complete soft tissue coverage of the socket (typically 4–8 wks)	Increased soft tissue area and volume facilitates soft tissue flap management Resolution of local pathology can be assessed	Site morphology may complicate optimal placement and anchorage Treatment time is increased Socket walls exhibit varying amounts of resorption Adjunctive surgical procedures may be required Procedure is technique-sensitive
Type 3	Substantial clinical or radiographic bone fill of the socket (typically 12–16 wks)	Substantial bone fill of the socket facilitates implant placement Mature soft tissues facilitate flap management	Treatment time is increased Adjunctive surgical procedures may be required Socket walls exhibit varying amounts of resorption
Type 4	Healed site (typically >16 wks)	Clinically healed ridge Mature soft tissues facilitate flap management	Treatment time is increased Adjunctive surgical procedures may be required Large variations are present in available bone volume

From Hammerle CH, Chen ST, Wilson TG, et al. Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. Int J Oral Maxillofac Implants 2004:19(Suppl):27; with permission.

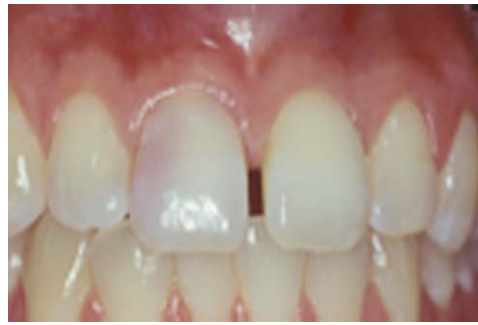

Fig. 1. Preoperative presentation of tooth #8 with internal resorption.

Histology and clinical trials

Many preclinical and human clinical studies have been published regarding immediate implant placement [15–18]. Variables addressed in the studies include implant numbers, implant types, submerged versus nonsubmerged healing, the use of membranes or grafting materials, tooth positions, and follow-up periods. Furthermore, the results of these studies range from pure clinical and radiographic assessments to histologic findings.

Most reports on immediate implant placement describe small periimplant osseous defects resulting in a gap measurable from the wall of the extraction socket to the surface of the implant [19,34]. This defect type has been defined as the horizontal defect dimension (HDD) or ''jumping distance'' [35]. Reentry and histologic studies have shown that these small defects heal with significant bone fill regardless of the placement practices or

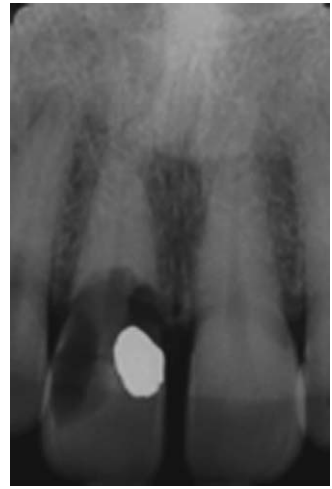

Fig. 2. Preoperative radiograph of tooth #8 with internal resorption.

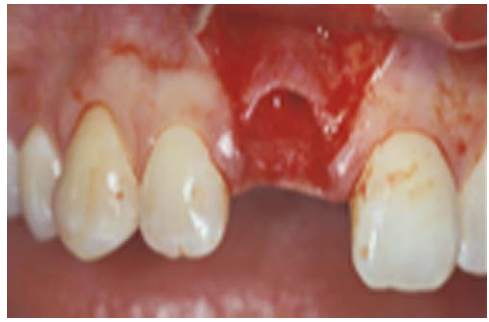

Fig. 3. Buccal view of full-thickness flap and beveled vertical releasing incisions.

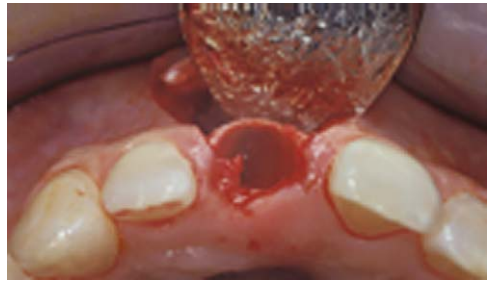

Fig. 4. Completion of degranulation following periotome extraction.

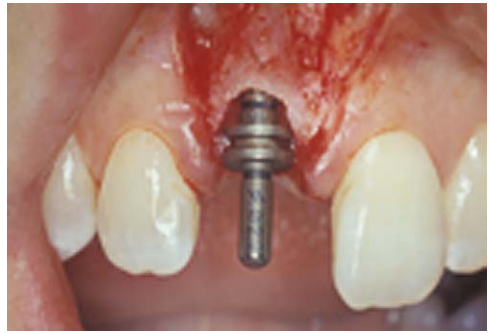

Fig. 5. Occlusal–cervical and mesial–distal orientation determined with a 2.8-mm gauge.

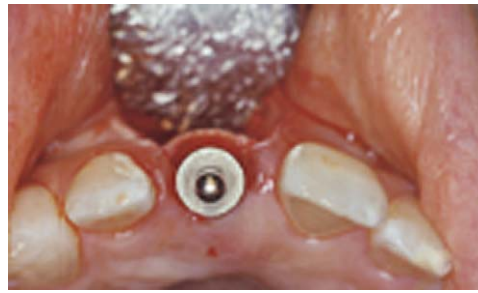

Fig. 6. Buccal–lingual and mesial–distal orientation determined with a 2.8-mm gauge.

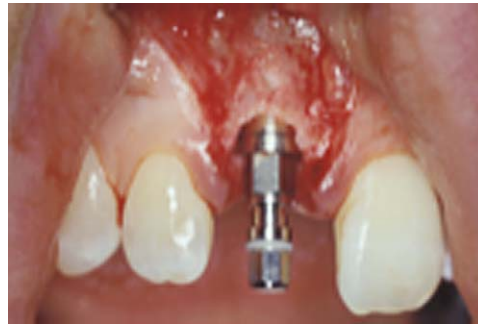

Fig. 7. Buccal view of implant placement.

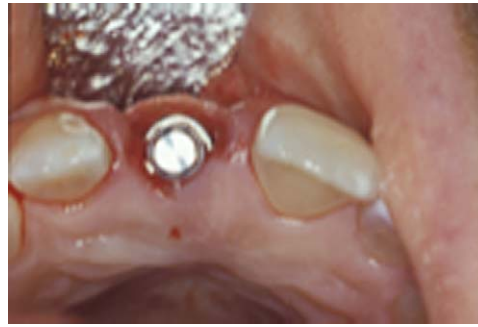

Fig. 8. Occlusal view of implant placement showing buccal HDD.

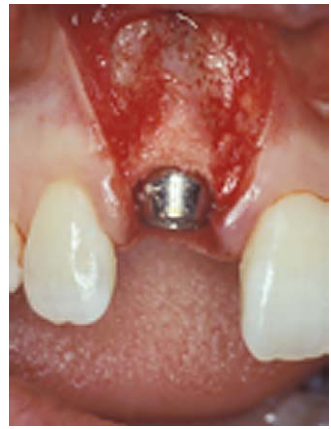

Fig. 9. Buccal view of healing cap insertion and placement of autogenous bone graft.

augmentation methods chosen. Several studies have shown that when the HDD was found to be 2 mm or less in width, no augmentation or membrane was required [35–39]. However, studies illustrating dehiscence or fenestration defects have been shown to benefit from the use of barrier membranes and bone grafting [7, 40–42]. One study observed favorable results in dehiscence defects treated with a resorbable collagen barrier and anorganic bovine bone material. This finding is of particular importance when addressing sites with local bony pathology. Often in such cases, at least one of the socket walls has been traumatized or lost due to infection. Studies have shown a high degree of success in treating dehiscences with a wide variety of methods and materials, including expanded polytetrafluoroethylene membranes and freeze-dried demineralized bone allograft, resorbable collagen membranes and anorganic bovine bone [43], or autogenous bone grafts alone. However, the use of a nonresorbable membrane increases the likelihood of postsurgical infection and requires secondary surgery to retrieve

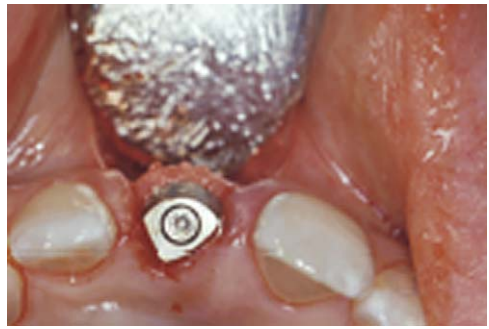

Fig. 10. Occlusal view of autogenous bone graft into the HDD.

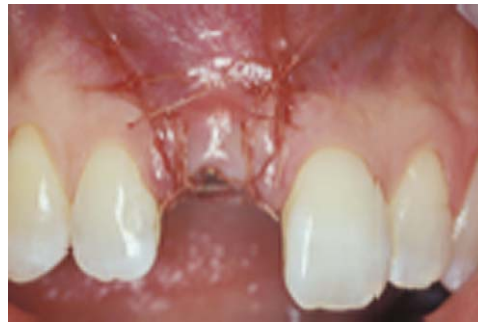

Fig. 11. Buccal view of flap closure.

the membrane [17,44,45]. Furthermore, studies have shown less than ideal bone fill when a nonresorbable membrane becomes prematurely exposed [42,46,47].

The International Team for Implantology consensus paper discussing immediate implant placement identified 18 studies having a follow-up period ranging from 1 to 4 years [18]. All but 4 of the studies involved a submerged placement protocol. The implants under study had varied surfaces: machined, titanium plasma-sprayed, hydroxyapatite-coated, grit-blasted, and acid-etched. The cumulative survival rate (CSR) for immediately placed implants ranged from 89.3% to 100%. Implants having a roughened surface as opposed to a smooth machined surface were shown to have a higher CSR.

Indications

Clinical indications for replacing teeth with immediate implants include retained deciduous teeth, vertically and horizontally fractured teeth, teeth lost to nonrestorable dental caries, periodontal disease, endodontic failure, and poor esthetics [16]. These situations generally offer the clinician the ability to obtain primary mechanical stability with immediate implant

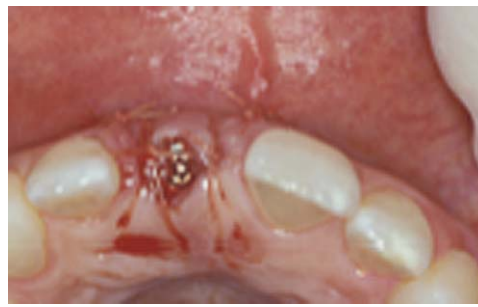

Fig. 12. Occlusal view of flap closure.

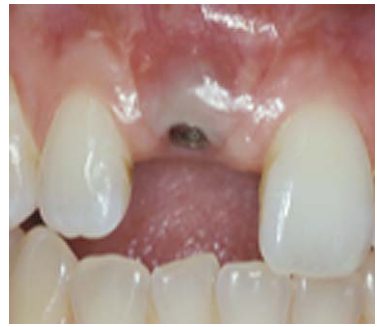

Fig. 13. Buccal view of soft tissue healing at 12 weeks.

placement by engaging either pristine bone 3 to 5 mm beyond the apex of the affected tooth or engaging the lateral walls of the socket [19]. These criteria generally limit the procedure to single-rooted teeth unless a wide volume of inter-raducular bone exists in molar areas. Generally, immediate implants are not inserted into the root sockets of molars due to poor positioning for ideal prosthetics, as well as poor bone quality [48].

Treatment protocol

Figure 1 presents the preoperative view of tooth #8, shown radiographically (Fig. 2) to exhibit internal resorption. Following administration of local anesthesia, a 15 blade is used to create a sulcular incision along the buccal aspect of the planned implant site, and a vertical releasing incision to spare the adjacent papillae (Fig. 3). The vertical releasing incision must be beveled 45° to insure ideal flap closure and to prevent the formation of scar tissue. A full-thickness flap is elevated and extended beyond the anticipated apical extension of the preplanned implant length. This method permits careful evaluation of any pathology present at the periapical region of the tooth to be extracted. The tooth in question is then extracted using a method involving minimal trauma to the bone and surrounding soft

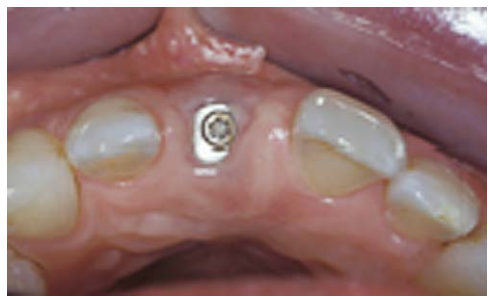

Fig. 14. Occlusal view of soft tissue healing at 12 weeks.

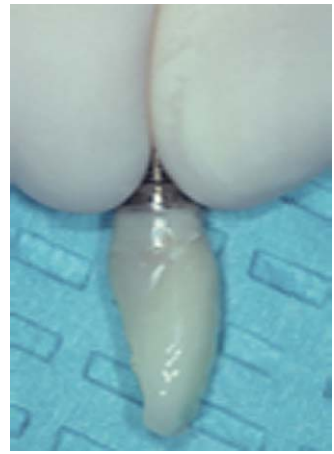

Fig. 15. Fabrication of acrylic screw-retained provisional crown.

tissues. Generally, this extraction is accomplished using a periotome directed along the proximal and buccal surfaces of the tooth root, taking care to avoid fracturing the thin buccal plate noted in cases of a type one gingival/bone phenotype. A forceps of anatomic design can be used to rotate the tooth root in a clockwise–counterclockwise fashion to retrieve the root from the alveolus. Should difficulty arise with this method, the tooth in question should be sectioned vertically with a surgical length carbide bur. Following extraction, the socket is then thoroughly degranulated with curettes and diamond rotary instrumentation to remove all remnants of the periodontal ligament and granulation tissue (Fig. 4). Depth gauges of

Fig. 16. Buccal view of acrylic screw-retained provisional crown.

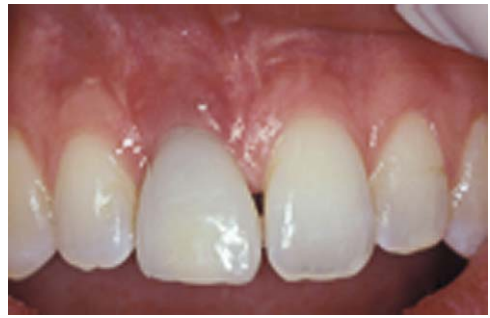

Fig. 17. Insertion of acrylic screw-retained provisional crown.

various diameters are inserted to ascertain the socket architecture before the initiation of the osteotomy. If primary stability of the implant cannot be achieved by increasing the length or width of the socket as ascertained by inserting the final diameter depth gauge, then no attempt should be made with immediate placement and a delayed type two or type three protocol should be followed (see Table 1).

Initiation of the osteotomy should be performed in standard fashion with the initial penetration point for the anterior maxillary teeth approximately 2 mm coronal to the extraction apex and along the palatal wall. This position should ensure that the buccal aspect of the implant does not rest against the buccal plate resulting in compression necrosis. The initial bur penetration point for maxillary premolars and all mandibular single-rooted teeth is directed toward the exact apex of the extraction socket. When preparing the depth of the osteotomy, be aware of the position of the anticipated restorative platform, as it should be located ideally as expected in a delayed or late placement method (Figs. 5 and 6). No attempt should be made to purposely plan the implant restorative platform deeper than 2 to 3 mm apical to the cementoenamel junction of the final restoration (Figs. 7 and 8).

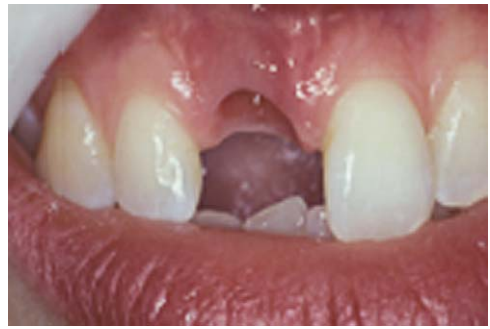

Fig. 18. Soft tissue sculpting following placement of provisional crown.

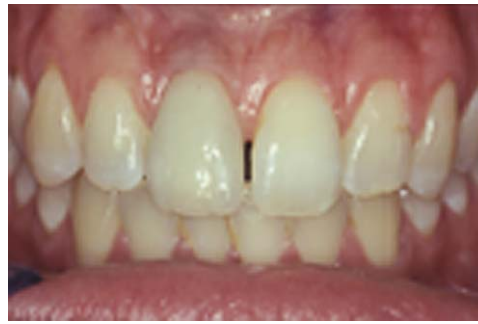

Fig. 19. Postrestoration photograph at 1 year.

Following implant insertion, an appropriate healing cap is selected depending on the desire for a submerged, semisubmerged, or nonsubmerged healing approach. Should an HDD greater than 2 mm exist or a dehiscence be present, osseous grafting and the use of a membrane is required (Figs. 9 and 10). Many times, autogenous bone grafting material can be obtained along the buccal plate, lateral to the implant site, using an osseous bone scraper/collector. Additionally, should increased soft tissue volume be needed, a connective tissue graft should be placed before flap closure. The soft tissue phenotype will dictate the method of flap closure. A type one soft tissue phenotype benefits from a fully submerged or semisubmerged technique, while a type two soft tissue phenotype may be addressed with a semisubmerged or nonsubmerged approach (Figs. 11 and 12). Suture material of 5-0 or smaller and with a minimal wicking effect should be chosen to tie the interrupted

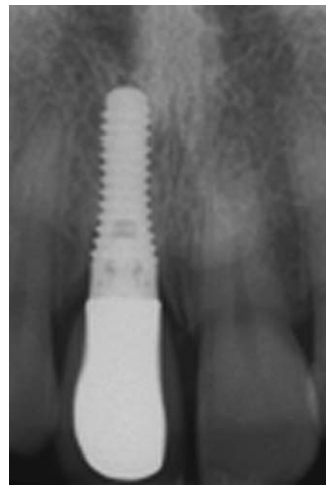

Fig. 20. Postrestoration radiograph at 1 year.

sutures, with the first suture placed to properly position the coronal margin of the flap in the desired location. Suture removal can be accomplished in 7 to 10 days (Figs. 13 and 14) with the insertion of a fixed, screw-retained acrylic provisional restoration at 12 weeks postsurgery (Figs. 15, 16, and 17), and the definitive restoration delivered following the completion of soft tissue sculpting (Figs. 18, 19, and 20).

Summary

The goal of dental implant treatment is to provide safe, predictable, and cost-effective tooth replacement therapy to patients. Treatment methods for these patients should be supported by evidence-based, peer-reviewed literature. Initially, endosseous dental implants were placed into an edentulous site following a sufficient period of socket healing. The caveat of this statement, though, is that only four longitudinal studies with mean follow-up periods between 3 and 5 years have been reported in the literature, despite numerous case reports with findings up to 12 months in length. Currently, the literature notes a nonrandomized pattern of techniques related to immediate placement protocols pertaining to timing of placement as well as augmentation techniques.

Continued publications discussing bone remodeling, limits of the HDD, esthetic outcomes related to gingival phenotypes, and flapless surgeries are needed to advance this concept of immediately placed dental implants forward for the next 10 years.

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Implants in the Esthetic Zone

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The introduction of osseointegration by Brånemark and coworkers [1,2] and replacement of lost teeth by implants have revolutionized oral rehabilitation while significantly advancing restorative dentistry. Implant-supported restorations in edentulous or partially edentulous patients have been shown to be highly predictable in numerous studies [3–8]. In the early years of modern implantology, the chief concern was tissue health and implant survival. Over the last decade, there has been an increasing appreciation that esthetics is just as important to the success of the final restoration as health. Indeed, it can be said to represent a different aspect of health. The World Health Organization has defined health as a state of "complete physical, mental, and social well-being, and not merely the absence of disease and infirmity." Patients increasingly demand restorations that are as esthetic as they are functional. Unlike implants in the early years of osseointegration, many of the implants now being placed are in the anterior maxillary region and other esthetically sensitive areas.

Consequently, many recent studies have concentrated on treatment outcomes of implant therapy performed in the esthetic zone [9–13]. In a review of the recent literature, Belser and colleagues reported that dental implants in the anterior maxilla have an overall survival and success rate similar to those reported for other segments of the jaw [14]. In an 11-year retrospective study, Eckert and Wollen evaluated 1170 implants placed in partially edentulous patients and found no differences in survival rates of the implants with regard to their anatomical location [15]. In a 5-year multicenter study, Henry and colleagues reported an implant success rate of about 96% for single-tooth replacements in the anterior maxilla. However, they also reported an esthetic failure rate of about 9% for implant placement in this area [4]. This underscores the critical importance of esthetics as a determinant of implant success and patient satisfaction.

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Implant placement and restoration to replace single or multiple teeth in the esthetic zone is an especially challenging area for the clinician, particularly in sites with multiple missing teeth and with deficiencies in soft tissue or bone. Preservation or creation of a soft tissue scaffold needed to create the illusion of a natural tooth is often challenging and difficult to achieve [16,17]. Placement of a dental implant in the esthetic zone is a technique-sensitive procedure with little room for error. A subtle mistake in the positioning of the implant or the mishandling of soft or hard tissue can lead to esthetic failure and patient dissatisfaction [14,18,19]. This article presents guidelines for ideal implant positioning and for a variety of therapeutic modalities that can be implemented for addressing different clinical situations involving replacement of missing teeth in the esthetic zone.

Diagnosis and treatment planning

To achieve a successful esthetic result, implant placement in the esthetic zone demands thorough preoperative diagnosis and treatment planning combined with excellent clinical skills. Preoperative assessment of the patient's expectations is also of paramount importance. If the patient is found to have unrealistic expectations, a careful explanation might be necessary to clarify what the patient should expect. The skills of the entire implant team, consisting of the restorative dentist, implant surgeon, and dental technician, are all required to develop and execute a comprehensive, well-sequenced treatment plan. Such teamwork is indispensable to achieve a superior result.

Data collection

The development of a proper treatment plan requires accurate and comprehensive data collection. The database must include the patient's chief complaint, comprehensive medical history, dental history, results of extra-oral and intra-oral clinical examinations, radiographic examination results, documentation of patient expectations, and an assessment of risk factors for implant failure (esthetic or functional) [20]. Uncontrolled medical conditions; parafunctional habits, such as bruxism; poor compliance with oral hygiene or maintenance regimens; active periodontal disease; and smoking status should be evaluated and taken into consideration.

For ideal implant placement and optimal esthetic restorations, a comprehensive evaluation of the edentulous site must be performed [18]. Facial, dental, and periodontal status must be evaluated. A facial evaluation provides general esthetic parameters, such as orientation of occlusal plane, lip support, symmetry, gingival scaffold, and smile line. A dental evaluation provides information about the edentulous site in three dimensions, as well as information about occlusion, adjacent teeth, interarch relationships

and presence of diastemata. Finally, a comprehensive periodontal examination, including home care assessment, periodontal charting, and radiographic analysis, are essential for an optimal functional and esthetic result [21].

Gingival recession and biotypes

The gingival biotype should be assessed because such an assessment will partly determine the risk for postsurgical recession [22,23]. A thin, highly scalloped gingival biotype is much less resistant to trauma from surgical or restorative procedures and, consequently, is more prone to recession in comparison with a thick, flat gingival biotype. A thin gingival biotype dictates placement of the implant in a slightly more palatal position to reduce the chance of recession and prevent a titanium "shadow" from showing through the thin gingival tissue. Similarly, the implant should be placed somewhat more apically to achieve a proper emergence profile and avoid a ridge lap restoration [18].

Because patients with minimal gingival thickness are at higher risk of esthetic failure, it may sometimes be prudent to recommend soft tissue augmentation or conventional prosthetic prosthesis rather than implant placement. At the very least, such patients should be informed of the possibility of postoperative recession and the esthetic consequences. Kan and colleagues reported that peri-implant mucosal dimensions were greater in patients with a thick gingival biotype than those with a thin biotype [24]. The long-term stability of esthetic soft tissue around an implant restoration depends largely on the presence of adequate soft tissue volume in a vertical and buccolingual direction [25]. An adequate volume of soft tissue provides a good emergence profile of the implant restoration and serves to mask the underlying metal implant, especially when combined with suitably apical placement. A subepithelial connective tissue graft may be considered to augment soft tissue volume when insufficient tissue volume is present [26]. More rigorous studies are needed to determine the actual risk factors for postimplant recession and its treatment.

Interdental papilla

The supporting bone influences the establishment of overlying soft tissue compartments and the bone quality and quantity must be carefully assessed [21,27]. The vertical bone height in the interproximal sites, as well as the horizontal thickness and vertical height of the buccal bone wall in the edentulous site, are important determinants of esthetic success [19,24,27–31]. The bone crest should be within a physiological distance of 2 to 3 mm of the cemento-enamel junction or, when recession is present, 2 to 3 mm of the buccal gingival margin (Fig. 1).

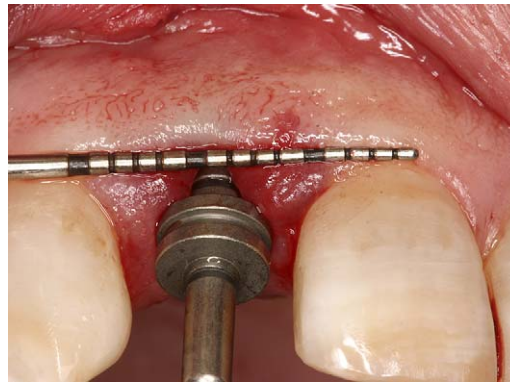

Fig. 1. Apicocoronal position of implant. Implant platform should be within 2 to 3 mm apical to the mid-buccal gingival margin.

The distance between the underlying interproximal bone height on the adjacent natural teeth and the final prosthetic contact point dictates the formation and spontaneous regeneration of the interdental papillae associated with the implant. If this distance is more than 5 mm, the complete papilla formation will be compromised. This often leads to the so-called ''blank triangle'' [32,33]. This effect may differ according to whether the implant is adjacent to another implant or a natural tooth. For example, Kan and colleagues reported that the height of the interproximal papilla of the crown is independent of the proximal bone level next to the implant, but is related to the interproximal bone height of the neighboring teeth [24].

Tarnow and colleagues found that, in most cases, the vertical distance from the crest of bone to the height of the interproximal papilla between adjacent implants is 2 to 4 mm [31]. Papillary height can, therefore, be partially influenced by spacing of the implants and placement of the contact point. It is also likely that emergence profile and interproximal restoration contours may also play a role in papillary form, but these determinants are more difficult to study and no good evidence supports specific recommendations.

A diagnostic wax-up is often required, especially in cases involving placement of multiple implants. The wax-up previews the future restoration and potential difficulties and can be used to educate the patient during the informed consent process. A duplicate cast can be fabricated from an impression of the wax-up and be used to create a surgical template, which serves as a guide to the surgeon during implant placement. The entire treatment plan should be developed with input from the entire implant team.

Following the development of a proper treatment plan, the plan is presented to the patient and thoroughly discussed, along with a consideration of the risks, benefits, and alternative forms of therapy. Informed consent

is obtained and the patient's expectations are again determined. Only after this discussion can surgery be undertaken.

Implant placement

The surgical approach must be carefully planned and executed. Tischler has proposed guidelines for implant placement and restoration in the esthetic zone [34]. According to these guidelines, the surgeon should:

- Employ a conservative flap design;
- Evaluate the existing bone and soft tissue;
- Time the placement correctly;
- Visualize the three-dimensional position of the implant;
- Consider healing time before implant loading;
- Consider the determinants of emergence profile; and
- Select a proper abutment and final restoration design.

The implant should be considered the apical extension of the restoration and the preferred design of the restoration should guide the surgical placement of the implant [27,35]. This concept is known as restoration-driven implant placement, in contrast to the previously accepted concept of bone-driven implant placement. Restoration-driven implant placement mandates that the implant is placed where it can be properly restored. If the desired site is lacking in bone or soft tissue, then augmentation procedures must be employed to create an acceptable site. Optimal esthetic implant restoration depends on proper three-dimensional implant positioning [36]. Four positional parameters contribute to the success of the restoration and all must be carefully considered during implant placement. These are the buccolingual, mesiodistal, and apicocoronal positions relative to the implant platform, as well as the angulation of the implant. Prosthetic design factors (eg, cement- versus screw-retained prosthesis) are also critical.

Buccolingual position

An implant placed too far buccally often results in a dehiscence of the buccal cortical plate and has a high potential for gingival recession. In addition, this placement vastly complicates the restoration of the implant. On the other hand, an implant placed too far to the palatal often requires a ridge-lap restoration that is both unhygienic and unesthetic [13,18,37]. Proper buccolingual positioning of the implant simplifies the restorative procedure, results in a proper emergence profile, and facilitates oral hygiene. The buccal wall must maintain a thickness of at least 1 mm to prevent recession and improve esthetics. In his study of over 3000 implants, Spray measured the vertical dimension of facial bone between implant placement and

uncovering stage, comparing these changes to facial bone thickness. As the bone thickness approached 1.8 to 2 mm, bone loss decreased significantly and some evidence of bone gain was seen [38].

The ideal buccal-lingual position is a function of the desired crown location and the design of the implant and abutment. Placement should be such that the crown emerges naturally from the soft tissue scaffold to create the illusion of a natural tooth [39]. To achieve this, the centerline of the implant must often be located at or near the center of the tooth it replaces [40]. The implant must be positioned in such a way that the buccal aspect of the implant platform just touches an imaginary line that touches the incisal edges of the adjacent teeth (Fig. 2). There are, however, situations requiring that the implant be placed in a more palatal position (eg, in patients presenting with a thin gingival biotype [18]). Conversely, it is sometimes wiser to place the implant in slight labioversion. Occlusal considerations occasionally necessitate such placement, particularly in cases involving excessive vertical overlap [18,27].

Mesiodistal position

To avoid an unfavorable esthetic outcome, the available mesiodistal space must be carefully measured so that an implant of the proper size may be selected and proper implant spacing planned. Placement of an implant too close to adjacent implants or teeth may result in interproximal bone loss with subsequent loss of papillary height. Studies have shown that, in addition to the vertical component, there is a lateral component to the crestal bone loss around the implant [29,41]. Based on these findings, a minimum distance of 1.5 to 2 mm should be maintained between implants and neighboring teeth and, in the case of multiple implants, a space of 3 to 4 mm at the implant abutment level should be maintained between implants [29,41]. A strong inverse correlation exists between crestal bone loss at adjacent teeth or between implants and the horizontal distance of the implant fixture to the tooth or

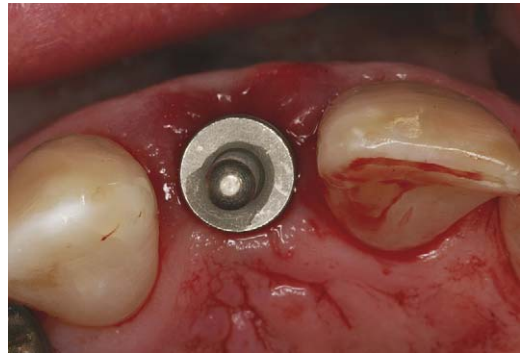

Fig. 2. Buccolingual position of implant. Buccal aspect of the implant platform touches an imaginary line that touches the incisal edges of the adjacent teeth.

implant [29,41]. In the case of a maxillary central incisor site, it may be desirable to place the implant slightly to the distal to mimic the natural asymmetry of the gingival contour often seen in these teeth.

Apicocoronal position or countersink

Apical positioning of the implant is required to mask the metal of the implant and abutment. This positioning may involve countersinking the osteotomy site. The degree to which this is done and the manner in which it is accomplished will depend, in part, on the design of the implant head. The amount of countersinking required is somewhat dependent upon the implant diameter [22]. The wider the implant, the less distance is needed to form a gradual emergence profile. In such cases, less countersinking will be required. The distance from the platform to the mucosal margin is sometimes referred to as ''running room.'' The countersink should provide sufficient running room to form a gradual transition between the implant platform and the contour of the restoration (ie, emergence profile). A variable amount of running room is needed to compensate for an implant platform that often has a smaller diameter than that of the cervix of the tooth it replaces. Without apical placement to compensate for the difference in diameter, the transition from implant to tooth can be abrupt.

In general, the more apical the placement of the implant, the better the emergence profile [42]. However, locating the implant-abutment interface more apically means losing more crestal bone for establishing the periimplant biological width [43–45]. It is generally accepted that the crestal bone is reestablished 1.5 mm apical to the implant-abutment interface. This spacing is also known as the microgap. The apicocoronal position of the implant should provide a balance between health and esthetics. The emergence profile and the location of the microgap are the two most important parameters affecting health and esthetics. Generally speaking, there is an inverse relationship between these two parameters. The more apical the implant placement, the more esthetic the restoration (and the less healthy the tissue). Excessive countersinking of the implant can cause saucerization, which is the undesirable circumferential vertical and horizontal crestal bone loss, and subsequent gingival recession after loading. Conversely, superficial placement of the implant can lead to visible metal margin or optical reflection and a compromised restoration without a gradual, pleasing emergence profile [46].

In a patient without gingival recession, it is generally acceptable to use the cemento-enamel junction (CEJ) location of adjacent teeth as a point of reference to determine the apicocoronal position of the implant platform. The sink depth of the implant shoulder should be 1 to 2 mm for a one-stage implant or 2 to 3 mm for a two-stage implant apically to the imaginary line connecting mid-buccal of CEJs of the adjacent teeth without gingival recession. It is essential to take into consideration the varying CEJs of the

adjacent teeth. For example, the CEJ of the maxillary lateral incisor is usually located 1 mm more coronally than the CEJs of the adjacent central incisor and canine. In patients with gingival recession, the mid-buccal gingival margin can be used as a reference in lieu of the CEJ.

A final consideration involves the potential for additional growth of the maxilla. It has been suggested that implants should be placed only after the age of 15 in females and 18 in males [47] to avoid potential problems caused by further skeletal growth. However, some evidence shows continuous vertical growth of the maxilla after age 18 [48,49], so the issue is not entirely resolved.

Implant angulation

Ideally, implants should be placed so that the abutment resembles the preparation of a natural tooth. In screw-retained prostheses, poor angulation can alter screw placement, which may have a significant effect on esthetics [46]. Implants positioned with too much angulation either toward the palatal or the buccal often compromise esthetics and may also impact home care [42]. It is generally accepted that the implant angulation should mimic the angulation of adjacent teeth if the teeth are in reasonably good alignment. Most implant systems include a provision for some type of angled or custom abutments to compensate for situations where ideal alignment may not be possible. Surgical guides can help provide the right angulation, as this may be difficult to visualize at the time of surgery. In the maxillary anterior regions, a subtle palatal angulation is sometimes recommended to increase labial soft tissue bulk and to avoid the problems with thin buccal walls described earlier [34].

Timing of implant placement following tooth removal

Garber has described three scenarios for the timing of implant placement following extraction [27]. Immediate placement occurs at the time of tooth extraction, staged placement occurs at least 8 weeks following extraction, and delayed placement is performed 3 months or more following extraction. A simplified scheme, presented below, considers only two groups—implants placed immediately following extraction and those placed a variable time following tooth removal.

Immediate placement of implant at the time of extraction

Following tooth removal, a variable amount of ridge collapse takes place because of bone resorption. This bone loss can occur in either buccal-lingual or apicocoronal dimensions or in both [50–52]. As much as 3 to 4 mm of buccolingual and apicocoronal bone resorption can occur during the 6 months following extraction. This bone resorption reduces bone available

for implant placement and may preclude such treatment altogether. To correct these defects, complex regenerative procedures are sometimes required. Unfortunately, these procedures involve additional treatment time, morbidity, and cost.

To avoid these problems, a technique has been introduced involving simultaneous tooth extraction and immediate implant placement [39]. This technique allows for bone and soft tissue preservation and shortens treatment time. Placing implants immediately or soon after extraction preserves bone and overlying soft tissue, according to clinical observations [28,53]. The necessary initial implant stability is obtained through the use of longer and wider implants, which are capable of engaging bone in the apical and palatal portions of the socket. Several studies have shown the success rates of immediate implants to be comparable to those placed in healed extraction sites [54–56]. Since the hard and soft tissue scaffolds can be maintained by immediate implant placement, it is appropriate to consider this option in the esthetic zone. However, because of poor planning and surgical misadventure, compromised esthetic results are sometimes observed following immediate placement.

Atraumatic extraction

After clinical and radiographic evaluation, the hopeless tooth is atraumatically extracted so as to preserve both the bony socket wall and soft tissue architecture. A number of instruments have been developed for this purpose, including the periotome [57,58]. The periotome, a slim elevator-like instrument, is introduced into the periodontal ligament space and used to sever the periodontal ligament. The instrument is gradually advanced toward the apex of the tooth. Care should be taken to preserve the thin buccal wall of maxillary incisors. When necessary to preserve the integrity of the socket, the tooth is carefully sectioned and the fragments carefully removed [59]. Whenever possible, the surgeon should avoid reflecting a flap to preserve the vascular supply and periosteum covering the bone (Fig. 3). This will minimize bone resorption [60]. Once the extraction is completed, the socket is debrided and then evaluated.

Implant placement

The decision regarding immediate implant placement is determined by three factors:

- Absence of acute noncontained infection;
- Achievement of initial stability of the implant; and
- Sufficient quantity and quality of bone present.

In the presence of disseminated infection in an extraction socket, delaying placement for about 3 weeks postextraction may be considered to allow for resolution of local pathology and achievement of primary soft tissue closure [34]. The integrity of the socket is evaluated. If the socket wall is intact and

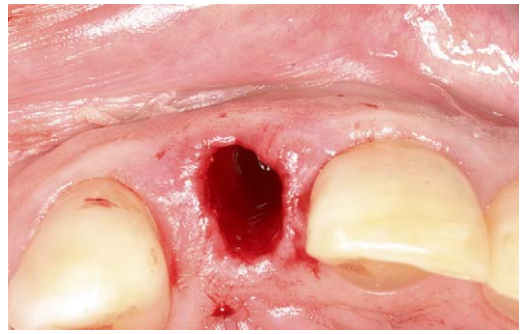

Fig. 3. Atraumatic tooth extraction. Avoidance of flap reflection preserves the vascular supply.

a favorable horizontal and vertical level of both soft tissue and bone architecture is present, immediate implant placement may be attempted. The necessary initial implant stability is obtained through the apical and palatal engagement of existing bone of the maxillary socket by using a long implant. Tapered implants or implants with wider diameters can also be of use in engaging the bony walls.

The three-dimensional placement of the implant is visualized and planned using the surgical guide. It is often helpful to gauge the dimensions of the socket relative to implant configuration by placing various depth gauges in the socket. Some minimum amount of apical stability is required. Unfortunately, evidence is insufficient to give clear guidelines, but in our clinic we must be able to engage at least 6 mm of bone of reasonable quality before considering immediate placement. The depth gauge helps us make that assessment. A minimum of 1 mm of buccal plate should be maintained to enhance long-term prognosis and reduce the risk of soft tissue recession. A concomitant soft tissue augmentation at the same time of implant placement may be recommended in patients with a thin gingival biotype to further reduce the risk of soft tissue recession and buccal bone resorption.

After an immediate implant placement into extraction socket, it is critical to assess the horizontal space, if any, from the implant surface to the socket wall. Studies have shown that no bone augmentation is needed if the peri-implant space is 2 mm or less because spontaneous bone fill and osseointegration will take place when using a rough surface implant [61–63]. In sites where the peri-implant horizontal defect measures more than 2 mm, a bone regenerating technique is required to predictably achieve bone fill and increase the percentage of bone-to-implant contact [61].

When a slight horizontal defect in the socket buccal wall is present, the size of this defect should be determined. If this defect is less than 5 mm in the apicocoronal direction [64] or less than one third of the mesiodistal dimension between the adjacent teeth [65], immediate implant placement

at the time of extraction can be accomplished. Depending on the size of the dehiscence, lateral bone augmentation [65] or guided bone regeneration may be performed as needed [66–68].

In the case of larger bony defects, more extensive augmentation is required. Generally, if sufficient initial stability of the implant can be obtained, a bone grafting procedure with membrane can usually be performed at the time of placement [69–75]. In the case of bony defects so extensive that implant placement is precluded, then delayed implant placement following lateral ridge augmentation is indicated. Grafting materials used for this purpose include both autogenous bone [76–78] or allograft bone replacement grafts [72,79].

Vertical (apicocoronal) bone loss is usually the result of periodontal disease and represents a particularly difficult challenge. No surgical approach is available to predictably augment the ridge height. Some case reports suggest a surgical approach using nonresorbable membrane [80,81], while others suggest using a submerged implant to maintain space under a barrier membrane [82,83]. A nonsurgical approach, orthodontic extrusion, has been introduced to increase the volume of the bone and the height of the soft tissue [64]. The tooth is gradually and slowly extruded by orthodontic forces, bringing with it bone and soft tissue. At the end of tooth movement, the tooth is removed and an implant placed. Obviously, this technique is time-consuming and does not address the problem of mature edentulous sites that require additional vertical bone height. Some investigators report good success with distraction osteogenesis, but that discussion is beyond the scope of this paper. For further information on this modality, the reader should refer to recent reviews [84,85].

Implant placement in edentulous sites

When an edentulous site in the esthetic zone is planned for implant placement, the site must be thoroughly evaluated. Garber has proposed a classification for such sites [86]. This classification depends on the type of reconstruction needed to get good positioning of the implant.

Garber Class I

When favorable horizontal and vertical levels of both soft tissue and bone are present, ideal implant positioning is a straightforward procedure. A concomitant soft tissue augmentation at the same time of implant placement is preferred in patients with a thin gingival biotype to prevent the risk of soft tissue recession and buccal bone resorption.

Garber Class II

Sites with no vertical bone loss and slight horizontal bone deficiency measuring about 1 to 2 mm narrower than normal can be expanded by using serial osteotomes instead of drilling, according to the method described by

Summers [87]. This technique will permit slight expansion of the bony ridge horizontally while simultaneously compressing the maxillary cancellous bone to improve the bone quality. However, this technique has not been investigated and insufficient evidence exists to make evidence-based recommendations. As always, one alternative is to get sufficient initial stability of the implant and lateral augmentation of the ridge using bone grafting techniques [69–71] or bone generation techniques [69,71–75].

Garber Class III

For sites with no vertical bone loss and horizontal bone loss greater than Class II, implant placement can be attempted, provided an initial stability is achieved. Guided bone regeneration is necessary.

Garber Class IV

In sites with no vertical bone loss but significant horizontal loss, it is necessary to use a staged approach in which the ridge is widened with guided bone regeneration. Implants are later placed after a suitable healing period of several months [76–79], using block bone grafts or guided bone regeneration techniques [69,72]. Autogenous bone has generally been the graft material of choice in these procedures.

Garber Class V

Sites with extensive apicocoronal bone loss present a significant challenge to the surgeon. As noted above, there are no well-documented surgical approaches available to predictably augment bony ridge height. Some case reports suggest a surgical approach of guided bone regeneration using a nonresorbable membrane and delayed implant placement [80,81], while other investigators suggest tenting barrier membranes with an immediately placed, submerged implant as a space-making device under the membrane [82,83]. Distraction osteogenesis has been used to augment the ridge height, but no long-term clinical data is available on outcomes in this application [88–90].

Regardless of the type of procedure planned for the mature site, proper flap management is critical for success. Careful attention should be paid to incision design and flap extension in an effort to preserve the blood supply of the flap. A papillae sparing incision (parapapillary incision) may be used to preserve blood supply to the delicate interdental papillae and to minimize the potential of postsurgical recession [91,92] (Fig. 4). Implant placement without incision is mentioned in the literature [93]. In this procedure, the implant is placed into predetermined abundant bone through an opening made by a soft tissue punch. There is insufficient data to properly evaluate this procedure, but the author does not recommend it because this approach does not permit adequate visualization of the bone. Such visualization is necessary for proper three-dimensional positioning of the implant.

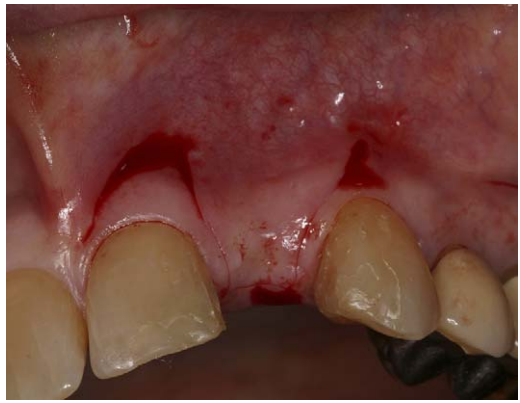

Fig. 4. Papillae sparing incision. Avoidance of papillae reflection minimizes postsurgical recession.

To achieve a successful esthetic result and good patient satisfaction, implant placement in the esthetic zone demands a thorough understanding of anatomic, biologic, surgical, and prosthetic principles. The ability to achieve harmonious, indistinguishable prosthesis from adjacent natural teeth in the esthetic zone is sometimes challenging. Placement of dental implants in the esthetic zone is a technique-sensitive procedure with little room for error. Guidelines are presented for ideal implant positioning and for a variety of therapeutic modalities that can be implemented for addressing different clinical situations involving replacement of missing teeth in the esthetic zone.

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Maxillary Sinus Augmentation

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The placement of dental implants has revolutionized our ability as oral health care practitioners to manage and restore the edentulous posterior maxilla with a fixed prosthesis. The challenge of dental implant therapy in the posterior maxilla has driven the profession to develop new techniques for the management and treatment of the deficient maxillary alveolar ridge. Unlike the posterior mandible, where avoidance and management of the inferior alveolar nerve are paramount, the critical structure in the posterior maxilla is the sinus. Although Tatum [1] was first credited with augmentation of the maxillary sinus for implant placement, Boyne's [2] landmark paper described the use of autogenous bone grafting with long-term follow-up. From those initial investigations, many materials and techniques have become available to the implant surgeon. As a result, an understanding of wound biology and graft physiology has become even more critical. The maxilla itself is different in its function, physiology, and bone density than the mandible. These differences, in combination with the unique and varied anatomy of the maxilla, pose a challenge to the surgeon in creating bone height and width sufficient for implant placement in harmony with planned prosthetic rehabilitation. However, a thorough knowledge of contemporary augmentation procedures mitigated by proper patient selection can lead to effective long-term solutions in the management of the deficient posterior maxilla.

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Anatomy and physiology of the maxillary sinus

The maxillary sinus, or the antrum of Highmore, is usually the largest of the paired paranasal sinuses [3]. Each maxillary sinus has a volume of approximately 15 cc and is generally pyramidal is shape. The sinus has two growth phases. The first phase occurs during the first 3 years of life. The second phase begins at age 7 and continues to age 18, paralleling the eruption of the maxillary permanent dentition. From a space perspective, the maxillary sinus occupies the vast majority of the maxillary bone with its inferior surface just above the maxillary teeth and extending superiorly to just beneath the orbit. Anteriorly, the maxillary sinus is found just behind the anterior wall of the maxilla and the medial extension forms the lateral nasal wall. Posteriorly, the maxillary sinus is bounded by the infratemporal surface of the skull, from which the sinus is separated by the infratemporal fossa. The average dimensions of the sinus are 33 mm high, 23 mm wide, and 34 mm in an anterior-posterior length. The floor of the maxillary sinus usually is directly above the three posterior maxillary molars, although the sinus floor may extend to the apices of the premolars and also, but rarely, to the canine. The sinus may ''invade'' the alveolar bone surrounding the roots of the posterior maxillary teeth, where it may pose a surgical hazard when extracting teeth in this area (Fig. 1). The formation of septa (ie, Underwood's septa), both complete and incomplete, within the sinus is often noted. Velasquez-Plata and colleagues recently reported an incidence of septa as revealed by computed tomogram in 24% of the sinuses in 156 patients [4].

The anterior superior alveolar, infraorbital, and posterior superior alveolar nerves and arteries provide both the innervation and blood supply to the sinus. The maxillary ostium provides drainage of the sinus and egress

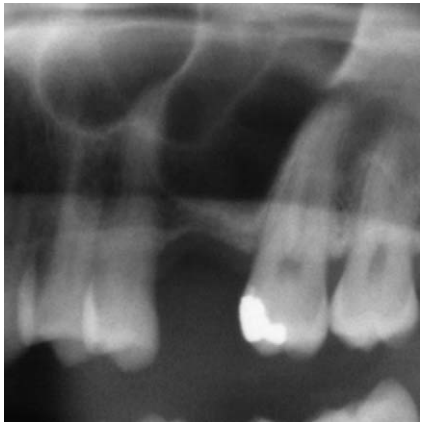

Fig. 1. Pneumatization of the maxillary sinus prohibits dental implant placement until the antrum can be augmented sufficiently to receive an implant.

of mucous and lymphatic fluid into the nasal cavity. The ostium is located on the highest and most medial aspect of the sinus wall, making dependant drainage difficult at best. The ostium drains into the semilunar hiatus of the middle meatus of the nasal cavity, a configuration that can further complicate drainage. In a septated sinus, accessory ostia are usually found to facilitate drainage of the separated compartments.

There are many theories regarding the function of the paranasal sinuses. However, none are widely accepted [5]. According to these postulations, the physiologic functions of the paranasal sinuses include decreasing skull weight; providing vocal resonance; improving olfaction; adding humidity to air to keep tissues in the nose, mouth, and throat moist; and regulating intranasal pressure. The sinus is lined by a thin, ciliated mucous membrane of respiratory mucosa. The cilia move the overlying mucous blanket toward the ostium rapidly at a rate of approximately 6 mm per minute, helping to overcome its relatively nondependant drainage position. In addition to removing particulate matter from the sinus, the mucous blanket also acts to prevent desiccation of the tissues.

Surgical approaches

There are many well-documented approaches for augmentation of the maxillary sinus in preparation for implant therapy. These approaches range from very simple to complex. Some investigators have even suggested augmenting the sinus immediately following the extraction of a maxillary molar [6]. In a given clinical situation, the surgeon must determine which approach is best suited for the management of specific deficiencies in the posterior maxilla. This determination is usually elucidated by the severity of the maxillary alveolar atrophy and the requirements for the patient's planned restorative treatment. In most cases, insufficient high-level evidence is available to formulate evidence-based guidelines for practitioners.

In its simplest form, the Le Fort I osteotomy is an aggressive and necessary tool in the surgeon's arsenal of maxillary bone grafting techniques for the patient with severe maxillary atrophy [7]. Here, the maxilla is separated from the skull base in a controlled manner through intra-oral access. The accomplishment of maxillary down fracture allows the surgeon unparalleled access to the maxilla. From this vantage, cortico-cancellous grafting in large volumes proceeds unimpeded. The surgeon is afforded the opportunity to graft the maxillary floor as well as the lateral walls. In addition, simultaneous maxillary advancement for the severely deficient maxilla permits a better dental relationship for prosthetic treatment planning. In most circumstances, dental implants can also be placed at the same time, with primary stability afforded by block cortical bone grafting. The decision to proceed with a Le Fort I osteotomy should be mitigated by the severity of maxillary atrophy, as well as risks imposed by anesthesia and major surgery in patients

who are often elderly and may also present with significant medical problems. In the skeletal facial deformity population, the sinus membrane is routinely transgressed and in some cases stripped entirely. However, this has not been clinically shown to adversely affect bone healing at the osteotomy sites or grafted areas of the maxilla.

The lateral approach, which is used far more often, is essentially a variation of the classic Caldwell-Luc technique for access to the maxillary sinus (Fig. 2). This approach permits the implant surgeon to gain access to the inferior aspect and floor of the sinus. An incision is made at the height of the crestal bone with releasing incisions as needed posteriorly or anteriorly to reduce flap tension. An osteotomy is created in the lateral maxillary sinus wall. Measures should be taken to protect the sinus mucosa. The lateral

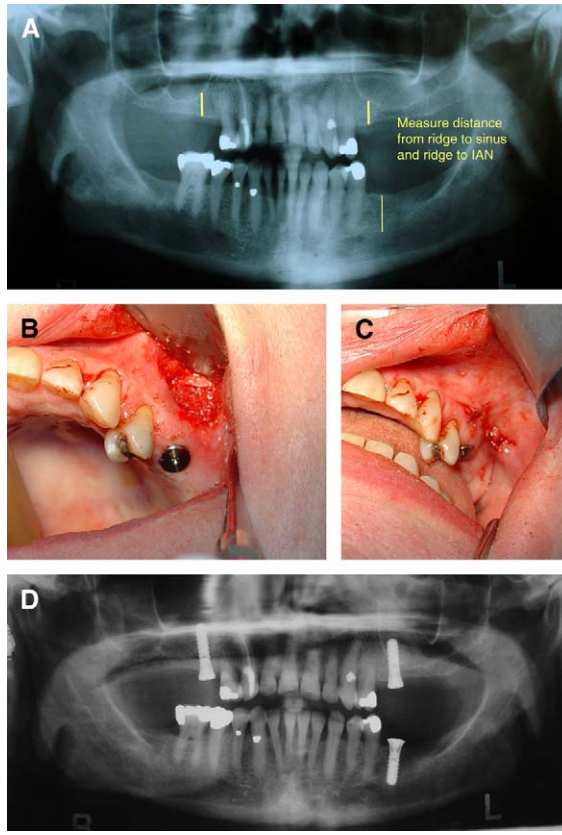

Fig. 2. (*A*) A typical maxillary sinus augmentation case begins with imaging, measurement, and diagnosis. (*B*) After incision, flap reflection, sinus mucosa lift and implant placement, the augmentation material can be packed around the implant. (*C*) The flap is replaced and incision closed. (*D*) An image confirms appropriate implant placement and adequate sinus augmentation. *Abbreviation:* IAN, inferior alveolar nerve.

maxillary wall is then either fractured medially off a superior ''hinge'' or pushed bodily into the sinus. The mobilized lateral maxillary wall segment forms a ''roof'' under which grafting can proceed along the maxillary sinus floor as necessary. Dental implants can be placed simultaneously with this technique, and with the implants in place, the surgeon has the opportunity to meticulously place the graft material as needed around the exposed fixtures. However, primary stability of the implants requires approximately 4 mm of bone height. In the severely atrophic maxilla (ie, <4 mm of bone height), consideration must be given to a staged approach where the bone graft is allowed to consolidate before the dental implants are placed.

Other approaches to the maxillary sinus can be made through the lateral nasal wall or through the alveolus itself. The nasal approach is primarily an antrostomy, which is an approach used by oral and maxillofacial surgeons as well as otolaryngologists for the management of sinus pathology and is not discussed further in this article. Augmentation of the sinus through the alveolus can be performed through an osteotome technique whereby progressively larger osteotomes are ''tapped'' through the alveolus into the sinus floor, ostensibly pushing bone superiorly and therefore creating vertical height through the implant site. This approach is essentially a blind technique. Therefore care must be taken by the surgeon to prevent completely perforating through the sinus with the osteotome to decrease the chance for oral-antral fistula. In addition, there is no opportunity to ensure adequate volume or proper placement of the ''pushed-up'' bone graft to facilitate dental implant placement.

Alloplastic materials for augmentation

The popularity of alloplastic grafting materials has surged in recent years (Table 1). Such materials may be used alone or in combination with autogenous bone, demineralized bone, blood, or other substances. They have the potential to eliminate or at least reduce second surgical site morbidity. Also, they are easy to use and are frequently less expensive than the overall cost for bone harvest. The most common alloplastic grafting materials are those composed of some form of hydroxyapatite (HA) or, more specifically, calcium phosphate ceramics [8,9]. By itself, HA has a dense, porous osteoconductive structure, which forms a scaffold for bone in-growth. Studies have shown clinical success with these materials, but most involve relatively small samples [10]. Some alloplastic grafting materials made mostly of HA or calcium phosphate ceramics, also contain calcium-poor carbonate apatites, which are resorbed by osteoclastic activity. This resorption is then followed by a phase of osteoblastic new bone formation. However, the efficiency of this process remains open to argument.

Another alloplastic grafting material is β-tricalcium phosphate (TCP) [10]. This material has been certified for the regeneration of bone defects in the

Table 1
Characteristics of some common alloplastic and allogeneic materials

Graft material	Brand name	Physical characteristics	Advantages	Disadvantages
Deproteinized sterilized bovine bone	BioOss (Osteohealth, Shirley, New York)	Natural bone mineral with trabecular architecture	Osteoconductive bone substitute	Nonliving
Hydroxyapatite (bovine) (coral) (nonceramic)	Interpore (Interpore International, Irvine, California); Osteogen (Stryker, Kalamazoo, Michigan)	Porous	Osteoinductive	Nonliving
Demineralized freeze-dried bone		Blocks, granules	Osteoinductive; essentially no disease transmission	Nonliving
β Tricalcium phosphate	Cerasorb (Curasan, Research Triangle Park, North Carolina	10–65 μm porous granules	Bone regeneration	Resorption
Calcium sulfate	Calforma Osteoset (Wrighty Medicalk Technology, Arlington, Tennessee); Capset (LifeCore Biomedical, Chaska, Minnesota)	Porous crystals, pellets, powder	Osteogenic	Resorption
Bioactive glass	Biogran (Implant Innovations (3i), Palm Beach Gardens, Florida)	90–710 μm resorbable spheres composed of silicon, calcium, sodium, and phosphorous	Osteogenic	Resorption
Polymethylmethacrylate	Bioplant HTR (Bioplant, South Norwalk, Connecticut)	Highly porous co-polymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrylate with barium sulphate and calcium hydroxide or calcium carbonate coating	Radiopaque, osteopromotive, hypoallergenic, hydrophilic	Nonresorbable

entire skeletal system. It is completely resorbed and replaced by natural, vital bone after 3 months to 2 years. TCP is composed of porous granules generally 10 to 65 μm in diameter. Collagen and blood vessels invade the porous granular system and provide a matrix for new bone deposition. It is reported to be mechanically stable, without induction of immunologic reactions or infection. A recent study shows that an anorganic bovine bone graft material is superior to TCP in promoting new bone formation in the sinus [11].

Calcium sulfate, commonly called gypsum, is another material that has been used to assist in the augmentation of the maxillary sinus [12]. Calcium sulfate has been used in bone regeneration as a graft material, graft binder/extender and as a barrier for guided tissue regeneration. Calcium sulfate comes in an α-hemihydrate and a β-hemihydrate form. In the α-hemihydrate form, calcium sulfate is porous with irregular crystals. In the β-hemihydrate form, calcium sulfate has rod- and prism-shaped crystals. Similar to tricalcium sulfate, calcium sulfate also is completely resorbed over 6 to 8 weeks and does not evoke any substantial host response. Calcium sulfate is purported to be osteogenic, with the ability to induce new bone formation.

Pecora and colleagues performed a series of studies in which they used calcium sulfate as a graft material for the maxillary sinus [13]. Following a successful case report, these investigators performed a prospective, longitudinal study in which 65 sinuses were grafted using different applications of calcium sulfate [14]. Implants were then placed and followed for at least 1 year, with an overall success rate of 98.5% for 130 implants. Histological analysis indicated mature bone in all specimens.

Bioactive glasses, another class of materials, are unique in that they actually bond to bone [14,15]. Bioactive glasses generally contain silica, calcium, and phosphate. These are usually delivered as granules that are 90 to 710 μm in diameter with submicron sized pores (ie, mesopores) that increase the overall surface area. They are extremely biocompatible and evoke no inflammatory response when implanted. While bioactive glasses do bond to bone, they also appear to have an osteogenic effect that induces osteoblasts.

Tadjoedin and colleagues compared bioactive glass particles measuring 300 to 355 μm with autogenous bone obtained from the iliac crest [16]. Results were evaluated histomorphometrically at 4, 6, and 15 months postaugmentation. The test sinuses received 80% to 100% bioactive glass mixed with 0% to 20% iliac crest bone particles, while the control group received only autogenous bone. The control group (autogenous only) sinuses contained 42% bone compared with 39% for the group that received bioactive glass and autogenous bone. Based on the histologic outcomes noted in the study, Tadjoedin and colleagues recommend that 12 months healing time is required if 100% bioactive glass is used for sinus augmentation, while 6 months is sufficient for mixtures of 80% autogenous bone and 20% bioactive glass. An earlier study by this group showed that sites where bioactive glasses were used and sites where autogenous bone was used were indistinguishable at 16 months [17].

Cordioli and colleagues evaluated the use of bioactive glasses for sinus augmentation in a group of 12 patients [18]. Titanium implants with 2-3 threads were placed in the grafted sites at the time of sinus augmentation. All sinuses had dimensions from crest to sinus floor of 3 to 5 mm. After 12 months post-loading, 26 of the 27 implants were stable, with one failure.

A specialized form of polymethylmethacrylate is yet another material for augmentation of the sinus. It is a highly porous copolymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrylate with a coating made of barium sulfate and calcium hydroxide or of barium sulfate and calcium carbonate [15,16]. It is considered to be radiopaque, osteopromotive, hypoallergenic, and hydrophilic. While it is biocompatible, it does not resorb.

It has been suggested that alloplastic materials are not suitable for sinus augmentation due to incomplete resorption and poor bone formation. Indeed, some investigators suggest that only 20% of the graft eventually forms bone and that this bone forms densely along the sinus floor rather than uniformly throughout the graft. However, a recent systematic review of this literature examined 893 studies and concluded that ''the use of grafts consisting of 100% autogenous bone or the inclusion of autogenous bone as a component of a composite graft did not affect implant survival'' [19]. Despite these limitations, alloplastic materials can occasionally be useful in the management of small areas requiring augmentation in the sinus, especially in combination with demineralized or autogenous bone, to expand graft volume.

Allogeneic materials for augmentation

Allogeneic grafts are composed of two different types—mineralized and demineralized [20,21]. Mineralized bone is of little use in sinus augmentation because of its lengthy process of bone formation in the hypovascular environment of the sinus. However demineralized bone is commonly used because, as a result of processing, the inherent bone morphogenetic protein (BMP) remains behind. The BMP proteins work to form an osteoinductive graft by stimulating adjacent undifferentiated cells to form bone. These graft materials are available from tissue banks. However, there remain some concerns associated with their use, including cost and the risk, albeit low, of disease transmission. More often, these materials are combined with autogenous grafts to expand their volume but can be used alone with relative success. Recent advances in biotechnology have allowed for the isolation and engineering of pure BMP proteins for bone grafting. These materials have undergone initial testing and have proved very promising, but have been approved only for certain orthopedic problems. If made available for wider use, the prospect of improved results in nonautogenous maxillary sinus grafting is a possibility.

Autogenous bone

Autogenous bone is the gold standard by which all other graft materials are measured. Its advantages include high osteogenic potential, unquestioned biocompatibility, and no possibility of disease transmission. As implied, a second surgical site is required, with the attendant donor-site morbidity. In addition, the length and cost of the procedure are both significant. A number of donor sites have been routinely used in maxillary sinus bone grafting. These include the anterior and posterior ilium; the tibia; and various intra-oral sites, such as the maxillary tuberosity, the mandibular ramus, and the mandibular symphysis (Table 2).

The ilium is one of the most common sites for obtaining graft bone in sinus surgery where extra-oral harvest is performed. The ease of surgical access, low postoperative morbidity, and large amounts of readily available cancellous and cortical bone contribute to the popularity of the procedure. The operation for graft harvest is performed under general anesthesia, usually in the hospital inpatient setting. However, a trephine technique has been developed that can be modified for use in the outpatient setting (Fig. 3). This technique can provide an adequate amount of bone for sinus augmentation. However, the technique is a blind procedure with inherent risks, such as perforation medially into the abdominal cavity. Formal iliac crest harvest begins with an incision made lateral to the anterior iliac spine with reflection of soft tissue medially. The dissection is carried to bone through the overlying fascia and the medial aspect of the ilium is exposed. An osteotomy is then created along the superior aspect of the iliac crest with medial extensions. The cortical bone is then removed for grafting or fractured medially to expose cancellous bone. Approximately 20 to 40 cc of bone is available from the anterior ilium and almost double this amount is available from the posterior ilium. The iliac harvest is usually reserved for those patients in whom cortical as well as cancellous bone is required for structural support or for additional implant stability. Although complications can occur, the risk of long-term gait disturbance is relatively low, especially with a medial approach and care not to strip the lateral musculature of the pelvis.

The tibia has an established and well-documented success rate associated with autogenous grafting (Fig. 4). The advantages of tibial bone graft harvest are that it can be performed in the operating room or the office in the outpatient setting. Large amounts of cancellous bone are available and patients are ambulatory immediately after surgery. An incision is made adjacent to Gerdy's tubercle on the lateral aspect of the tibia. Dissection proceeds to the lateral aspect of the tibial bone where a circular osteotomy exposes the underlying cancellous bone. Perforation of instrumentation into the knee joint can cause serious complications. However, when executed with proper technique, the risk of surgical misadventure is minimal. This site does not provide a significant quantity of cortical bone. Therefore the procedure lends itself to sinus augmentation in cases where only cancellous bone is required.

Table 2
Characteristics of various autogenous bone harvest sites

Graft material	Advantages	Disadvantages	Amount of bone available	Complications
Anterior ileum	Most reliable grafting source; cortical and cancellous bone can be harvested	Distant second surgical site; requires general anesthesia	20–40 cc	Gait disturbance, hernia, paresthesia, infection
Trephined anterior ileum	May be performed as an outpatient with sedation and local anesthesia; most reliable grafting source	Distant second surgical site	20–40 cc	Infection
Tibia	May be performed as an outpatient with sedation and local anesthesia	Distant second surgical site; cortical bone not available in significant quantities	20–40 cc	Gait disturbance, infection, tibial plateau fracture
Posterior mandible	Local second surgical site	Limited quantity and quality of bone	5 cc	Infection, jaw fracture, paresthesia
Anterior mandible	Local second surgical site; cortical and cancellous bone can be harvested	Limited quantity and quality of bone	5 cc	Pain, dental injury, infection, jaw fracture
Maxillary tuberosity	Local second surgical site	"Fatty" consistency of bone	2–3 cc	Infection, antral perforation, alveolar fracture

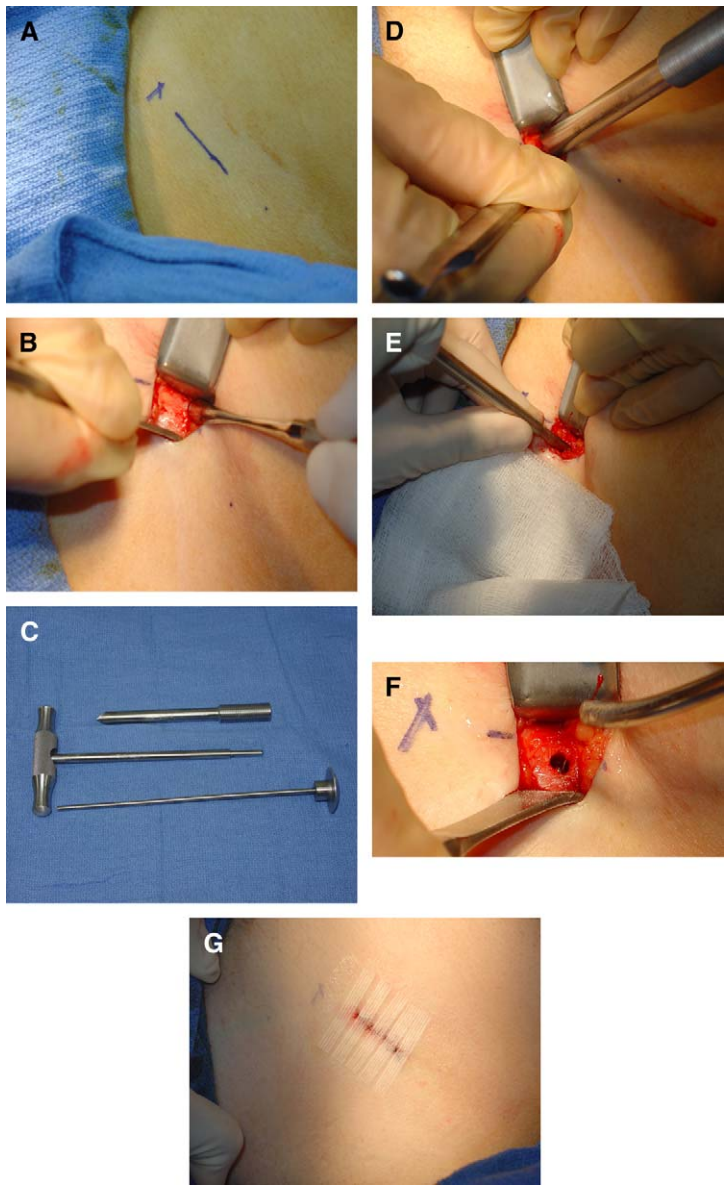

Fig. 3. (*A*) The surgical approach to the ileac crest begins by outlining the incision over the crest, posterior to the ischial tubercle. (*B*) Dissection is carried through skin, subcutaneous tissue, and fat, to Scarpa's fascia and periosteum. (*C*) A trephine is a tool for harvesting bone in a minimally invasive manner. (*D*) The sleeve of the trephine engages the bone. (*E*) The blade is rotated and advanced to traverse the cortical plate and engage cancellous bone. (*F*) The core is removed. (*G*) The incision is closed in layers.

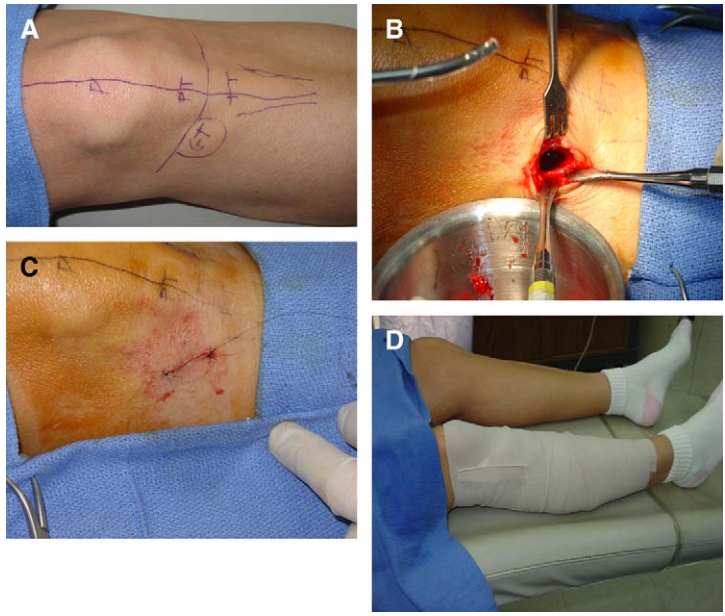

Fig. 4. (*A*) The surgical approach to the tibia begins by identifying the important landmarks. (*B*) Incision and dissection are carried down to the periosteum. (*C*) The incision is closed in layers. (*D*) The surgical site is dressed.

The intra-oral sites for autogenous bone graft harvest have been relatively popular for sinus augmentation secondary to the ease of harvest near the operative site without the need for external incisions. Popular specific sites of harvest include the anterior mandible, the lateral-posterior mandible, and the tuberosity of the maxilla itself. Limitations of harvest from these sites include the relatively small amount of bone that can be harvested and the nature of the graft, which becomes mostly cortical because of the anatomy of the jaws. In addition, harvesting from these sites poses risks of dental injury and jaw fracture.

Harvesting of graft from the anterior mandible is particularly appealing because of the mandibles embryonic derivation from membranous bone and thus improved resistance to graft resorption. Here, an incision is made in the anterior mandibular vestibule or sulcus of the mandibular dentition and the dissection is carried through the mucoperiosteum to the bone. The dissection continues in the subperiosteal plane until the inferior border of the mandible is identified. Taking care to remain below the roots of the anterior dentition, an osteotomy is designed through the facial cortex of the mandible. Graft harvest can then proceed using one of two different methods, depending on augmentation requirements. If cortical bone is required, the facial cortex of the mandible is then outlined with a bur and the cortex is subsequently removed using an osteotome. A small volume of remaining

cancellous bone can then be harvested for grafting with a curette. If particulate bone is the primary requirement, a trephine drill is used to mill and harvest bone from the anterior mandibular cortex recovered from a suction trap. Closure, after hemostasis is achieved, then proceeds with special attention directed at the reconstructing the paired mentalis musculature to prevent soft tissue sag (ie, witch's chin).

Harvest of grafts from the posterior mandible proceeds in much the same fashion, except the incision is made in the posterior vestibule of the mandible or sulcus of the posterior teeth. The prominent external oblique ridge is ideal for harvest if present. Care must be exercised to avoid injury medially to the teeth or to the inferior alveolar nerve at the inferior extent of the graft harvest and the lingual nerve medially. As with the mandibular symphysis, harvesting block grafts from the posterior lateral mandible carries with it the potential risk of mandibular fracture.

The maxillary tuberosity harvest remains straightforward and is perhaps the least technically difficult procedure for intra-oral autologous bone harvest. However, only approximately 2 to 3 cc of bone can be harvested, which limits its usefulness, even if mixed with alloplasts or allogeneic materials (Fig. 5). In addition, the bone obtained is somewhat "fatty" in constitution and may not be ideally suited for some grafting procedures. Graft harvest begins by making an incision along the height of the tuberosity to bone with subsequent reflection of a full thickness flap. Ensure that the pterygomaxillary fissure is protected during surgery. Care must be taken to avoid fracturing the posterior maxilla during the procedure.

Complications of sinus augmentation

As noted above, the maxillary sinus does not have a dependent drainage system and therefore is susceptible to infection and fluid sequestration. The anatomy, however, also favors the implant surgeon in one important respect

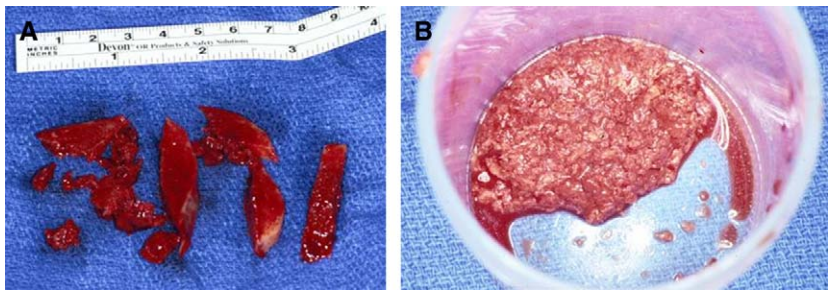

Fig. 5. Autogenous bone can be morselized and used alone (*A*) or mixed (*B*) with alloplastic or allogeneic material.

with regard to the location of the ostium. Because of the high location of the ostium on the medial wall of the sinus, it is unlikely to become obstructed by routine maxillary augmentation in the inferior region of the sinus.

Acute maxillary sinusitis is often heralded by pain in the operated sinus with associated congestion and with increasing severity. Other signs are fever and general malaise [22]. Acute infection is managed after surgery with antibiotic therapy directed at flora of the upper respiratory tract. Drainage may occur spontaneously through the wound margins or fistulize through the oral mucosa into the vestibule. If spontaneous drainage does not occur, surgical drainage should be provided for resolution of the infection. Unfortunately, in either case, the graft is compromised and will likely fail. The use of decongestants is somewhat controversial in the postoperative management of patients undergoing sinus augmentation because decongestants often act by vasoconstriction, which further decreases blood supply vital to healing in an already low-oxygen tension environment present in the sinus.

If dental implants are placed immediately at the time of grafting, immediate stability is vital for maintaining implant position and parallelism. Drifting of the implant can occur when adequate stability is not achieved. This is primarily a problem when the residual maxilla is only several millimeters in height and cortical grafts are not employed as a further anchor. If cortical grafting is not planned and the residual maxillary height is not sufficient for primary implant stability, consideration should be given to allowing graft consolidation to occur before attempting fixture placement.

Advances in biotechnology

The science of bone grafting promises great changes for dental implants. The relevant recent advances in biotechnology include those related to stem cell therapy and recombinant bone morphogenic protein. The pluripotentiality of human progenitor cells is well documented. Stem cell research seeks to capture this ability by obtaining these pluripotential cells and stimulating them to differentiate down specific cell lines. The stimulation of stem cells to form osteoblasts and subsequently form bone would be a tremendous advance in the realm of bone grafting. Meanwhile, the biotechnology of recombinant bone morphogenic protein has already arrived for direct patient care [23]. Currently, its use is restricted to certain clinical orthopedic applications by the US Food and Drug Administration. However, even with ultimate approval for use in the maxillofacial region, cost may limit its application for routine dental implant therapy. Platelet-rich plasma is yet another example of tissue engineering that has potential clinical applications in maxillofacial bone grafting [24]. This process involves the separation of autologous blood by centrifuge to yield platelet-rich plasma. This plasma concentrate contains elevated platelets and white blood cells. The platelets contain platelet derived growth factor, amongst other growth factors.

Theoretically, these factors significantly enhance wound and bone healing. This technology is used commonly for sinus augmentation procedures and is often combined with autogenous bone grafting. While some studies have shown encouraging results, others have failed to demonstrate an effect [25,26]. Thus, it is difficult to prescribe unequivocal evidence-based guidelines for the use of platelet-rich plasma [19].

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Implant Anchorage in Orthodontic Practice: The Straumann Orthosystem

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The modern era of dental implantology was ushered in by the pioneering work of Brånemark and his coworkers [1–6]. Their research demonstrated the relationship between bone and implant that now is known as osseointegration. They described osseointegration in histologic terms as the direct contact of living bone with the implant surface at the light microscopic level [7,8]. Schroeder and colleagues [9–12] further characterized this interface and termed the union of bone and titanium "functional ankylosis." Because of the work of these pioneers, dental implants have become a predictable means of tooth replacement.

Implants also have been used to provide orthodontic anchorage [13]. One such system is the Straumann Orthosystem implant (Institut Straumann, Waldenburg, Switzerland) [14–16]. This system consists of a small implant that is placed surgically in the midline of the anterior hard palate and allowed to integrate, after which it is attached to a transpalatal arch (TPA). The arch is bonded to two contralateral teeth (usually premolars) that provide anchorage for tooth movement. Upon completion of active tooth movement, the implant is removed surgically. This article provides an overview of this implant system and its application, including the anatomy of the bony palate and contiguous structures.

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Orthodontic anchorage

Control of anchorage is critical to the successful completion of most orthodontic treatment plans. Anchorage, in an orthodontic context, is defined as resistance to reaction forces that usually is provided by other teeth but sometimes is provided by the palate, head or neck, or implants in bone [17]. Examples of the first two categories involving teeth and palate include the TPA, stopped archwires, the Nance appliance, and intraoral elastics. Extraoral sources such as the back of the head and neck are also employed through headgear, but suboptimal patient compliance [18,19] and facial injuries have been reported [20,21].

All these conventional forms of anchorage have been used for the better part of the last 100 years. They offer varying degrees of successful anchorage, and they each have evolved with the on-going pursuit of absolute anchorage. Absolute anchorage, defined as 100% resistance against reactive forces, is required less often but is essential in certain cases; it has remained elusive. Osseointegrated implants are quickly living up to their potential to provide such anchorage [22–24].

Several types of implants have been used to provide orthodontic anchorage. Roberts and colleagues [25] used a two-stage endosseous implant in the retromolar region of the mandible to move two molars 10 mm mesially into an atrophic ridge. The implant remained stable for 3 years and was removed after completion of orthodontic treatment. The bone-to-implant contact was found to be 80%. A high rate of remodeling was verified through bone labeling.

Block and Hoffman [26] designed a hydroxyapatite-coated disc (the Onplant), which is 10 mm in diameter and 3 mm thick [26]. It is designed to be placed subperiosteally on the posterior portion of the palate where the vertical bone height is limited. Surgical placement is technically difficult, however, and a second-stage surgical uncovering is required.

In 1999, Melsen and colleagues [27] developed a 6-mm titanium implant for early loading called the "Aarhus implant." It was designed to be placed in multiple locations, (eg. between the roots of teeth). The mini-implant, 6 mm long and 1.2 mm in diameter, was developed to intrude teeth. A titanium plate is attached to the implant and acts as a hook for orthodontic attachment [28]. Mini-screws, unlike endosseous implants, do not attain true osseointegration and therefore are unable to provide the absolute anchorage offered by the Straumann Orthosystem implant and similar devices. The mini-implant achieves primary stability only through mechanical retention, which is less stable than osseointegration. Mini-screws have been shown to extrude and tip forward in the path of orthodontic loading [29].

The Straumann Orthosystem implant is a self-tapping, threaded titanium fixture with a diameter of 3.3 mm and insertion depths of 4 or 6 mm [14]. The surface of the intrabony portion of the implant has been grit-blasted and acid-etched to enhance osseointegration [30]. The implant has a smooth

transmucosal neck and normally is placed in the anterior mid-palatal region using a one-stage surgical technique (Fig. 1). After a healing period of approximately 12 weeks, the implant is connected to two contralateral teeth (usually premolars) by means of a TPA. These teeth then serve as the anchorage units. Considerations in placement of the Orthosystem implant include the avoidance of contiguous anatomic structures such as the nasal cavity, the degree of ossification of the palatal suture, and the quality and quantity of bone in the proposed implant site, all of which are discussed in this article.

Bone reaction to orthodontic implants

Implant stability and adjacent bone reaction have been evaluated both histologically and clinically after orthodontic loading. Trisi and colleagues [31] evaluated retromolar and palatal implants after orthodontic treatment was completed. All the implants were osseointegrated and stable after 12 months of loading. They also reported that treatment time was shortened and that the rate of remodeling was still elevated 18 months after placement. Wehrbein and colleagues [32] and Roberts and colleagues [25] also observed increased remodeling of bone adjacent to orthodontic implants. Melsen and colleagues [27] analyzed peri-implant bone reactions after orthodontic loading. The loading affected both the bone density and turnover, but the extent of osseointegration was independent of implant loading. Wehrbein and colleagues [33] analyzed bone-to-implant contact of retromolar and palatal implants. As in the studies previously cited, the implants were stable and well integrated.

It is well documented that osteoblast behavior may be affected significantly by different implant surfaces [30]. It is somewhat difficult to compare these studies, because differing implant systems and surfaces were used. Nonetheless, it seems clear that implants generally are capable of providing sufficient anchorage for orthodontic purposes, and the bone reaction to these forces seems to be favorable.

Fig. 1. Straumann Orthosystem implant.

Bone quality and quantity

Placement of implants in the bony palate has the potential to cause morbidity resulting from the proximity of structures such as the incisive canal and floor of the nasal cavity. Henriksen and colleagues [34] evaluated the bone in the midline of the anterior hard palate to determine whether there was sufficient bone for placement of 4-mm and 6-mm Orthosystem implants. Lateral cephalometric radiographs were taken of 25 dried skulls, and bone thickness was measured at a point described by the intersection of the midsagittal plane and a plane passing buccolingually through the first premolar teeth. Before the cephalometric exposure, the incisive canal was filled with gutta percha to make the canal radiopaque. Measurements were taken from the inferior aspect of the hard palate to the inferior border of the incisive canal. The mean mid-palatal vertical thickness, including the incisive canal, was found to be 8.6 mm. The mean dimension from the inferior aspect of the hard palate to the inferior border of the incisive canal, however, was only 4.3 mm. This measurement represents the amount of bone available for implant placement. These investigators found that only 50% of the skulls had 4 mm of bone at this site. The remainder of the skulls had less than 4 mm of bone in the mid-palatal region, thus precluding the placement of Orthosystem implants.

Wehrbein and colleagues [35] performed a clinical and radiographic examination of palatal bone in 12 subjects to determine the available bone in the mid-palatal region. Their findings suggest the mid-palatal region provides sufficient vertical support for palatal placement of Orthosystem implants of either 4- or 6-mm length. They reported that the vertical bone height is 2 mm greater than indicated by the cephalometric evaluation. Crismani and colleagues [36] reported similar results in a cadaver study. Specifically, they reported that the cephalometric image underestimated the superior extent of the bony palate by a mean value of 0.8 mm as compared with direct measurement. In the study by Wehrbein and colleagues [35], five patients showed radiographic evidence of implants protruding into the nasal cavity, but no perforations were found on clinical examination. Again, this finding is similar to data reported by Crismani and colleagues [36]. All studies cited in this section involved small numbers of subjects or specimens, so caution should be exercised in interpreting these data. It seems obvious that care must be taken during implant placement to avoid postsurgical morbidity [37].

Anatomy of the bony palate

The anterior portion of the hard palate is formed by the palatine processes of the maxillae, which meet in the midline to form the median palatine suture. The degree of ossification of the median palatine suture varies greatly, as discussed later. The bony palate is thicker in the anterior region but becomes progressively thinner posteriorly. The inferior surface of the

palatine process is uneven and somewhat concave, which has some clinical implications. The superior surface of the palatine process forms most of the nasal floor and is smooth and concave.

The incisive fossa is located in the midline directly behind the central incisors and contains the terminal branches of the nasopalatine nerve and septal branches of the sphenopalatine artery. The nasopalatine nerve provides sensory innervation to the palatal mucosa from canine to canine. The terminal branch of the greater palatine artery contributes to the blood supply of the anterior mucosa of the palate but rarely is of surgical significance [38]. The medial border of the palatine process is thicker in the anterior region. The nasal crest (crista nasalis) is formed by the union of the palatine processes and forms a ridge with which the vomer articulates. The Orthosystem implant is inserted into this area (assuming mid-sagittal placement).

Perforations of the nasal cavity

It is conceivable that placement of an implant in the bony palate could result in perforation of the nasal cavity. Wehrbein and colleagues [35] have suggested that the thick nasal mucosa will prevent open communication with the sinus if a slight perforation through the bony floor occurs subsequent to implant placement. Crismani and colleagues [36] reported that bone perforations of up to 1.3 mm did not result in perforation of the nasal mucosa [36]. A PubMed search using the keywords ''nasal,'' ''perforation,'' and ''implant'' in the title/abstract field found seven articles. Only two dealt with violation of the nasal cavity by palatal implants, and these were the previously cited works by Wehrbein and colleagues [35] and Crismani and colleagues [36]. There were no actual reports of adverse sequelae arising from these or similar implants.

There have, however, been reports of complications arising from perforation of the nasal floor by endosseous implants. One such report involved a 69 year-old woman who developed rhino-sinusitis as a result of two implants perforating the nasal floor [39]. The authors suggest that this condition was caused by changes in the nasal airflow and mucosal irritation and inflammation secondary to the implants. The apical portions of the implants were resected, and the rhino-sinusitis condition resolved. The patient's age may have been a factor, because Lantsov and colleagues [40] found that older patients have impaired circulation of the nasal mucous membrane caused by inadequate microcirculation.

Brånemark and colleagues [41] reported on 139 implants placed in dogs so as to perforate the nasal cavity or maxillary sinus. Twenty-three nasal-perforating implants (NPI) and 25 sinus-perforating implants (SPI) were observed for periods ranging from 2 to 5 years. The success rates were 96% and 88%, respectively. Forty-seven NPI and 44 SPI were observed for 5 to 10 years. The success rates were 72% and 70%, respectively, percentages

that fall below the criteria for implant success (80% at 10 years) [42]. These findings indicate that long-term stability and success of implants perforating the nasal cavity or sinus may be compromised.

An important caveat applies to these findings, however. Brånemark and colleagues [41] did not remove the implants, as would be done with the Orthosystem implant. The act of explantation involves the use of a small trephine, and it seems possible that removal of the implant could contribute to the formation of a patent nasal-oral fistula (whereas the orifice might be occluded functionally while the implant is in situ).

Although not entirely analogous, implants have been placed intentionally in the anterior nasal floor to secure nasal prostheses. Although these implants differ from palatal orthodontic implants, the results may have some relevance to the current discussion. Nishimura and colleagues [43] placed 19 anterior nasal implants for implant-retained nasal prostheses. Seventeen implants were 3 to 4 mm in length, and two were 7 mm in length. The patients were followed for 6 to 74 months. The success rate was 88.1% (15/17). Two implants failed; one failed to osseointegrate in irradiated bone, and the other exhibited inflamed and irritated tissue surrounding the abutment that did not resolve with nonsurgical therapy. These finding are consistent with a previous study in which 16 anterior nasal floor implants were placed and had a success rate of 89.5% (14/16) [44].

In summary, it is not possible to calculate the relative risk of perforation based on the current literature, nor is it possible to determine the likely sequelae of such an event. A useful concept is the number needed to harm, that is, the number of procedures that would be performed before a patient was harmed. This useful concept has become increasingly important in the discipline of evidence-based health care, and tables of such values are being developed for a variety of medical procedures. Such information is not yet available for palatal implant placement, although the authors' clinical experience (and that of others) suggests that significant morbidity is uncommon with the use of this system.

Suture ossification

The degree of ossification of the median palatine suture also is of potential interest when planning implant placement [37]. Persson and Thilander [45] examined histologically the palatal suture closure in 24 specimens from subjects ranging in age from 18 to 35 years. The authors reported that palatal suture ossification did not show any significant degree of closure until the third decade of life. Ossification was found to start earlier in the posterior than in the anterior segment of the suture and to progress faster in the oral than in the nasal aspect of the palate. Schlegel and colleagues [37] examined ossification of the mid-palatal suture anatomy at various ages. They removed trephined bone cores from the mid-palatal suture at

the first premolar site in 41 cadavers of persons aged 12 to 53 years at death. The investigators' findings indicate that closure of the median palatal suture is rare in individuals younger than 23 years of age. Furthermore, the authors propose implant placement posterior to a plane bisecting the first premolars, because the suture often is more ossified as one proceeds posteriorly. The authors suggest that the risk of failure is small because the implant will be in contact with bone around most of its circumference because of the small size of the sutural gap.

Melsen [46] performed a histologic study of 60 specimens from persons 0 to 18 years of age. The author investigated the morphologic development of the median palatine suture in three stages. During the infantile stage, the suture is broad and Y shaped. The suture becomes longer and winding in the juvenile stage. In the third, or adolescent, period the suture becomes increasingly tortuous and interdigitated. Revelo and Fishman [47] compared the mid-palatal suture using occlusal films with the skeletal maturity indicator (SMI). As the SMI stages proceeded through adolescence, the degree of fusion increased. The anterior portion of the suture had less fusion than the posterior aspect of the suture. By the end of adolescence (SMI 11), only 50% of the total mid-palatal suture was fused.

Wehrbein and Yildizhan [48] examined autopsied tissue blocks from 10 specimens from persons between 18 and 38 years of age at death to determine the correlation between the appearance of the median palatal suture on occlusal radiographs and histologic assessment of the degree of ossification. The degree to which patency of the suture can be assessed is determined by the coincidence of the central x-ray beam with the sutural space. In the group in which the suture was radiographically visible (group 1), the sutural space was parallel with the central beam. In the group in which the suture was not visible suture (group 2), the sutural space was not aligned with the path of the central beam. Group 1 also had a smaller amount of interdigitation than group 2. In group 2 the vomer was located immediately superior to the suture and was aligned with the space. The amount of obliteration and suture width was not a major factor in determining whether the visible suture was open. Based on these findings, it would seem that the degree of ossification of the median palatal suture cannot be predicted by occlusal radiography.

Bernhart and colleagues [49] proposed placement of orthodontic implants paramedial to the median palatal suture. Twenty-two patients were included in the study. CT was used to determine the vertical bone volume in the anterior palatal region. The results indicated the best location for implant placement was 6 to 9 mm posterior to the incisive foramen and 3 to 6 mm paramedial to the palatal suture. Implant placement 3 to 6 mm lateral to the median palatal suture coincides with Henriksen and colleagues' [34] findings that the width of the incisive canal is 2.5 mm. Bernhart and colleagues [49] placed short implants lateral to the palatal suture for orthodontic anchorage. Twenty-one patients were included in the study. None of the

implants failed during healing, although three implants failed during orthodontic loading. Two of these failures occurred shortly after loading was initiated; the third implant loosened 8.5 months after loading.

The absolute anchorage provided by palatal orthodontic implants has proven to be useful in orthodontic treatment and is well accepted by patients [50], but placement of these implants requires a certain quantity and quality of bone. Insufficient bone thickness conceivably could result in perforation of the nasal cavity.

Clinical protocol

A preoperative lateral cephalometric film is obtained, and the bony dimensions of the palate are estimated. Wehrbein and colleagues [35] have reported the radiographic bony thickness to be approximately 2 mm less than the actual bony thickness, but this report should be confirmed by other studies. The authors previously have reported that the first premolar site is ideal from the standpoint of adequate bone thickness [51,52]. Placement often is planned in a location slightly lateral to the mid-sagittal suture. The anterior hard palate is anesthetized. Specifically, nasopalatine and greater palatine blocks are usually administered.

A special mucosal trephine is used to remove the palatal mucosa at the proposed osteotomy site (Fig. 2), and the palatal bone is perforated with a small round bur. After removal of the mucosa with the trephine, the site should be inspected to ensure all soft tissue remnants are removed so that the implant will be fully seated against the bone with no intervening soft tissue. If the palatal surface is uneven or rough, it sometimes is desirable to smooth it with a rotary instrument, but care must be taken not to remove too much bone. It is the authors' clinical impression that early clinical stability is enhanced when the implant can be firmly seated so that the flat area abuts the bone over a broad area.

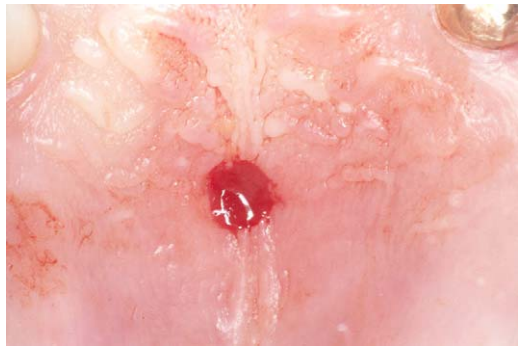

Fig. 2. Hole in mucosa created with trephine.

A profile drill is used to create the osteotomy site. The drill has a flat stop to limit depth of penetration. It is most important to align the drill so that the centerline of the hole is perpendicular to the bony surface. This precaution helps ensure that the flat of the implant rests firmly on the bone. If the hole is drilled at an angle to the surface, only one edge of the rim will rest on bone, and the implant will be much less stable. The self-tapping implant is connected to the insertion device, placed into the osteotomy site, and screwed in by hand until completely seated. Great care should be exercised to stop turning the implant once the flat surface is seated against the bone. Further turning of the implant at this point will cause the threads to be stripped or reamed and will result in instability. The manufacturer suggests that either a healing cap or a small screw be placed on the implant body. The authors use the small screw because it is less noticeable to the patient.

A lateral cephalometric radiograph is obtained postoperatively. The work of Wehrbein and colleagues [35] suggests that it is difficult to predict clinical perforations of the nasal mucosa, although Daniel's [52] findings contradict this assertion. Unfortunately, both studies involved small sample sizes, and more conclusive recommendations must be based on larger studies.

After placement, the implant is allowed to integrate for 12 weeks. The manufacturer recommends that the implant not be brushed for 7 days, although the authors generally have patients avoid brushing it for 2 weeks. During that time, chlorhexidine rinses are prescribed for use two or three times daily. The patient is seen for a variable number of postoperative visits. At postoperative week 10, success is judged by a lack of inflammation in the peri-implant mucosa, lack of patient symptoms referable to the implant, and a high-pitched sound on percussion (Fig. 3). An impression can be taken at week 10, but the implant should not be functionally loaded (ie, the TPA attached) until week 12 (Fig. 4).

Ten weeks after implant placement, an alginate impression is taken of the implant with an impression coping in place of the healing cap. An implant analogue is inserted into the impression cap, and the impression is poured in yellow stone. The resulting cast is sent to the laboratory for fabrication of

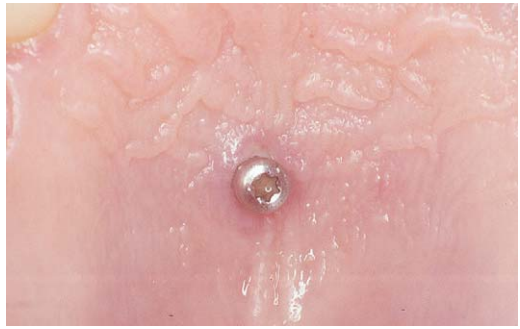

Fig. 3. Implant in situ, 10 weeks postoperatively.

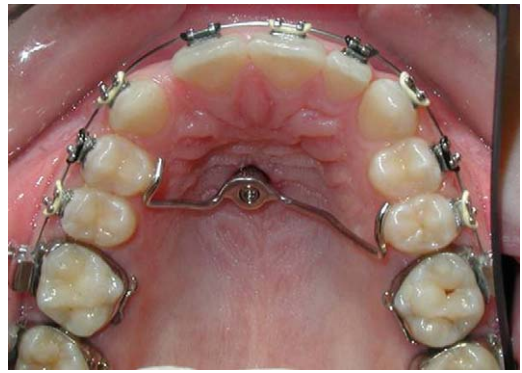

Fig. 4. Implant in situ, with transpalatal arch attached.

a TPA that will be secured to the implant and bonded to the teeth chosen to serve as anchorage units.

Upon completion of active tooth movement, explantation of the implant is performed using a purpose-built trephine. Before explantation, the TPA or screw is removed, and a special metal rod is placed on the implant to guide the trephine. The trephine is used at low speed and with copious irrigation to a depth of about two thirds of the insertion depth. It usually can be removed with a gentle rotational force with a pair of extraction forceps. After explantation, the wound is allowed to heal by secondary intention. The authors' postoperative protocol calls for the use of chlorhexidine rinses for 2 weeks postoperatively.

The authors believe that early mechanical stability (in the time between placement and osseointegration) is an important factor in ensuring the predictability of this particular implant. The stability during this period derives from the mechanical friction-fit of the implant within bone. With conventional tooth-replacement implants that have a sandblasted and acid-etched surface, this period can be quite short [53–55]. The orthodontic implant is much smaller in diameter and insertion depth, however, and its thread dimensions are smaller. These factors (plus its vulnerable location on the palate) may make it especially susceptible to micromotion [56]. Every precaution should be taken during placement to ensure that the implant is as stable as possible. These precautions include careful osteotomy preparation combined with careful insertion of the implant during placement.

Summary

Conventional means of achieving orthodontic anchorage have a number of shortcomings. To some extent, these shortcomings can be overcome through the use of orthodontic anchorage. The Straumann Orthosystem implant system offers a method for achieving absolute anchorage. Surgical

placement of these implants involves the potential for violating certain contiguous structures such as the floor of the nasal cavity. Knowledge of the anatomy of the area and careful planning are essential to avoid postoperative morbidity. The use of a preoperative lateral cephalometric radiograph is recommended, although other imaging modalities may offer advantages over this modality and may someday supplant it.

Care must be taken during osteotomy preparation and insertion of the implant to avoid introducing mechanical instability. It may be wise to use the 4-mm implant (in lieu of the 6-mm version) whenever possible. Placement of the implants should, in most cases, be limited to the region contiguous with a line bisecting the contralateral first premolars. Although the influence of ossification of the suture on implant integration is not established definitely, it may be prudent to place the implant slightly lateral to the suture (especially in younger individuals). The clinical experience of the Divisions of Periodontology and Orthodontics at the University of Kentucky suggests that these implants may be a valuable adjunct to conventional orthodontic tooth movement. Care in planning and execution has resulted in a high degree of success with minimal morbidity.

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Simplified Impression Technique for Implant-Supported Crowns

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Dental implants have become a widely accepted method for replacing missing teeth. While many oral surgeons and periodontists are actively involved in the surgical placement of dental implants, many general dentists do not perform such placements because they are intimidated by the seeming complexity of the procedures and hardware. In response to perceived complexity, dental implant manufacturers have developed implant systems that facilitate and simplify impression-taking [1]. As such simplified protocols become more common, implant-borne restorations will become more widely used by the profession as a routine treatment modality.

The restorative phase typically begins during the diagnostic process preceding implant placement. At that stage the limitations and compromises are most easily recognized and accommodated. Also, that stage is best for determining the number and location of the implants. During this planning stage, surgical guides are often fabricated [2]. These guides communicate to the surgeon where the restorative dentist would like the implant placed. If an implant cannot be placed in the preferred location due to a lack of bone, grafting is performed to permit such placement.

A general restorative dentist is typically familiar with many of the basic restorative aspects of implant dentistry. Nevertheless, implant-supported restorations are distinctly different from tooth-borne restorations in that they require a mechanism for attaching the restoration to the implant. This component is termed the abutment [3].

The ITI Dental Implant System, known as a Straumann implant (Institut Straumann AG, Waldenberg, Switzerland), can be used predictably in

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partially and completely edentulous maxillae and mandibles with high success rates [4]. This article describes a simple technique for restoring a single-tooth posterior Straumann implant. This technique uses an impression cap or pickup coping, which is an impression coping that is automatically retained in the impression after removal from the mouth [3]. The advantage of this technique is that the impression caps, in conjunction with paired laboratory analogs and burnout copings, help ensure marginal detail and accurately relate the restoration to the implant abutment and the remaining teeth and soft tissue [2,5].

This technique has been used to teach implant restoration in the predoctoral implant program at the University of Kentucky College of Dentistry. This program has been in existence for over 6 years and has enjoyed a high rate of success. The primary emphasis is on mastering these relatively simple restorative techniques before preceding to more complex situations that may involve open-tray techniques and the like. The protocols used in this program are, in part, described below. Emphasis is placed on those steps that are unique to implant-borne restorations generally and, more specifically, the ITI system.

The standard clinical protocol is listed in Box 1.

Modified clinical protocol: adjusting the solid abutment

To adjust the solid abutment, the following modified clinical protocol is suggested:

1. After placing the solid abutment that most closely fits the interocclusal space, torque it to 35 Ncm. Adjust the abutment with a titanium-cutting carbide bur, such as the Brasseler H283FQ (Brasseler USA, Savannah, Georgia) or a crosscut fissure bur, taking care to avoid nicking the implant shoulder. A diamond bur can also be used. Check for adequate clearance. A finishing bur or fine-grit diamond should be used to create a slight bevel around the top of the abutment so as to remove any sharp edge created by the modification.
2. If a wide body Straumann implant (ie, wide neck solid abutment with a 6.5 mm shoulder) is used, the occlusal opening must be sealed with a flexible but durable material (eg, polyvinyl silicone) that can be easily removed if necessary.
3. Place an impression cap (white) over the shoulder of the implant. Again, there should be a definite ''snap'' or click and the impression cap should rotate around the shoulder of the implant. Because the abutment has been altered, the positioning cylinder cannot be used.
4. When making the impression, inject light body impression material through the holes in the top and lateral walls of the impression cap, then over and around the cap.

Box 1. Standard clinical protocol for restoring single-tooth posterior Straumann implant

1. Select the proper shade of porcelain.
2. Inject a polyvinyl silicone occlusal registration material over the implant healing screw, completely filling the edentulous space, and have the patient close into maximum intercuspation (Figs. 1 and 2). Allow the material to set. Remove the occlusal registration material and section it in a mesiodistal direction through the opposing functional cusp tip or tips. Measure the interocclusal clearance (vertical space) using a periodontal probe as depicted in Fig. 3 [6]. Then select the appropriate solid abutment based on the available vertical space: 4.0 mm (yellow/gold), 5.5 mm (gray/silver), or 7.0 mm (blue). For Straumann wide-neck implants (WNIs) select 4.0 mm (green) or 5.5 mm (brown).
3. Remove the implant healing screw (healing abutment) with the screw-carrying-system (SCS) screwdriver. Clean and dry the internal aspect of the implant. Align the vertical groove on the selected abutment with the laser-etched line on the outside of solid abutment driver. Carry the abutment intraorally in the driver, insert it into the implant, and tighten with finger pressure (Figs. 4, 5, and 6). If a WNI abutment is used, bring the abutment to the mouth with a SCS screwdriver. A gauze sponge should be ''unfolded'' and used to block the oropharynx so as to protect against aspiration should a component be lost in the mouth.
4. Check clearance with opposing teeth in maximum intercuspation (Fig. 7). If necessary, select a shorter abutment. If the laboratory technician determines that the interocclusal space is inadequate, the technician can shorten the laboratory analog, and then prepare a reduction coping, which the dentist uses to adjust the intraoral abutment at the appointment, during which the crown is cemented. If the shortest abutment (yellow/gold) interferes with opposing occlusion, the solid abutment will have to be adjusted (see below). If restoring the implant at the present shoulder location would give an unesthetic result, the shoulder of the implant may need to be prepared, as described below.
5. Place the boxed end of the ratchet and torque control device (torque wrench) over the driver handle. The directional arrow must be pointing in the clockwise direction and toward the torque bar with the teardrop-shaped end. If the torque bar is

on the counterclockwise side, flip the wrench over. If only the arrow is pointing in a counterclockwise direction, pull the arrow out, flip it over, and push it back into the handle. Using one hand to hold the holding key, use the other hand to grasp the tear drop and move the torque bar to the 35 Ncm mark (Figs. 8 and 9).

6. Place the white impression cap over the implant shoulder (Fig. 10). There should be a definite ''snap'' or click. When properly seated, the impression cap will rotate on the implant when gently twisted.
7. Line up the flat side of the positioning cylinder (It has a flat, raised tab.) with the flat side of the abutment. Slide the positioning cylinder completely onto the solid abutment. As this is a ''friction'' fit, there will be no ''snap.'' However, the lowest portion of the horizontal flange on the positioning cylinder must be flush with the superior edge of the white impression cap when properly seated (Fig. 11).
8. Make a final impression using polyvinyl silicone or polyether impression material, carefully syringing the impression material around the positioning cylinder and impression cap assembly (Figs. 12 and 13).
9. Upon removal of the impression tray, verify that the impression-cap–positioning-cylinder assembly are captured in the impression material and that the impression is an accurate negative reproduction of surrounding soft and hard tissues (Fig. 14). The impression cap and positioning cylinder should fit together tightly. If there is impression material between the positioning cylinder and the impression cap, this indicates that the cap was either not fully seated or was dislodged during the impression-making process (Fig. 15). If this is the case, the impression procedure must be repeated.
10. Do not remove the abutment. Provisionalize the abutment with the accompanying protective cap or fabricate a provisional crown. Cement with temporary cement.

5. Provisionalize the abutment with the accompanying protective cap or fabricate a provisional crown. Cement with temporary cement.

Modified clinical protocol: adjusting the shoulder of the implant

To adjust the shoulder of the implant, the following modified clinical protocol is suggested:

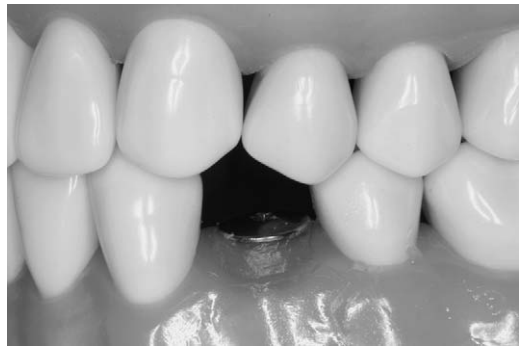

Fig. 1. Implant healing cap.

1. Using previously described procedures, select a solid abutment, and torque it to 35 Ncm. Evaluate the relationship of the implant shoulder to any adjacent implants, teeth, and to the gingival crest. If adjacent implant shoulders touch each other or if the implant shoulder is exposed, thus creating a condition for an unacceptable esthetic result, the shoulder of the implant should be adjusted. The abutment will likely be adjusted as well.
2. If a wide-neck Straumann implant (wide neck solid abutment with a 6.5 mm shoulder) is used, the occlusal opening must be sealed with a flexible but durable material that can be easily removed if necessary.
3. The shoulder can be prepared with conventional diamonds. However, bur companies manufacture burs with specific metallurgical properties that make them more suitable for preparing titanium implants. Dentists who restore implants should have a small supply available for making these adjustments.

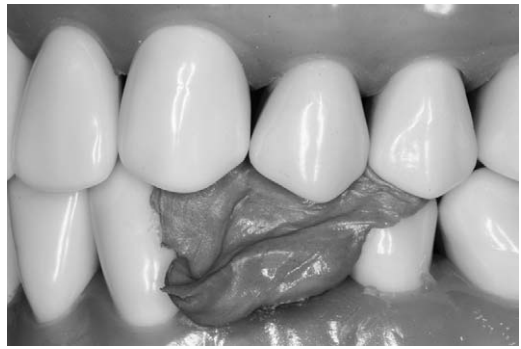

Fig. 2. Polyvinyl silicone interocclusal registration in maximum intercuspation.

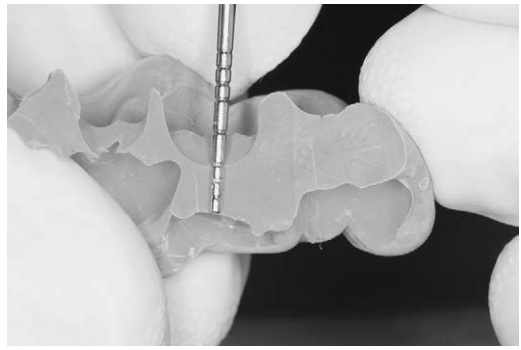

Fig. 3. Measuring interocclusal clearance.

Fig. 4. Solid abutment and driver.

Fig. 5. Aligning mark on driver with groove on abutment.

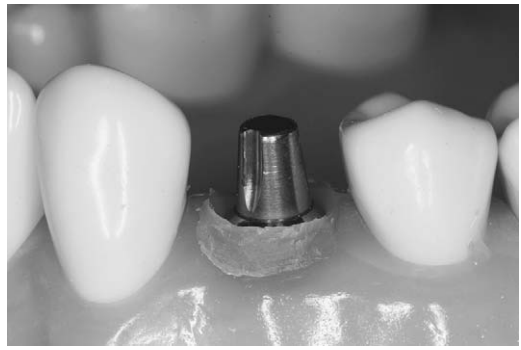

Fig. 6. Abutment in place; hand tightened only.

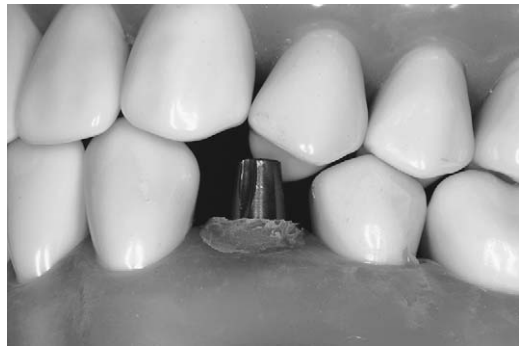

Fig. 7. Checking interocclusal clearance.

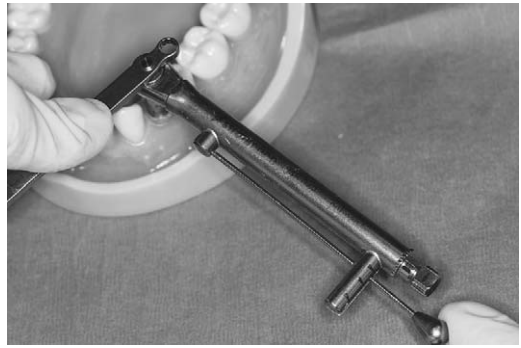

Fig. 8. Torque wrench and holding key in place.

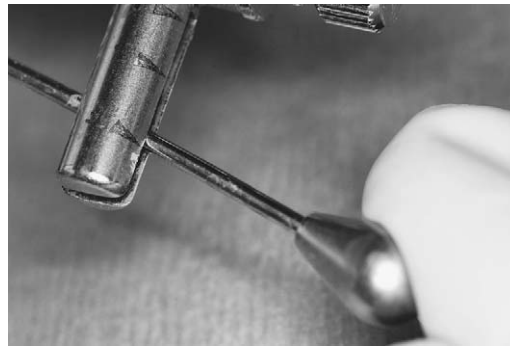

Fig. 9. Torqued to 35 Ncm.

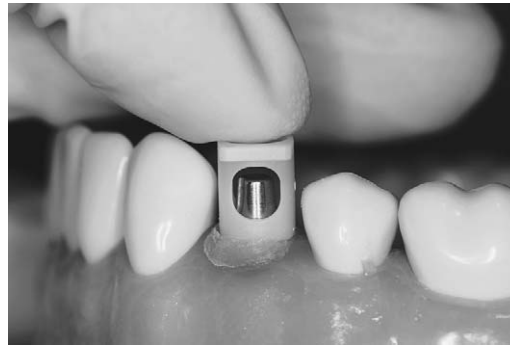

Fig. 10. Placing impression cap.

Fig. 11. Placing positioning cylinder.

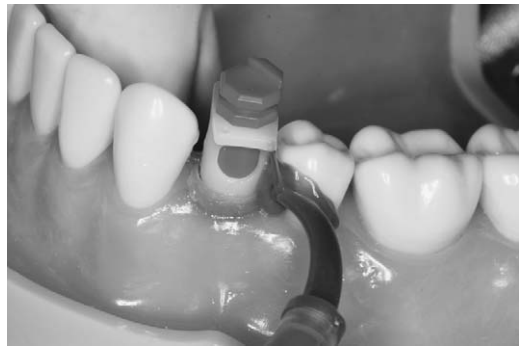

Fig. 12. Syringing impression material around cylinder and cap.

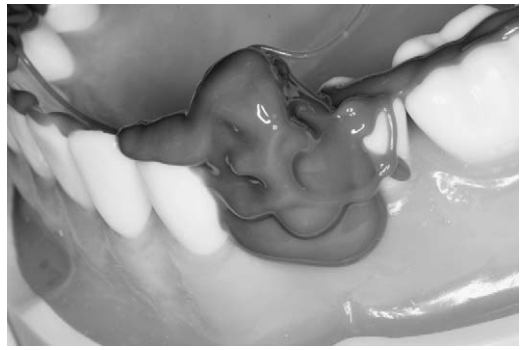

Fig. 13. Light body impression material over cylinder and cap.

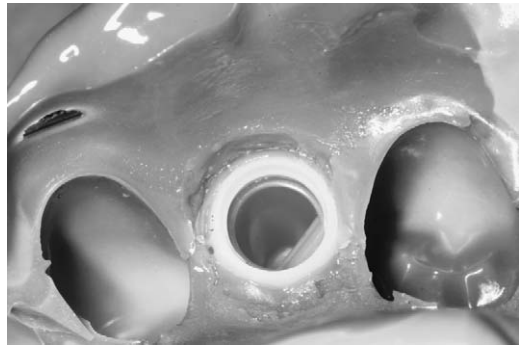

Fig. 14. Accurate impression with correct position of cylinder and cap.

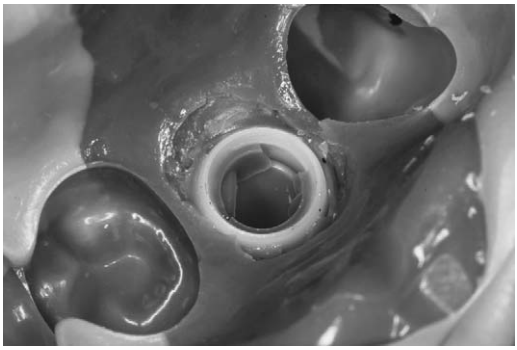

Fig. 15. Malposition of cylinder and cap.

4. Once the shoulder has been lowered to either create clearance or a more esthetic finish line, a conventional crown and bridge technique is used to make the impression. Use gingival retraction techniques and materials to expose the new finish line. Impression caps and positioning cylinders cannot be used if the ITI implant shoulder has been altered.
5. Inform the dental laboratory technician that the implant shoulder has been altered so materials and methods can be altered accordingly. It is possible to create an index coping to communicate to the lab how much material was removed. This is done by placing a small amount of fast-setting resin, such as the resin used to index cast frameworks for fixed partial dentures. After this resin sets, the top of the resin index is gently reduced in height with a bur or diamond until it is flush with the modified abutment surface. This is then removed and sent to the lab, where it can be placed on the analog, thus providing a guide so that the technician can reduce the implant analog by an appropriate amount.

Laboratory phase

The laboratory phase of this technique involves the following four steps:

1. In the dental laboratory, the corresponding analog is positioned in the impression. The shoulder should audibly click into place. To optimally contour the crown, always use a gingival moulage. Using conventional techniques, a working model is fabricated from die stone.
2. An appropriate plastic coping is selected and pressed onto the analog until it clicks into place, and then reduced to the height of the abutment. Subsequently, wax is overlaid on the plastic coping to create the crown's metal substructure.
3. After casting, the "snap-on" lip must be removed with a reaming tool. Then, the cast coping is fitted onto the analog.
4. Finally, the structure is trimmed and veneered with porcelain according to anatomical guidelines.

Seating and cementation of the crown

The process of seating and cementing the crown requires four steps:

1. Seat the crown and evaluate interproximal contacts with dental floss.
2. Make occlusal adjustments, similar to that of a natural tooth, with light occlusal force, eliminating occlusal contacts. Establish final maximum intercuspation contacts with a heavy occlusal force.
3. Because dental implants most effectively resist forces directed axially, lateral forces on posterior implant-supported crowns must be minimized for long-term success. Therefore, flatter inclines with no eccentric contacts are essential [7].
4. When completely seated and adjusted, cement the veneered crown onto the intraoral abutment.

Summary

Using well-designed dental implant systems, oral surgeons or periodontists and general dentists can collaborate to provide their patients esthetic and functional replacements for missing teeth. When used to replace posterior teeth, Straumann solid body abutments may be impressed with relatively simple techniques and the resultant crowns seated and cemented with only minor modifications to traditional protocols.

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THE DENTAL
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Evidence-Based Decision-Making: Implants Versus Natural Teeth

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The pioneering work of Brånemark ushered in a new era in dental prosthetic treatment. It is not hyperbole to state that osseointegration and root-form implants have revolutionized dental treatment. In the course of treatment planning, however, questions often arise as to the predictability of implant-borne prostheses vis-à-vis other forms of dental treatment. In particular, data regarding the relative predictability and longevity of fixed partial dentures, removable partial dentures, endodontic treatment, and conventional dentures are often needed to make evidence-based treatment decisions. Unfortunately and somewhat surprisingly, few efforts have been made to compare such treatment modalities with implant outcomes. This article compares the outcomes of selected treatment modalities with regard to their relative predictability and longevity. Specifically, outcomes for endodontic treatments are compared with those for single-tooth ITI Dental Implant System implants, and outcomes for conventional mandibular dentures are compared with those for implant-retained overdentures.

Endodontic treatment outcomes

Initial nonsurgical endodontic treatment

A common clinical decision-making situation exists when a tooth is found to be nonvital. Often, the decision the clinician must make is whether to extract the tooth and place an implant or perform endodontic treatment.

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Although some investigators have attempted to provide guidelines for clinical decision-making [1,2], outcomes studies that provide evidence for clinical guidance are not plentiful. One very large epidemiological study is that of Salehrabi and colleagues [3], who reported on nonsurgical endodontic treatment outcomes in 1,462,936 teeth in 1,126,288 patients. The study sample is based on the records of the Delta Dental Insurance Data Center and reflects the claims experiences of the insured. Patients included in the study were insured by Delta continuously from 1995 to 2002. The study showed that 97% of the teeth were retained 8 years after the teeth were initially treated with conventional nonsurgical endodontic techniques. Only 3% of the teeth experienced suboptimal outcomes, such as re-treatment, extraction, or apical surgery. Meanwhile, 85% of teeth requiring extraction did not receive full coronal coverage.

Closely related to the above study is an earlier report by Lazarski and colleagues [4]. They used the same Delta Dental claims database to assess outcomes following 110,766 nonsurgical endodontic procedures. The patient population was enrolled in Delta Dental continuously from January 1, 1993, through December 31, 1998. Thus, a large proportion of the data set from the Lazarski report is a subset of the data set in the Salehrabi study. Accordingly, in any systematic review, these studies should not be counted as distinct and discrete. In the study by Lazarski and colleagues, 44,613 cases showed ''incidences of extraction, re-treatment, and periradicular surgery equal to 5.56%, 2.47%, and 1.41%, respectively.'' All teeth in this study had at least 2 years' follow-up. Thus, the outcomes for 9.44% of the teeth might be considered suboptimal, while approximately 90% of the teeth healed uneventfully. Over a mean follow-up period of 3.5 years, 94.44% of the treated teeth remained functional.

Collectively, these studies suggest that nonsurgical endodontic treatment enjoys a high degree of predictability. However, this interpretation has some potential problems. When the investigators state that 97% of the teeth were retained, they mean that there is no record in the Delta Dental database of these teeth being extracted or re-treated. It is possible, if unlikely, that some needed treatment was never provided. Perhaps, also, some treatment was provided but not submitted to the insurance carrier. Validation of a small, randomly selected subset of this population may have been worthwhile, especially since some prospective studies have reported contradictory findings. One simple (though imperfect) method of cross-checking the data might involve checking to see if claims for fixed–partial-denture pontics were ever submitted for any of the treated teeth (thus implying that the teeth in question were extracted).

Tilashalski and colleagues [5] conducted a prospective cohort study of 873 subjects. An in-person interview and clinical examination were conducted at baseline, 24 months after baseline, and 48 months after baseline, with telephone follow-up at 6-month intervals. Seventy-five teeth received nonsurgical endodontic treatment and were followed for at least 1 year or

until extraction. Mean follow-up time was 24.8 months. Definitive restorations were placed in 79% of the teeth at a mean time of 4.4 months postendodontic therapy. Following endodontic therapy, 81% of the teeth were retained and 19% were extracted, a much higher failure rate than reported by Salehrabi and colleagues despite a much shorter follow-up time.

The so-called "Toronto Study" is an attempt to assess the long-term outcomes of initial nonsurgical endodontic treatment [6–9]. This study is being conducted and reported in phases. All treatment was performed by graduate students who were supervised by practicing specialists in endodontics. In Phase I of the study, 450 teeth were treated with either the Schilder vertical condensation technique or the step-back, lateral-condensation approach. Teeth were assessed clinically and radiographically for evidence of periapical healing. At the conclusion of the follow-up period, only 120 teeth were available for examination. The overall "healed" rate was 81%. The healed rate for teeth without radiographic evidence of periapical pathology at initial presentation was higher (92%) than for teeth with periapical lesions (74%). The primary predictor of healing response was the presence or absence of periapical pathology.

The latest report from the Toronto Study gives the combined outcomes of Phase I through III and includes a treatment group of 532 teeth [6]. Somewhat surprisingly, only 132 of the original 532 teeth were available for reexamination. The excluded teeth included 142 dropouts, 10 extractions, and 248 "discontinuers." An analysis of the overall combined data from all phases showed the treatment success of the vertical condensation technique is 89% while that of the lateral condensation technique is only 73%. Single-rooted teeth had a higher success rate than did multirooted teeth (92% versus 83%) and teeth with preexisting periapical pathology had a lower success rate (80%) than those that did not have such findings (93%). Similarly, teeth that experienced intraoperative complications had a lowered success rate (76%) than those without complications (88%).

As an aside, it is difficult to reconcile the various numbers used in these reports of the Toronto Study. For instance, Marquis and colleagues [6] refer to a total of 532 teeth, while Farzaneh and colleagues [7] state that "the inception cohort consisted of 523 teeth in 444 patients." Of greater concern is the difficulty in ascertaining the number of teeth extracted and the timing of the extractions. Farzaneh and colleagues [7] state that 395 teeth were lost to follow-up, including "25 extracted" teeth. Marquis and colleagues [6] state that 10 teeth were extracted. Furthermore, it is not clear why extracted teeth were not counted among the failures, since it appears these teeth received treatment (although it is not absolutely clear that this is the case).

Lastly, it is well recognized that patient follow-up is often difficult in long-term cohort studies. Nevertheless, the low rate of teeth and subjects available for reexamination is a matter of concern. Certainly, this group includes successfully treated patients who have moved, for example, but it may also include patients who have had teeth extracted due to endodontic

or restorative complications. Indeed, dissatisfaction with treatment may be a reason for patients to leave a study.

In contrast to the low follow-up observed in the Toronto Study, Ørstavik and colleagues [10] reported a comparatively low attrition rate of 135/810 roots (i.e., dropouts accounted for 135 of 810 roots). These investigators reported an overall success rate of 90%. Those teeth that initially presented with chronic apical periodontitis had a success rate of 79%. Those teeth without such a history had a 94% success rate. The classification of "chronic apical periodontitis" was made based on the radiographic appearance of the periapical tissues.

It is difficult to explain the disparate results reported in the studies cited above. Yet conclusions must be drawn to formulate guidelines for clinical decision-making. On the one hand, the two insurance-based studies came from extremely large sample sizes. On the other hand, samples of these studies overlapped considerably and they are both retrospective studies based on data mining, as opposed to prospective studies, such as the Toronto Study and the work of Tilashalski and colleagues. One of the most fundamental tools of evidence-based medicine is the hierarchy of evidence. Simply stated, some studies are more compelling than others. Systematic reviews and meta-analyses of well-designed clinical trials constitute the highest level of evidence. Next are individual randomized controlled trials. According to a generally accepted principle of ranking evidence, prospective studies are more compelling than are retrospective studies involving data mining. It is, therefore, appropriate to rank those studies that are prospective (Table 1) above retrospective studies. Even so, the extremely large sample size and the private-practice setting make the Delta studies compelling. In the end, no simple formula determines which of these groups of studies is more valid. If one accepts the prospective studies cited in this review, the overall success rate of endodontic therapy is significantly less than the rate in those studies

Table 1
Endodontic outcomes

Study	Success (no periaptical [PA] pathology) %	Study design
Salehrabi et al [3] (includes some of Lazarski et al [4] sample)	97	Retrospective (data mining of insurance claims database)
Lazarski et al [4] (includes some of Salehrabi et al [3] sample)	94	Retrospective (data mining of insurance claims database)
Tilashalski et al [5]	81	Prospective
Toronto Study (vertical condensation) [6]	89	Prospective
Toronto Study (lateral condensation) [6]	73	Prospective
Ørstavik et al (no chronic PA lesion) [10]	94	Prospective
Ørstavik et al (chronic PA lesion) [10]	79	Prospective

using the Delta database. Therefore, the issue as to the predictability of initial, nonsurgical endodontic therapy must await additional studies or, perhaps, additional analysis of the Delta database.

Endodontic re-treatment

In considering treatment guidelines, it is also necessary to consider the predictability of endodontic re-treatment. Some studies suggest that persistent periapical infection may persist or emerge following endodontic treatment in as many as 30% of endodontically treated teeth [11]. Re-treatment of such teeth is much less successful than initial treatment. Friedman stresses the need for good information upon which to base clinical decisions in such cases and has especially recommended that a careful cost–benefit analysis be used in making such decisions. Hepworth and Friedman [12] reviewed the extant endodontic outcomes literature in 1997 and reported overall success rates for nonsurgical re-treatment of 66% compared with 59% for apical surgery. These numbers may have less relevance today, given the technical advances during the intervening years.

Endodontic outcomes: summary

It is likely that multiple factors are involved in determining endodontic outcomes. Although a number of these have been reported [13], the authors lack good models to forecast outcomes accurately. Such information could be of great interest to the dental profession as well as third-party payers [14]. From the works cited above, it seems reasonable to assess the risk of failure as higher when certain conditions are present. These include chronic periapical infection or radiolucency, previously unsuccessful endodontic treatment, presence of multiple roots, and coexisting periodontal disease. In particular, re-treatment of teeth that have been previously treated endodontically seems to be often associated with poor outcomes. More well-designed studies are needed to quantify the risk of endodontic treatment failure in various clinical situations.

Single-tooth implant restorations

This article is limited to studies of single-tooth, implant-supported crowns (Table 2). Bragger and colleagues [15] studied a group of 48 patients who had 69 single crowns installed on 69 ITI implants over 10 years. Five implants were lost due to biological issues and 2 crowns had to be remade due to technical failures, for a total failure rate of 10%. Levine and colleagues [16] reported the results of a retrospective evaluation of ITI implants placed in 12 centers throughout the United States involving 174 implants placed in 129 patients. All implants functioned for 2 years or more. An overall survival rate of 95.2% was reported.

Table 2
Implant outcomes (ITI dental implant system)

Study	Success or survival rate	Study design
Bragger et al	90	Prospective
Levine et al	95	Prospective
Ferrigno et al	91	Prospective
Astrand et al	97	Prospective
Lambrecht et al	99	Prospective
Fuggazotto et al	97	Prospective
Buser et al	97	Prospective

Ferrigno and colleagues [17] report good results after placement of ITI implants in the posterior maxilla using the osteotome sinus lift technique. These workers placed 588 implants and report a cumulative survival rate of 94.8% and a cumulative success rate of 90.8%. Interestingly, short implants (ie, 8 mm) had success rates equal to longer implants (ie, 10 and 12 mm).

Astrand and colleagues [18] report 3-year results on a group of 77 ITI implants. The survival rate was 97.3%. This was one of the few randomized controlled trials to compare implant systems. In this study, Brånemark implants were compared with ITI implants in a group of 28 patients. Both systems experienced a 97.3% survival rate and minimal postloading bone-loss was noted in both groups.

Lambrecht and colleagues conducted a study of 468 ITI implants [19]. This included a small number studied retrospectively and larger number studied prospectively. The investigators calculated 10-year cumulative survival and success rates. These rates were 99.2% and 96.4%, respectively.

In a multicenter study reported by Fugazzotto and colleagues [20], 979 implants having a length $\geq$9 mm were inserted in maxillary molar positions and restored following 12 weeks of healing with individual crowns. The implant surfaces were either plasma-sprayed titanium (TPS) or sandblasted acid-etched (SLA) and were followed up to 84 months. A cumulative success of 94.5% and 98.7% were reported for maxillary first molars and maxillary second molars, respectively.

Although not limited to single-tooth restorations, Buser and colleagues [21] conducted a long-term evaluation of 2359 nonsubmerged ITI implants. In Part I of the multicenter study, teeth in 1003 patients were treated and restored with 393 removable and 758 fixed restorations. All implants were documented annually up to 8 years with a cumulative survival rate of 96.7% and cumulative success rate of 93.3%.

A meta-analysis was undertaken by Lindh and colleagues [22] to assess the survival of implants in partially edentulous patients. Although not limited to ITI implants, this meta-analysis is worthy of inclusion. These investigators reviewed 66 studies published between 1986 and 1996. Of these, only 19 studies met the inclusion criteria. Those studies included data from 2686 implants, including 570 single units and 2116 fixed

partial-denture abutments. Life-table analysis was used. The survival rate for fixed–partial-denture abutments was 93.6% after 6 to 7 years of service. The corresponding value for single crowns was 97.5%.

Summary and clinical application

Implant-supported single crowns seem to have a success rate that is generally superior to the success rate associated with nonsurgical endodontic therapy. Indeed, if one limited the analysis to prospective studies only, implant therapy appears more predictable. In situations where the risk of endodontic failure is higher (eg, chronic periapical infection), implant therapy seems to be more predictable. This may also be true of endodontic re-treatment. Clearly, further studies are needed to provide better guidance as to when an implant is preferable to endontic therapy. Even so, from the evidence in this article, some general guidelines emerge, particularly with regard to endodontic therapy. Some of the above-cited studies show that significant periapical radiolucencies are associated with suboptimal outcomes. Similarly, multirooted teeth have a poorer prognosis, as do teeth that experienced an ''intraoperative complication.'' Also, recrudescent periapical infection in a previously obturated tooth is associated with a poor prognosis. Any of these circumstances may cause the clinician to consider the implant alternative.

Implant-supported mandibular dentures vis-à-vis conventional dentures

Overview

Investigators at McGill University have conducted a series of interesting studies on patient outcomes with implant-retained overdentures vis-à-vis conventional mandibular dentures. In one of their investigations, 60 edentulous subjects were randomly assigned to receive either a conventional mandibular denture or an implant-supported overdenture [23]. The implant-supported prosthesis was supported by two ITI implants with ''ball-shaped retentive anchors.'' Overall satisfaction was approximately 36% higher in the implant group and this difference increased with time. Chewing satisfaction was also higher in the implant group. Although this study employed dentures retained by two implants with ball attachments, high satisfaction has also been reported with dentures retained by a bar connecting two implants [24]. Awad and colleagues [25] have reported similar short-term results, although this may represent findings from the same sample. A study of prosthodontists indicated that implant overdentures (IODs) were easier to fabricate than conventional dentures [26].

Morais and colleagues [27] studied the effect of denture type on nutritional status. These investigators reported that the implant-retained overdenture (IOD) patients scored better in several areas, including percent

body fat, skin-fold thickness, waist–hip ratio, girth, serum albumin, hemoglobin, and serum B12 levels. These investigators suggest that IOD treatment may enhance the nutritional status of edentulous patients. It has been suggested that these differences are due to adverse dietary selection by wearers of conventional dentures [28]. Because of chewing inefficiency, such individuals are unable to chew hard or tough foods and this limitation results in certain dietary problems.

Heydecke and colleagues [29], also of the McGill group, examined differences in social and sexual satisfaction between conventional and implant-borne dentures. In this study, 102 subjects were randomly assigned to receive either conventional mandibular dentures or overdentures retained by two implants. The impact of the dentures on various social and sexual activities was assessed at baseline and 2 months after completion of treatment. Subjects in the IOD group experienced significant improvements in eating and in kissing and other sexual activity, as compared with the conventional denture group.

The same group [30] examined the cost and effectiveness of the two types of dentures in a group of 60 subjects, 30 of whom received IODs, while 30 received conventional dentures. These investigators compared the actual costs of providing the service versus the perceived value of the service by the patient and determined that the IOD was a cost-effective intervention.

The treatment time involved in delivering services is of great interest to practicing clinicians and those who pay for their services. In that vein, it seems appropriate to compare treatment times involved in delivering implant-borne dentures versus conventional dentures. One recent study reported the time required for implant placement until the time of preliminary impressions (referred to by the authors as the ''surgical phase''). Treatment was performed by a surgeon and prosthodontist [31]. Patients required a mean of four visits to the surgeon. These visits took a total mean time of 109 minutes (and 125 minutes for the surgical assistant). Mean time spent with the prosthodontist was 46 minutes (with a mean of two visits). In addition to scheduled visits, prosthodontists required a mean fabrication time of 296 minutes for an IOD versus 282 minutes for a conventional denture. The time included all time required from preliminary impressions through 6-month follow-up. The mean number of appointments required was 10.1 for the IOD group and 10.8 for the conventional denture group.

Based on these and other findings, the McGill group has suggested that the implant-supported overdenture be considered the standard of care for edentulous adults [32].

General satisfaction with implants vis-à-vis natural teeth

Pjetursson and colleagues [33] conducted a study of patients' satisfaction with implant treatment 10 years following implant placement. The study was part of a longitudinal cohort of implant patients and included 104

implant patients who had a total of 214 implants placed 5 to 15 years previously (mean: 10.2 years). A visual analog scale was used as the survey instrument. This study found that 97% of the subjects were satisfied or highly satisfied with function and chewing comfort. Meanwhile, 72.1% perceived no difference in chewing comfort experienced with teeth or implants, with 17.3% feeling more secure with teeth and 7.7% feeling more secure with implants. Over 95% were satisfied or highly satisfied with phonetics and esthetics. Similar percentages indicated that they would elect to have implants placed again.

Summary and clinical application

On the basis of their work, the McGill group recommended that the implant-retained overdenture be considered the first-choice, standard-of-care treatment for the edentulous mandible [32,34]. This group has made a convincing argument through a thoughtful analysis of their research results.

Summary

There are many difficulties in comparing implant outcomes studies with other treatment modalities (or even with other implant studies). Chief among these are the differences in study methodology and statistical analysis. One especially troublesome point concerns the criteria used to determine success. While some studies look at such criteria as chewing satisfaction, appearance, comfort and similar factors as advocated by Albrektsson and colleagues [35], other studies consider only survival (i.e., how long the implant remains in the mouth). This makes comparisons difficult. Additionally, while many studies employ well-recognized statistical techniques of survival analysis, others do not. Lastly, it seems problematic to lump all implant systems together. While it is often stated that there seems to be a rough equivalence between many root-form, titanium implant systems, little actual evidence supports this position. Indeed, given the diversity of implant surfaces and designs, such differences seem highly likely. Evidence of such differences is sometimes reported in the literature, although such studies are rare [36]. Even in implants of similar design, manufacturing differences could conceivably play a role in determining clinical outcomes. In this brief article, the authors attempted to compensate for potential differences between systems by confining the review to one system. Further work needs to be done in this area. Unfortunately, such comparisons are unlikely to be funded and such studies, however desirable, are unlikely to be forthcoming. One notable exception is the work of the McGill group. This series of studies is an elegant comparison of two dental treatments and is an example of the type of trial that is needed.

As dental implants have become more predictable, the clinician is often confronted with the dilemma of whether to use implants or other modalities. The survival and success rates reported by many implant investigators often

exceed the success rates of some forms of traditional dental treatment. In particular, it could be argued that implant-borne prostheses have better outcomes than apical surgery, conventional endodontic re-treatment, and conventional dentures. More and better outcomes studies are needed to provide survival and success rates for conventional dental therapy.

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Implant Maintenance

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Endosseous root-form implants have become an integral part of dental reconstruction in partially and fully edentulous patients. It has been estimated that approximately 300,000–428,000 endosseous implants are placed annually in the United States [1]. The success of dental implants is highly dependent on the integration between the implant and intraoral tissues, hard and soft. The successful integration of the osseous tissue structures to titanium implants, termed "osseointegration" by Dr. Per-Ingvar Branemark, has been well documented [2–4]. Current knowledge indicates that the maintenance of a healthy soft tissue barrier is as important as osseointegration itself for the long-term success of an implant-supported prosthesis [5]. The long-term prognosis of an implant is related directly to routine assessment and effective preventive care. To maintain healthy tissues around dental implants, it is important to institute an effective maintenance regimen. Different regimens have been suggested, but it is unclear which are the most effective [6]. This article evaluates the literature regarding implant maintenance. Factors affecting the soft tissue surrounding endosseous root-form implants also are discussed, and procedures for assessment of the implant and the treatment of reversible disease in implant maintenance are outlined.

Structure and function of the peri-implant tissues

It is important to have a basic understanding of the peri-implant soft tissue structures. The interface of the soft tissue with the implant is critical in sealing the intraoral environment from the endosseous part of the dental implant [7]. This biologic soft tissue seal, which is analogous to the epithelial attachment of the tooth, protects the implant–bone interface by resisting the challenge of bacterial irritants and the mechanical trauma resulting from restorative procedures, masticatory forces, and oral hygiene maintenance [5]. The soft tissue (perimucosal) seal that forms around the coronal

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part of a dental implant is about 3 mm in corono-apical direction and consists of two zones, one of epithelium and one of connective tissue [8]. The outer surface of the peri-implant mucosa generally is covered by keratinized stratified squamous epithelium that is analogous to the gingiva. Although keratinized tissue may be less susceptible to bacteria at the implant–soft tissue interface [9], lack of keratinization has been reported to have little adverse effect on implant survival [10], especially in areas of healthy tissue. The barrier epithelium, only a few cells thick, is continuous with outer surface tissue and terminates about 2 mm apical to the soft tissue margin. Both epithelia harbor hemi-desmosomes and have the appearance of a basal lamina [11].

The vascular system of the peri-implant mucosa derives solely from the alveolar supraperiosteal blood vessels because there can be no contribution from a periodontal ligament [12]. The remaining 1 to 1.5 mm of soft tissue margin, between the apical portion of the barrier epithelium and the alveolar crest bone, is composed of connective tissue. These connective tissue bundles originate from the alveolar crest and run parallel to the abutment surface. Unlike periodontal attachment surrounding natural teeth, there is no insertion of connective tissue fibers into the implant surface. The connective tissue ''cuff'' is held in close approximation to the epithelial attachment that surrounds the implant. In the presence of keratinized mucosa, the connective parallel fibers are woven with circular fibers running circumferentially around the implant. The connective tissue immediately adjacent to the implant is rich in collagen and is relatively acellular and avascular, making it histologically similar to scar tissue [13].

Many authors have discussed biologic width and implants. When comparing the collective measures in biologic width of sulcus depth and the dimensions of junctional epithelium and connective tissue contact, the results of studies of natural teeth [14,15] and those of implants remain dimensionally stable. There are differences in the ratios for nonsubmerged [16] versus submerged implants [13,17]. Although a healthy connective tissue seal can be achieved on both types of dental implant systems, the epithelial attachment is more apically located on submerged implants because of the presence of the so-called ''microgap'' [18]. Although the actual measure of the separate components of the biologic width around implants can change at different times after insertion, the overall sum of the sulcus depth, junctional epithelium, and connective tissue contact surrounding the implant does not change. This stability indicates that the biologic width is a physiologically formed and stable structure over time [19]. Biologic width is one of many factors to consider when monitoring the progress of osseointegration and health of peri-implant tissues during the first critical year after placement and afterwards during maintenance visits.

Peri-implant disease

Implants, like teeth, are susceptible to bacterial plaque accumulation and calculus formation. In fact, because of a lack of connective fiber insertion

and decreased vascular supply around the implant, there may be greater susceptibility to plaque-induced inflammation [20]. Plaque will form on implant surfaces as soon as they are exposed to the oral cavity. The initial pellicle formation on implants is similar to that on natural teeth, but the initial adhesion rate of specific bacteria may vary [21]. The composition of bacterial plaque is similar on implants and natural teeth [22]. Gram-positive facultatively anaerobic rods and cocci were found around periodontally healthy teeth and successful implants. In edentulous patients, bacteria colonizing the implant surface are derived from the microflora in saliva, which in turn are derived from various oral niches such as the dorsum of the tongue and tonsillar crypts [23]. In partially edentulous patients opportunistic periodontal pathogens such as *Actinobacillus actinomycetemcomitans*, *Prevotella intermedia*, *Peptostreptococcus micros*, and *Fusobacterium nucleatum* have been identified in association with peri-implantitis [24]. Periodontal pathogens identified in pockets before implant placement can be detected at implant sites 3 months after exposure to the oral environment [25]. Other data suggest that periodontal pathogens such as spirochetes may be transmitted from residual teeth to implants within 6 months of implant placement [26,27]. Proliferation of these pathogens can result in an inflammatory response and may lead to peri-implant infections.

The term ''peri-mucositis'' refers to the reversible inflammation of the soft tissue surrounding the implant and is somewhat analogous to gingivitis. ''Peri-implantitis'' is defined as an inflammatory process affecting the bone surrounding the osseointegrated implant and may be viewed as somewhat analogous to periodontitis [28]. Supragingival calculus is more common on implants than subgingival calculus, which is seldom seen. Calculus that forms on implant surfaces may be less tenacious than calculus around natural teeth and is easier to remove because the low surface energy of the titanium abutment surface attracts proteins with low surface affinity [29]. When the surface of the abutment fixture is exposed to the oral environment, any calculus attachment is much more adherent and difficult to remove [29].

The mucosa surrounding the implant exhibits an inflammatory response to plaque formation similar to that seen in the gingiva that surrounds the natural teeth. Although the formation of biofilm and the initial inflammatory response between the dento-gingival structures and the gingivo-implant structures are similar, studies have shown that the pattern of spread of inflammation differs [20,30]. Because of the smaller numbers of fibroblasts in peri-implant tissues, inflammatory cell infiltrate extends into the bone marrow spaces of the alveolus. Thus, it has been suggested that the peri-implant mucosa is less effective than the gingiva in preventing further progression of the plaque-induced lesion into the surrounding bone. This progression can lead to peri-implantitis and potential failure of the implant [31]. It is, however, difficult to reconcile these theoretical constructs with the remarkably high success rates observed in numerous implant outcomes studies. Peri-implantitis seems to be a rather uncommon condition, but it is

prudent to implement maintenance measures that will reduce the incidence of these infections further, because implant loss often involves significant morbidity, expense, and inconvenience.

Clinical signs and symptoms of peri-implant disease include edematous tissue and bleeding after gentle probing with a blunt instrument, with a potential of suppuration [9]. Discrimination must be made between reversible peri-mucositis, with no loss of supporting bone, and irreversible peri-implantitis, in which there is progressive loss of osseointegration. Radiographic evidence will show vertical bone destruction with an associated peri-implant pocket. Pain is not a typical feature of peri-implantitis and, if present, usually is associated with an acute infection. The final stage of peri-implant disease is mobility of the fixture or a continuous radiolucency around the implant. The overall frequency of peri-implantitis is in the range of 5% to 10% [32]. The actual need for surgical removal of the implant is reported to be much lower and to occur mostly during the first year after placement [33]. Even with signs of infection, implant loss could remain low if appropriate preventive and interventional treatment strategies are followed after closely supervised monitoring and diagnosis. Indeed, reversal of peri-implantitis and reintegration of surface-enhanced implants recently has been demonstrated in an experimental peri-implantitis model [34]. In that study, significantly greater reintegration was noted with a sandblasted, acid-etched surface than was seen with smooth-surfaced implants.

Maintenance regimens for dental implants

Maintenance programs for implants should be designed individually because there is a lack of data detailing precise recall intervals, methods of plaque and calculus removal, and appropriate antimicrobial agents for maintenance around implants [35]. The first interaction with the implant patient in regard to maintenance should be a review of home care ability and motivation before the placement of the implant [36]. It is important that the patient understand his or her responsibility in caring for the implant. The role of the patient is that of cotherapist; the therapist and patient must form a therapeutic alliance, as in dental care that does not involve implants. The patient's motivation and skill in performing oral hygiene measures may influence the prosthetic design [37]. It has been suggested that a patient's inability to achieve adequate oral hygiene be considered a possible contraindication to implant placement [38].

The following post-placement parameters should be evaluated and considered before the restorative phase: quantity, quality, and health of soft and hard tissues, implant stability, implant position and abutment selection, and oral hygiene assessment [39]. Because peri-implant lesions result from opportunistic infections that may lead to loss of supporting bone, it is mandatory to monitor peri-implant tissues at regular intervals in hope of implementing early interventions when signs of disease are noted. Studies have

shown that mucositis lesions can exhibit apical progression after 3 months of plaque buildup around implants [40]. Therefore a 3-month maintenance regimen is recommended within the first year of implant placement. Depending on risk factors, oral hygiene compliance, and assessments, the recall interval can then be extended to 6 months [41]. Because periodic evaluation of the dental implant is vital to its long-term success, the following factors must be evaluated at each maintenance appointment:

- Presence of plaque and calculus
- Clinical appearance of peri-implant tissue
- Radiographic appearance of implant and peri-implant structures
- Occlusal status, stability of prostheses and implants
- Probing depths and presence of exudates or bleeding on probing
- Patient comfort and function [39]

In addition to the evaluation, the maintenance appointment also should include

- A thorough review of oral hygiene reinforcement and modifications
- Deposit removal from implant/prosthesis surfaces
- Appropriate use of antimicrobials [42]
- Reevaluation of the present maintenance interval, with modification as dictated by the clinical presentation

Clinical assessment

Assessment of home care

Evidence from animal and human studies has established the importance of the microbial biofilm in the pathogenesis of peri-implant disease [30,43]. Therefore it is logical to monitor oral hygiene habits by routinely assessing plaque accumulation around dental implants. The amount of plaque around implants always should be evaluated and documented [44]. Two indices have been developed for such plaque assessments. Mombelli and colleagues [25] suggest numerical scoring (0 = no visible plaque, 1 = plaque recognized by running probe over smooth margin of implant, 2 = visible plaque, 3 = abundance of soft matter) of visible marginal plaque amounts, whereas Lindquist and colleagues [45] suggest a similar quantification (0 = no visible plaque, 1 = local plaque accumulation, 2 = general plaque accumulation greater than 25%) of plaque percentage. Another method of quantifying plaque accumulation is to compute a simple percentage of surfaces with plaque accumulations. Six areas of plaque (three buccal and three lingual) are recorded in the same manner used with natural teeth. A resulting percentage of identified surfaces can be calculated and compared with an established threshold set for acceptable oral hygiene. The clinician can decide whether to incorporate the use of dyes or stains. Although this method may take a little more time, it develops a record the presence of plaque on all individual

implant surfaces that can be easily compared over time. Because the implant abutment surface is highly polished, calculus does not tend to accumulate as easily or as tenaciously on implants as on natural teeth [46].

Examination of peri-implant soft tissue

The clinical appearance of peri-implant tissues is another evaluation that should be completed during a routine maintenance visit. Redness, swelling, and alterations of color, contour, and consistency of the marginal tissues may be signs of peri-implant disease. The appearance of peri-implant tissue also may be influenced by the characteristics of the implant surface [47,48]. Several suggested methodologies to evaluate the clinical appearance of the mucosa around implants involve measures of bleeding. Numerical indices by Mombelli and colleagues [9] and by Aspe and colleagues [49] are similar to the traditional gingival index but have been modified and adapted for application around dental implants. Another study recommends the use of the O'Leary index, a visual measure for periodontal tissue condition [50]. Using an index consistently is more important than the choice of index.

Radiographic examination

Radiographic interpretation of peri-implant alveolar bone has proven to be one of the most valuable measures of implant success [51]. Radiographic interpretation is particularly important when probing cannot be used to evaluate an area because of constricted implant placement or lack of access because of prosthetic placement. Radiographs are important when used to compare osseous changes over time. As with radiographic evaluation of natural teeth, there is low sensitivity in detecting early pathologic and bone remodeling, making the results confirmatory to a clinical diagnosis. Early lesions may not be noticed until they are more advanced [52]. In particular, panoramic radiographs with poor resolution can be used only for screening. Standardized periapical radiographs using long-cone paralleling technique are recommended [53], but panoramic films actually may be superior to intraoral exposures in some cases. In the final analysis, the choice of imaging modality must be tailored to the clinical and anatomic circumstances of the individual patient. Digital subtraction radiology can increase the sensitivity significantly but is seldom used in the clinical setting, for a variety of reasons [54]. A stable landmark, which should be identified for each fixture evaluated, is the implant shoulder (collar contour) for one-stage transmucosal implant systems or the apical termination of the cylindrical portion of the implant for two-stage submerged implant systems [55]. The implant threads on screw-type fixtures can be used as a reference to compare osseous peri-implant dimensional changes between on-going series of radiographs. When making measurements from radiographs, allowance must be made for dimensional distortion, which may vary considerably [56]. Normally, a postoperative radiograph is taken

immediately after implant placement to verify position and provide a benchmark for future comparisons. Future imaging requirements would be based on the clinical situation of the particular patient. One interval that has been recommended (in the absence of obvious clinical problems) is 1, 3, and 5 years, with films obtained thereafter based on the clinical situation [57].

The radiograph should reveal bone in close apposition to the implant body. Anticipated crestal bone loss for the first year after insertion is approximately 1 mm, with an average 0.1 mm subsequent bone loss per year. This loss is seen primarily in submerged (two-stage) implants; it has been suggested that this crestal loss results from the existence and microbial colonization of a microgap. It has been reported that greater bone loss occurs in the maxilla than in the mandible, but this finding has not been universally observed [58]. Failing implants often exhibit a thin radiolucent space that may mimic a normal periodontal ligament space but may also exhibit larger, saucerlike defects at the alveolar crest. The periapical area also should be free of significant radiolucencies.

Rapid bone loss, which may not be radiographically evident, may be associated with fractured fixtures, initial osseous trauma during insertion, stress concentrated at the marginal bone by overtightening of fixtures during placement, trauma from occlusion, poor adaptation of prosthesis to abutment, normal physiologic resorption, and plaque-associated infection [58].

Occlusal evaluation

The occlusal status of the implant and its prosthesis must be evaluated on a routine basis. Occlusal overload can cause a host of problems, including loosening of abutment screws, implant failure, and prosthetic failure. The occlusal contact patterns should be evaluated, as should the mobility of the implant and opposing teeth. Successful implants are not perceptibly mobile. Indeed, failing implants are not mobile until all or most of the bone has been lost. The occlusion also should be evaluated at every maintenance appointment. There is little evidence available concerning implant survival and occlusion. Although it is not known if nonaxial loading is detrimental to osseointegration, it has been established that abnormal occlusal loading will negatively affect the various components of the implant-supported prosthesis [59]. Any signs of occlusal disharmonies, such as premature contacts or interferences, should be identified and corrected to prevent occlusal overload. The implant-protected occlusion should have light centric contact with no contacts on lateral excursions. A check of occlusion should hold shim stock only with hard clinched teeth. Implant prostheses should be examined when bruxism or other parafunctional habits are exhibited. Excessive concentrated force can result in rapid and substantial peri-implant bone loss [60].

A failed implant connected to a multiunit prosthesis may mask evidence of mobility, although such an implant would almost always exhibit

significant bone loss on radiographic examination. It has been suggested that a fixed, multiple-unit, retrievable implant-retained prosthesis be removed periodically to assess mobility, gingival health, and hygiene status, although there is not universal agreement on this point. All prostheses should be evaluated for mobility during routine maintenance evaluation. Any movement would indicate possible lack of osseointegration of the fixture, possible failure of the cement bond between the superstructure and the retainer, or screw failure by fracture or loosening. Screw loosening is a common problem [50]. Either the screw that retains the abutment or the screw that retains the crown can be loose. In the case of the abutment screw, it is sometimes difficult to determine whether the actual implant or only the screw is loose. One useful hint is the presence of a parulis or fistula located within the keratinized mucosa in close proximity to the microgap. Once the abutment is loose, the microgap widens considerably, which results in heavier microbial colonization, often resulting in the formation of a fistula.

Other methods have been developed to assess the degree of bony support. One of the earliest devices known as the Periotest is designed to assess subclinical mobility [61], but the diagnostic significance of the resulting values has been questioned [62].

Peri-implant probing

Peri-implant probing depth should be measured routinely during maintenance appointments [63]. Measurement of probing depth around implants is more sensitive to force variation than around natural teeth [64]. Therefore less probing force (0.2–0.3 N) is recommended around implants. Even with this lesser force, it was found that the probe caused a separation between the surface of the implant and the junctional epithelium, but not within the connective tissue adaptation. Five days after clinical probing, healing of the epithelial attachment seemed to be complete. This finding suggests that clinical probing around osseointegrated implants does not have detrimental effects on the soft tissue seal or jeopardize the longevity of oral implants [65]. Concern has been expressed about the possibility of introducing pathogens into peri-implant tissues while probing. Indeed probe penetration increases with the degree of inflammation, exceeding the connective tissue adaptive level by a mean of 0.52 mm [63]. Even with the influence of variables such as the roughness of the implant body, difficult access, and location of the microgap in submerged implants, the advantages of probing (eg, the simplicity of the method, the immediate availability of results, and the ability to demonstrate topographic disease patterns) make probing an indispensable part of implant maintenance assessment [66]. Probing depths can be influenced by the thickness and type of mucosa/epithelium surrounding the implant. Shallow depths usually are associated with a keratinized collar, whereas deeper probing depths are associated with mobile alveolar mucosa surrounding the implant [67].

Use of a fixed reference point on the implant abutment or prosthesis for a reliable measurement of attachment levels is recommended [68]. Successful implants generally have a probing depth of 3 mm, whereas pockets of 5 mm or more serve as a protected environment for bacteria and can exhibit signs of peri-implantitis [69]. Peri-implant probing should be avoided during the first 3 months after abutment connection to avoid disturbing healing and establishment of the soft tissue seal [70]. The peri-implant probing attachment level correlates closely with radiographically measurable peri-implant bone changes. It is recommended that probing be a part of each maintenance recall appointment [54].

Bleeding on probing

Another suggested parameter for evaluation of the status of the implant during maintenance is the presence of exudate or bleeding on probing. Bleeding on probing indicates inflammation of soft tissue, whether around natural teeth or implants. Controversy exists as to whether bleeding on probing represents traumatic wounding of the tissue or demonstration of clinical inflammation [71]. Bleeding on probing alone has been found to be a poor predictor of progression of periodontal disease, but its absence at successive maintenance visits may be a reasonably good negative predictor of attachment loss [72]. A positive correlation has been found between bleeding on probing and histologic signs of inflammation at peri-implant sites [73]. Also, predictive values for disease progression are high when combining high bleeding on probing scores with positive microbiologic testing [74].

Several indices have been developed to assess marginal mucosal conditions around oral implants. One index scores the amount of bleeding on probing [9]. Another index scores various levels of tissue color and consistency [49]. Although several promising studies have addressed the use of peri-implant sulcus fluid analysis for markers of inflammatory mediators in peri-implant disease, at this time it can be stated only that a potential exists for using biochemical markers to monitor the host response during the supportive phase of implant therapy [55]. Also, too little is known presently to recommend the routine use of microbiologic assays in determining risk for peri-implant tissue loss. The value of microbiologic testing increases after signs of peri-implant disease have been detected. Such information may be helpful for the differential diagnosis of peri-implantitis and for treatment planning [7].

Subjective symptoms

It is important to discuss patient comfort and function at each maintenance appointment. Pain or discomfort may be one of the first signs of a failing implant, usually presenting with mobility [75]. There may be persistent discomfort before any radiographic changes are detected [76]. A fractured or loosened screw should be the first suspicion when a patient complains

of a loose implant or discomfort. Function in regard to occlusal status, mobility, and presenting prosthetic conditions has already been discussed.

Patients should be placed on a regularly scheduled, individually designed maintenance program including monitoring of the peri-implant tissues, the condition of the implant-supported prosthesis, and plaque control [77]. An established protocol suggests a 3-month recall visit to limit disease progression and to allow treatment of disease at an early stage [50]. After the first year the maintenance interval can be extended to 6 months if the clinical situation seems stable [30].

Oral hygiene instruction

Based on the condition of the tissue and the assessment of the presence of plaque and calculus around implants, a thorough review of oral hygiene instructions should be implemented. Ideally a home care assessment has been made before the implant fixture is placed surgically [36]. Patients who have dental implants usually have a history of less-than-ideal home care, resulting in the partially or totally edentulous state. Also these patients may fall into the extremes of lack of home care because of postsurgical fear of causing damage, on the one hand, or overzealous home care trying to stay totally plaque-free, on the other. Either of these situations can lead to an undesirable outcome [78]. High plaque scores are correlated positively with peri-implant mucositis and increased probing depths around implants [79]. Smooth implant surfaces form less plaque than roughened surfaces [80]. Therefore it is important to use and recommend home care aids that do not alter the implant abutment surface and are safe and effective with daily use [81]. The clinical situation and the type of implant influence the timing of initiating home care measure. During healing periods, when mechanical plaque control is contraindicated, chemical agents (eg, chlorhexidine) should be used. A variety of devices, including soft-bristled brushes, dental floss, and interproximal brushes with a nylon-coated core wire, may be used. There is evidence that certain electromechanical brushes may be superior to manual brushing for many patients [82]. Smaller-diameter toothbrush heads such as end-tufted brushes or tapered rotary brushes may be of benefit in difficult-to-access areas. Besides the interdental brush, interproximal plaque may be removed by many types of floss (eg, plastic, braided nylon, tufted, coated, woven, yarn, and gauze). These products have been found to be safe for daily use, especially with multiunit or hybrid-type prostheses [83].

Just as with the tissues surrounding natural teeth, the health of the peri-implant tissues depends on inhibiting and preventing early plaque formation, removing existing plaque, and interrupting the progression of peri-implant mucositis to peri-implantitis [50]. The professional procedures and techniques for achieving such maintenance can vary considerably from those used for natural dentition. Maintaining the surface integrity of the transmucosal titanium abutment is crucial to avoid negatively affecting

the surrounding soft tissue. Roughened surfaces can contribute to the accumulation of bacterial plaque and allow recolonization with pathogenic bacteria [84]. If there is no sign of inflammation, probing depths are 3 mm or less, and there is little plaque, it can be assumed that the area is sparsely colonized by nonpathogenic gram-positive bacteria, and the risk for periimplant complications is low. In such cases, zealous instrumentation of the implant surfaces is contraindicated [72]. When only soft debris is present, deplaquing the surface is beneficial. The use of a rubber cup and tin oxide or a specially designed prophylactic paste for titanium with fine abrasive content is recommended as the safest modality [81], but regular rubber cup polishing was found to be equal in cleaning effectiveness to regular brushing and air-polishing [85]. Because air-powder abrasive systems may have minimal effect on titanium surfaces, they may be used in implant plaque and stain removal, but excessive and prolonged exposure air-polishing can cause significant, undesired alterations [86]. For titanium implant abutments, it has been demonstrated that scalers made from stainless steel [81], titanium [87], or titanium-tipped stainless steel [50] roughen implant surfaces, creating scarring and pitting. The same effect is seen when metal ultrasonic inserts are used on implant surfaces. Gold-plated instruments leave no initial traces of residue on smooth titanium surfaces, but when used on rough surfaces the gold coating wears down, exposing the underlying alloy and leaving an unsuitable surface [88]. Research has shown that the use of plastic scalers produced insignificant alteration of the titanium implant surface following instrumentation [87,89]. Therefore, plastic instruments are recommended for scaling titanium implant surfaces, even though residues from the instruments are left behind [88]. Some plastic instruments are very flexible and can be difficult to use when removing calculus from implant surfaces. Plastic instruments reinforced with graphite are more rigid and can be sharpened. It is best to use a dedicated stone for sharpening graphite-reinforced plastic implant instruments so that metal filings are not transferred to the plastic instrument from a previously sharpened metal instrument [90]. Plastic probes often are recommended to prevent surface alterations, although there is no compelling evidence that the use of metal probes is detrimental to health [91]. Nonmetal ultrasonic tips are suitable for implant maintenance [92]. Although many researchers have proven that surface alterations are generated with metal instruments and ultrasonic inserts, the literature does not show that implant complications increase as a result of such surface alterations [35]. Nevertheless, it seems prudent to recommend that plastic or nylon instruments be used for implant débridement until more definitive research findings offer guidance in this area.

With a goal of promoting optimal health by inhibiting plaque formation and by altering existing plaque from pathogenic to nonpathogenic microorganisms around implants, topical antimicrobials should be considered for use in maintenance procedures. It has been documented that topical antimicrobials such as products containing chlorhexidine digluconate (0.12%),

plant alkaloids, or phenolic agents produce minimal implant surface alterations [81]. Mechanical débridement and mechanical débridement supplemented with chlorhexidine (0.12%) can reduce plaque, inflammation, and probing depths in patients who have peri-implant mucositis [93]. The chlorhexidine mouthrinse can be applied with a cotton swab or with a toothbrush around the peri-implant tissues when staining of esthetic restorations is a concern [94]. Antiseptic mouthrinses containing phenol-based therapeutic ingredients have been found to reduce plaque, gingivitis, and bleeding of peri-implant tissues significantly but do not improve probing depth or attachment level [95]. Although water is not classified as an antiseptic or antimicrobial agent, its use in a water-irrigating device on the lowest setting has been recommended, although there is insufficient published research to make recommendations in this regard [96]. Given the paucity of research in this area, it may be prudent to avoid the use of such irrigating devices.

Summary

Periodontal maintenance at individually established intervals is critical to the ongoing success of implant therapy. Periodic clinical assessment of the implant fixture, prosthesis, and surrounding tissue is critical to clinical success. Equally important is the professional removal of supragingival and subgingival deposits on a regular basis and counseling in home care techniques. Although further studies are needed before evidence-based protocols can be established, it seems prudent to recommend the routine implementation of an active maintenance program tailored to the circumstances of each individual implant patient. In most fields of medicine and dentistry, primary and secondary preventive strategies are usually superior to tertiary interventions, and this is likely to be true of dental implants as well [97].

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