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REVIEW ARTICLE

Biological mechanisms underlying complications related to implant site preparation

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1 | INTRODUCTION

Preparation of the site for dental implant placement is a key step of all implants' surgical procedures. Though it is a decisive factor that controls many variables related to implant osseointegration, it is often overlooked as a factor to consider in the prevention of implant-related complications. This chapter focuses on protocols for implant bed preparation and dissects the distinct procedural aspects of implant site preparation that may lead to adverse outcomes.

1.1 | Physiologic healing following implant site preparation

Implant bed preparation starts with the flap elevation in the conventional surgical procedure for implant placement or with limited mucosal tissue removal (eg, tissue punch) and osteotomy drilling through the mucosa in a flapless surgical approach. When a mucoperiosteal flap is elevated, removal of the periosteum exposes the alveolar bone to the oral cavity. The elevation of a full-thickness flap alone has profound effects on bone physiology. Given that one of the main sources of blood supply to alveolar bone stems from the vessels that traverse the periosteum (ie, supraperiosteal arterioles and their capillaries), the rapid compromise of oxygen and nutrient availability that results from flap reflection has direct effects on bone homeostasis. Interestingly, an experimental study in beagle dogs found that flap reflection without any further interventions to the bone led to 9% less medullary bone volume and a similar reduction in bone density on the experimental side than on the control side (ie, no flap reflection).[1] These findings serve to illustrate the highly dynamic state of the alveolar bone and its remarkable plasticity to noxious stimuli. The acceleration of cellular activities in response to vascular changes or mechanical forces that the bone cellular milieu demonstrates has been coined "regional acceleratory phenomenon"; this phenomenon governs the changes that occur following osteotomy preparation.[1]

Building upon the aforementioned example of the regional acceleratory phenomenon caused merely by reflection of a full-thickness flap, any mechanical manipulation of the alveolar bone (or the ridge) may be associated with bone resorption due to trauma and further bone remodeling after flap closure. There are many stages to implant bed preparation, including the following:

- the drilling process for the osteotomy
- drilling speed
- irrigation during osteotomy to control risk of overheating
- the implant body insertion.[2]

The remodeling process occurs after implant insertion, and the selected prosthetic design may influence the marginal bone stability around implants. These phases will be presented and discussed in this narrative review.

In cases where the alveolar ridge is narrow, supplemental techniques are involved, and these have an impact on implant stability, such as bone spreading (Figure 1), bone splitting (Figure 2), or grafting using particulate bone-grafting materials and the implementation of the guided bone regeneration technique. In addition, implant platform characteristics (surface pattern and platform shape), as well as type of implant-abutment connection, play a fundamental role in maintaining the crestal bone level around implants.

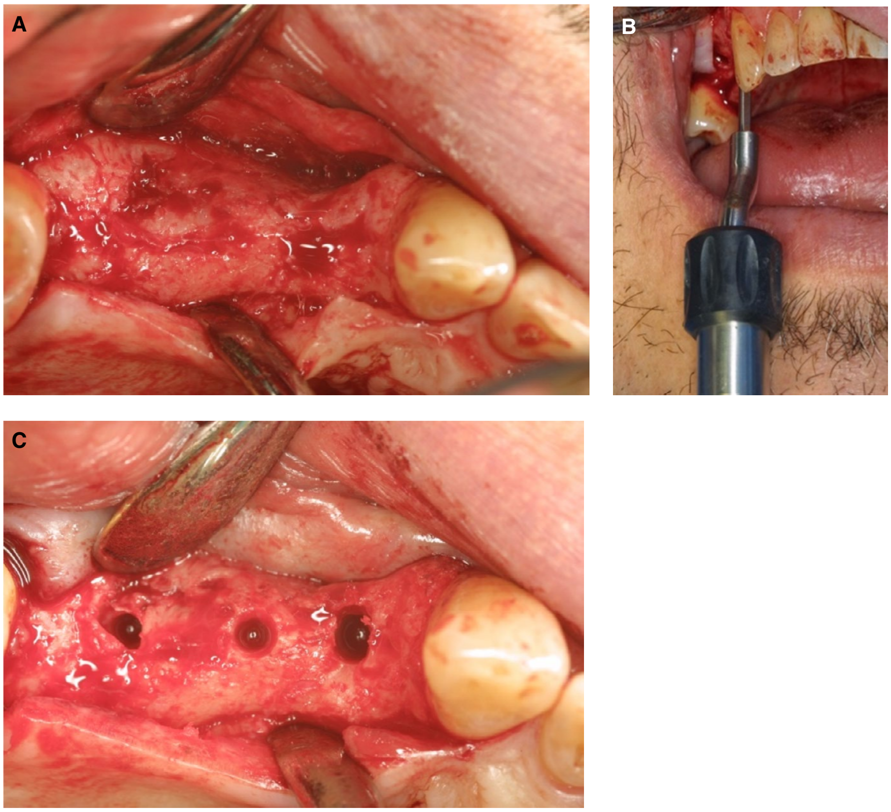


FIGURE 1 A, Bone-spreading technique (alveolar ridge expansion) using, B, chisel-type osteotomes; C, result immediately before implant placement preserving the bone at the osteotomy site

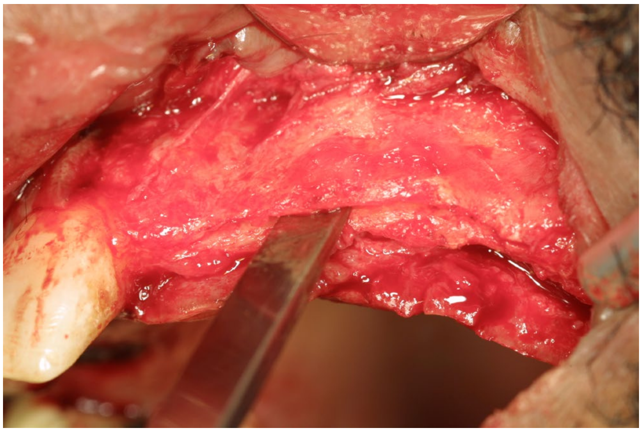


FIGURE 2 Bone splitting of the alveolar ridge separating the buccal and palatal plate of the ridge

1.2 | The role of the periosteum in osteotomy healing

From a biologic standpoint, the study by Park et al[3] showed that the periosteum is fundamental for early revascularization and can prevent the resorption of grafted bone.

This may also explain the structural and biologic benefits of the periosteum and supports the statement that an intact periosteum promotes regeneration. Also, in periodontics, partial-thickness periodontal flaps present revascularization in 14 days.[4] In addition, free gingival grafts can heal and be revascularized when they are placed on exposed periosteum. In contrast to this, bone resorption, as well as remodeling, was observed when these grafts were placed on exposed bone.[5] However, it was concluded that new bone formation was enhanced by the additional use of an expanded polytetrafluoroethylene membrane under a periosteum-lined mucoperiosteal flap when space maintenance was excluded as a critical factor.[6] In distraction osteogenesis procedures, the periosteum prevents external bone resorption in dogs.[7] In addition, animal studies in miniature pigs with mucoperiosteal flap elevation and ridge splitting have been compared with ridge splitting and partial-thickness flap procedures. Using this model system, the study by Stricker et al demonstrated that the periosteum prevents bone resorption, and the buccal bone volume was significantly better in the partial-flap procedures group than in the group with the elevation of a full-thickness flap.[8] The matrix composition of the periosteum defines its roles in bone growth, in cortical bone modeling and remodeling in response to mechanical strain, and in bone repair. Periostin is a key extracellular matrix component of the periosteum involved in periosteal functions. The matricellular protein periostin has several roles through all stages of bone repair in the early and the active healing phases (cartilage and bone deposition in the fracture callus) and in the final phase of bone bridging and reconstitution of the stem cell pool within the periosteum.[9] Moreover, in periodontology, periostin was discussed recently in the literature owing to its significance in collagen fibrillogenesis, cell migration, adhesion, response to mechanical stresses, and wound healing. It was shown to be an integral regulator of periodontal disease pathogenesis and repair.[10]

2 | RISK FACTORS FOR COMPROMISED IMPLANT INTEGRATION

2.1 | The drilling process

The osteotomy drilling technique is a sensitive process with many fundamental associated factors for crestal bone stability and osseointegration of dental implants. The irrigation during osteotomy using cold liquids (eg, saline), the speed of drilling, the use of specific implant designs to increase implant primary stability and avoid surrounding bone overcompression, and the sequential vs simplified drilling protocol have recently been discussed in the literature.

Studies using different drilling speeds have shown that the bone quality and not the osteotomy drilling speed appears to influence the primary stability of tapered dental implants.[11] Other researchers used low speeds without irrigation and evaluated the temperature increase in dense bone. Specifically, artificial blocks were drilled at a speed of 50 rpm (without irrigation) and were compared with blocks subjected to 1500 rpm with irrigation. These findings suggest that low-speed drilling without irrigation may not lead to overheating during drilling.[12]

From the biologic standpoint, “low-speed” (50 rpm) drilling without irrigation was recommended.[13] The technique is initiated with small-diameter drills, followed by sequential incremental changes in the drill diameter until the final drill was used that corresponded with the implant diameter. The authors suggested that the benefits of this technique are good control of drilling direction and depth, without increasing the temperature of the surrounding bone and allowing the collection of autologous bone and the preservation of cell viability. Using irrigation during drilling, the proteins and growth factors and other fundamental factors for bone regeneration will be easily dissolved, and therefore the low speed was recommended.

Additionally, a simplified drilling protocol using low-speed drilling does not negatively affect the osseointegration process and is comparable biologically to a conventional protocol.[14] This study was performed in the tibia of dogs using a 400 rpm drilling speed and different diameters of implants (3.75, 4.2, and 5 mm). Previous studies in dogs showed that the simplified (one drill) protocol for 10 mm implants with diameters 3.75 and 4.2 mm using a 900 rpm drilling speed presented comparable osseointegration outcomes to the conventional protocol.[15,16]

The simplified protocol consisting of a single drill vs multiple conventional drilling steps after 4 months of implant loading was also compared in 20 patients. The study concluded that both drilling techniques produced successful results over a 4-month postloading follow-up period, but the single bur procedure required less surgical time and led to less postoperative morbidity.[17]

A new hybrid drilling protocol (biologic plus simplified) was evaluated in comparison with a conventional drilling protocol. In vitro, thermal changes and effects on crestal bone loss and bone-to-implant contact in vivo were evaluated. In this protocol, no irrigation was used with an initial speed of 100 rpm, and a final drilling speed of 50 rpm was promoted. Thermometric changes were compared in both osteotomy groups using thermocouples. The new hybrid protocol increased the temperature similarly to the incremental conventional protocol and required twice the time for completion of the drilling procedure in vitro. Crestal bone loss and bone-to-implant contact in the hybrid drilling protocol were comparable to the conventional drilling protocol and did not affect the osseointegration process in vivo.[18]

The impact of the irrigation temperature on the osteotomy procedure using different drilling speeds was recently evaluated in vitro. The study was performed in bovine ribs using freehand and guided surgery approaches and demonstrated that drilling at 1500 and 2000 rpm, in a guided setting, caused temperature elevations that exceeded the bone necrosis threshold. A 2000 rpm drilling speed may produce potentially harmful temperatures also in a freehand setting. Irrigation at 10°C and 15°C kept temperature increments in the safe zone at 2000 rpm and 1500 rpm, respectively.[19] Evaluating the effect of different temperatures of the irrigation fluid during osteotomy[20] suggested that the use of 10°C precooled irrigation fluid is superior to warmer fluid for maintaining lower temperatures and reduces the difference between guided and freehand drilling. Based on previous studies, it was also concluded that infrared thermography was a method for accurate recording of temperature changes at and around the dental implant site and provided preliminary baseline data against that the cooling efficacy of different irrigation systems may be compared.[21] Recent studies also demonstrated that thermography appeared to more accurately reflect intraosseous temperature changes during implant site preparation than thermocouples did.[22] Therefore, the thermographic approach should be employed in the future in order to draw reproducible conclusions about the remodeling process occurring following bone drilling.

In an experimental study in sheep, healing was evaluated at implants installed in sites prepared in bone type 1 using different rotation speeds and cooling strategies. Two implant sites were prepared in each tibia using drills either at a high or a mixed speed under irrigation. At the mixed-speed sites, 60 rpm speeds without irrigation were applied for the last drill, the countersink, and during implant installation. No statistically significant differences between high and mixed-speed groups were found. It was concluded that the use of the last drill and the installation of the implant with or without irrigation yielded similar bone healing and osseointegration.[23]

However, thermal injury of hard bone, due to insufficient irrigation, caused massive resorption of the cortical bone and implant failure. Drilling procedures on hard bone need an adequate cooling supply because overheating of the bone matrix may induce complete resorption of dense bone around implants. Only internal irrigation protocols appeared to be more efficient than other types of cooling methods in preventing bone resorption around implants placed in a sheep mandible in vivo.[24]

2.2 | Insertion torque

Whether an insertion torque threshold exists that determines implant integration vs failure has been a highly contentious debate. In conventional implant osteotomy preparations, the quality of the bone is a key determinant of maximum insertion torque. Nonetheless, bone quality is an "umbrella term" that is empirically used in implant dentistry, but it largely fails to capture the complexity of alveolar bone physiology. The condition, structure, and morphology of the bone results from a highly dynamic equilibrium between bone apposition and deposition.[25] The key cellular regulators of this equilibrium are osteoblasts, osteoclasts, and immune cells. Importantly, whereas osteoblasts are of mesenchymal origin, osteoclasts are of hemopoietic origin and arise from the fusion of monocytic cells. Although beyond the scope of this chapter, several refined physiologic mechanisms are active to maintain bone function in response to functional, and to a certain extent parafunctional, stimuli through cell-to-cell crosstalk. For instance, T-cell activation and osteocyte sensing lead to increases in receptor activator of nuclear factor kappa-B ligand secretion that in turn initiates osteoclast maturation.[25,26]

The microcracks caused in the bone when an osteotomy is prepared are sensed as major stimuli, leading to osteoclast maturation.[26] Similarly, the compressive forces transferred to the medullary bone through implant insertion are stimuli that initiate osteoclastogenesis. This homeostatic response is a necessary component of the regional acceleratory phenomenon and, in turn, triggers pre-osteoblast proliferation and differentiation that will, in turn, be critical for implant integration. An example of this mechanism is the release of calcium ions because of osteoclastic responses that serves as a potent signal for osteoblasts.[27] Thus, insertion torque is an important factor that participates in the host response toward the implanted biomaterial. The question that arises is whether there is an optimal insertion torque to enable osseointegration or if an excess threshold exists that will lead to a failure to integrate.

As high insertion torques are generally considered favorable for improvement of implant stability and integration, an array of techniques has emerged, including modified drilling protocols, underpreparation of the osteotomy, bone condensing, and osseodensification. Trisi et al[28] and Wang et al[29] found that though implant osteotomy undersizing and condensation with tapered osteotomes increased interfacial bone density, it also led to microfractures (Figure 3) in the condensation zone and to osteoclast activity. A comprehensive assessment involving in vitro, and in vivo experiments showed that condensation caused very high interfacial strains, marginal bone resorption, and no improvement in implant stability. In another study, by Marin et al,[30] a 14% undersizing of the implant osteotomy (3.0 mm vs 3.5 mm osteotomies) without condensation resulted in statistically higher insertion torque for 10 mm long implants placed in a beagle dog model. However, analysis following healing revealed that this increased insertion torque did not lead to improved bone-to-implant contact or bone area fraction occupancy.[30] Collectively, this finding provides evidence of a need to rescue bone function during modified osteotomy preparation protocols, because increases in insertion torque are not necessarily correlated with high implant stability. Whilst insertion torque is measured in a single instance, implant stability is dynamic and only affected by insertion torque during the early phases of mechanical interlocking.

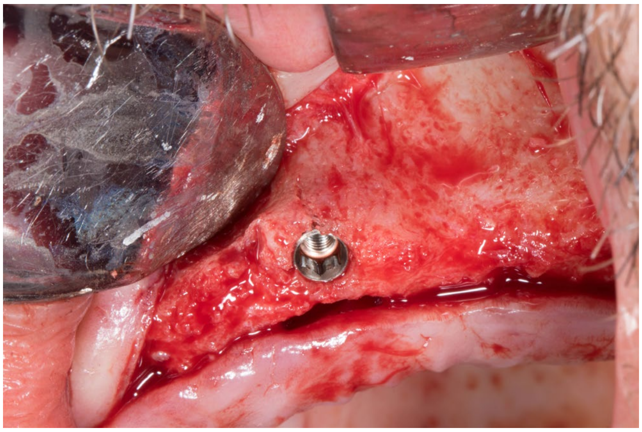


FIGURE 3 Microfracture of the bone due to bone compression during implant insertion without tapping

The favorable association between maximum insertion torque and primary implant stability is well established for maximum insertion torque values up to 70 N cm. In fact, the maximum insertion torque index has been established to reflect the relationship among maximum insertion torque, early stability, and loading protocols.[31] A large body of information suggests that such torque values are tolerated well, both in terms of implant osseointegration and biomechanical responses to insertion strains. For instance, Bidgoli et al[32] assessed 136 implants placed with either high or low insertion torques (45-70 N cm vs 20-30 N cm) and reported that bone levels around loaded implants were nearly identical for both groups. In another study, Duyck et al[33] compared high (greater than 50 N cm) with very low (less than 10 N cm) insertion torques in implants placed in rabbit tibiae and noted that, although after 2 weeks of healing the high torque group demonstrated increased bone-to-implant contact due to direct contact with existing bone, both groups had similar bone-to-implant contact after 4 weeks because of de novo bone formation in the low-torque group.

The placement of implants with very high insertion torques (ie, exceeding 70 N cm) remains a matter of scientific debate. There are studies that have shown that implants may cause pressure necrosis when being inserted with excessive insertion torques in sites of cortical bone, with the possibility of compromised osseointegration or bone and mucosal resorption.[34,35] Conversely, Khayat et al[36] reported on 42 tapered implants that were placed with insertion torques ranging from 70 to 176 N cm, left to heal submerged, and followed up clinically. The authors did not record any implant failures, and radiographic bone levels were deemed comparable to those of implants placed with maximum insertion torque of 50 N cm. The challenge lies in the substantial differences in macrogeometry among the available implant types that perform distinctly when inserted in dense cortical bone. Further research is warranted with stratification of implant macrogeometry to determine which implant designs are likely to cause pressure necrosis.

Lastly, a novel implant osteotomy preparation design has been introduced that is founded upon osseodensification of the osteotomy wall. This is possible with a specialized drill design that was used in a reverse drilling direction. This protocol generates residual bone chips during osteotomy drilling that established immediate contact between the implant system and bone structure. It was suggested that osseodensification leads to stability of the implant via physical interlocking between the implant surface and the residual bone chips and enhances the osteogenesis potential of the peri-implant region thanks to the retained osteoblasts within the chips, thereby accelerating bone healing in the proximity of the implant.[37-39] The osseodensification protocol is supported by a number of investigations documenting the mode of action of the drilling protocol and suggesting a potential to increase primary implant stability in low-density bone without any biomechanical complications.[40] Specifically, in low-density bone, endosteal implants inserted via osseodensification drilling presented higher stability and no osseointegration impairments when compared with the subtractive regular drilling technique, regardless of evaluation time or implant surface.

3 | IMPLANT-DESIGN-RELATED COMPLICATIONS

3.1 | The implant macrodesign

In general, implant design may affect initial implant stability, and tapered implants seem to have a better mechanical stability than parallel-walled dental implants do.[41,42]

Tapered implants achieved greater primary stability than parallel implants ex vivo. Clinicians with various levels of surgical experience consistently achieved good primary stability; however, experienced clinicians achieved higher resonance frequency analysis values with tapered implants in poor-quality bone.[42] Also, recent studies with narrow-diameter implants showed that a lower drilling speed in dense artificial simulated bone and a higher drilling speed in soft artificial simulated bone was associated with high primary stability.[43]

Clinical competency test studies with residents in clinical educational centers evaluated the stability of implants placed under direct supervision and restored with two implant-supported mandibular overdentures and found successful results after 2 years. The implant success rate was determined by measuring bone loss, mobility, pocket probing depth, and gingival and plaque indices.[44,45]

It has been reported that that the introduction of microthreads or “retention grooves” at the neck of the implant may assist in reducing distributing stress and reducing the extent of bone loss following the implant installation.[30] In addition, the progressive thread design seems to decrease the compression of the crestal bone, preserving the crestal bone loss.[46,47]

Recent studies have reported that implant geometries and bone density are the main factors involved in primary implant stability.[41] Large-thread implant designs are highly desirable in cases of poor bone quality. Each implant geometry generates an insertion torque value that is correlated to the stability of that specific implant in a specific bone quality, but the insertion torque is not an objective value to compare primary stability between different implant types.[48]

To improve the initial stability of dental implants, self-tapping was recommended.[49] Bone drilling is not an effective technique for improving implant stability and, following this technique, the use of self-tapping implants is highly recommended. Optimizing implant stability in soft bone can be achieved by a lateral bone-condensing technique, regardless of implant macrodesign.[49]

During the implant insertion, an increased compression of the bone will occur and the primary contacts with the implant surface will be increased. Peak insertion torque levels reduce implant micromotion. In addition, micromotion in soft bone was found to be consistently high, which could lead to failure of osseointegration. Thus, immediate functional loading of implants in soft bone should be considered with caution.[50] Also, additional studies showed that high implant insertion torque in dense cortical bone in a sheep mandible does not induce bone necrosis or implant failure, but it does increase the primary stability of implants, which is extremely important in immediate loading protocols.[51] Therefore, the osseodensification method as a method of improving initial implant stability and the surrounding bone volume was recommended in sheep bone in comparison with conventional drilling techniques in order to reduce micromovements.[28]

However, recent studies with narrow-diameter implants in vitro showed that the implant placement in dense bone may affect the quality of the implant-abutment connection, and a significant deformation of the implant-abutment interface was found for implant designs of well-known manufacturers. This may create significant prosthetic complications, potentially leading to implant failures.[52] In addition, titanium particle and ion release have also been reported.[53]

3.2 | Platform matching vs switching

Similarly, previous studies from our group[54] demonstrated that the bone in the anterior mandible after periosteum removal and grinding of the ridge in order to create the required adequate bone width and a plateau for implant placement suffers from crestal bone loss around implants with platform switching. Even though platform switching is reported to prevent crestal bone loss around implants,[55] a systematic comprehensive literature review on platform switching concluded that the role of platform switching in minimizing marginal bone loss remains debatable.[56] Bone loss around implants seems to be dependent on several factors, such as the platform features of the implant design (form and implant-abutment connection), three-dimensional implant positioning, prosthetic concept, width of alveolar ridge, and prevention of micromotion at the implant-abutment interface, and not merely placing implants according to the platform-switching concept (Figure 4).

The effect of bone resorption due to trauma or a long surgical procedure in conjunction with periosteum removal has been discussed previously,[43,57] and therefore the subcrestal implant placement has been recommended for many years, especially with

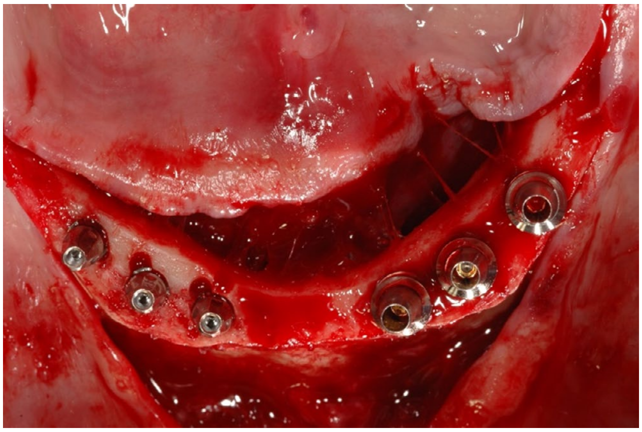


FIGURE 4 Implant diameter in relationship to the ridge width as a fundamental factor to avoid bone grafting (right-side implants with 3.5 mm diameter and left-side implants with 4.8 mm diameter; both implants with platform-switching concept)

implants with platform switching.[58] This kind of surgical protocol presents marginal bone stability within 18 months,[59] but more importantly there is clinical documentation and successful long-term clinical outcomes for over 13 years.[60]

Different studies claim that the type of implant-abutment interface (tapered vs butt joint) is associated with the presence of a microgap, and therefore of micromovements. Weng et al[61] compared in dogs the impact of the Morse-tapered connection with a classical butt-joint implant-abutment interface and demonstrated a more stable crestal bone over implants with Morse-tapered connections. However, this study[61] included implants without functional loading conditions (placement of a healing abutment) under similar submerged healing periods.[61]

In comparison with these studies, Romanos[62] compared implants with two different platform designs, similar surface features, and platform switching that were loaded in a similar concept (delayed loading) and splinted with adjacent implants in the posterior mandible of monkeys. The studies showed no histological differences between the two platforms, emphasizing the impact of the Morse-tapered connection at the implant-abutment interface and the lack of bacterial accumulation due to the absence of the microgap.[62] Initial studies performed at Gothenburg University by Ericsson et al[63] showed that microgaps in butt-joint connections are associated with bacteria, promoting inflammatory reactions around implants with the classical Brånemark system. To minimize the microgap, engineering studies confirmed the need for a relatively high torque of the abutment (35 N cm), and therefore sufficient resistance from the surrounding bone contributing to a delayed loading protocol and a good primary implant stability.

Micromovements in such implant-abutment connections have been demonstrated, compared with the Morse-tapered (conical) connections, which show high mechanical stability in vitro.[64] Bacterial penetration studies at the implant-abutment interface have examined different types of connections and concluded that leakage was significant between the groups. Despite controlled torque, the seal between the implant body and the abutment could not be maintained in all three of the systems tested.[65] Even the authors were critical in terms of the sealing capability of the different connections in vitro. The only clinical study in vivo today comparing two implant-abutment connections (conical vs butt joint) and splinted implants with platform switching, which were placed at the same time in a randomized split mouth design in the anterior mandible with a one-abutment concept, showed that periodonto-pathogenic bacteria are able to penetrate the butt-joint connection even though there was a lack of micromovement due to splinting with adjacent implants.[66] Therefore, there is strong evidence that crestal bone loss is also influenced by the implant-abutment interface design.

There is no doubt that biological consequences like the mechanical grinding of the alveolar bone to establish a flat ridge are associated with significant bone resorption for both implant-abutment connections.[54]

3.3 | Direct-abutment concept is different to the “one-abutment” concept

In an experimental study on dogs, Abrahamsson et al[67] investigated the effect of repeated healing abutment removal on the peri-implant tissues. In this study, abutments on the test side were removed and reconnected (five times) within 6 months, whereas abutments on the control side remained undisturbed. The results demonstrated that repeated abutment removal and reconnection resulted in significantly more soft tissue recession on the test side (about 1.5 mm) compared with the control side (approximately 0.7 mm). An explanation was that repeated abutment removal and reconnection induced micromotion at the implant-abutment interface, allowing microleakage.[68] These findings were corroborated by a recent systematic review that assessed seven controlled clinical trials in humans and found a significant protective effect of a single vs repeated abutment connection (95% confidence interval, 0.06-0.32 mm).[69]

To control micromotion and promote an undisturbed healing, Morse-tapered connections and the “one-abutment” concept without removal of the transmucosal component in two-piece bone-level implants were recommended.[58] In reality, this is a “direct abutment” concept, which demonstrates implant placement and connection with the final abutment (in the case of immediate provisionalization or immediate loading) or direct transmucosal abutment placement without removal. This must be differentiated from the “one-abutment” concept, when the implant may be connected with the healing abutment after implant placement and this abutment will be replaced with the final prosthetic abutment. In this latter case, the sealing between the peri-implant soft tissues and the prosthetic component will be disturbed in the case of the “one-abutment” and no “direct-abutment” concepts. This concept has been extensively promoted in various publications, with or without immediate functional loading.[62,70,71]

3.4 | Modification of the bone-implant interface

Various methods have been used in order to modify the bone-implant interface and improve the initial contacts between the implant body and the surrounding bone. In cases of narrow alveolar ridges, bone expansion techniques, such as bone splitting and bone spreading, have been recommended using special types of instruments (osteotomes) with different designs (chisel type, round). The extremely narrow ridge certainly needs to be grafted; and following bone healing, the remodeling establishes the bone quality for implant placement with good initial stability.

The so-called ridge expansion osteotomy technique demonstrated by Summers,[72] to widen the ridge in a routine office procedure, and the ridge split technique by Scipioni et al,[73] preserving the periosteum, showed long-term successful results without bone resorption. The study by Scipioni et al[73] showed implant survival rates of 97%-98.8% after 5 years.

The method of ridge splitting was introduced for the first time by Tatum in 1969.[74] Bone splitting using different devices, such as the piezo saw and osteotome, allows for implant insertion even with a ridge narrower than 3.5 mm with only a minimal risk of a bone plate fracture or perforation. Lateral crest splitting can be performed using various surgical tools (eg, chisels, rotary burs, and saws) or by using the piezosurgery unit.[75] The lateral ridge split augmentation technique, with immediate implant placement, reduces the time of the treatment and the time of the final prosthetic reconstruction. Furthermore, compression of the bone increases its density.[8]

In contrast to the splitting technique, the bone spreader technique is different from Summers' osteotome, both in clinical use and in armamentarium. The main advantage of the crest-expanding technique is that it is a less invasive procedure; the facial wall expands after the medullary bone is compressed against the cortical wall. Within the limits of this preliminary study, the cumulative survival rate for this method of implant placement is 95.58% at 3 years. This study confirmed that a bone spreader used in the maxilla shows an unusually low failure rate after 3 years.[76]

The osseodensification technique is a relatively new technique in the literature with potential benefits for many clinical situations. In general, modifications to conventional implant bed preparation use variations of the final drill diameter and drill sequencing or different drill designs applied to the surgical technique to increase implant primary stability.[77,78] Among these techniques are the osseodensification and underdrilling technique. Osseodensification is a technique that included bone preservation and condensation.[28]

In this technique, universal drills with a special tapered design operate in a clockwise or counterclockwise direction, thus allowing bone cutting or bone expansion and densification, respectively.[79] This technique is similar to the osteotome technique because it preserves and condenses the bone when the drills are used in counterclockwise rotation, but it also has the speed and tactile control of standard drills and can increase the initial implant stability.[28,79]

The undersizing osteotomy technique creates an osteotomy smaller in diameter than the size of the implant to be inserted in the preparation.[80] As a result, the contact between the walls of the osteotomy and the implant surface is increased, leading to a press-fit situation that also enhances the initial implant stability.[81,82] In very low density bone, customization of the undersized drilling protocol may be necessary.[80-82]

In vitro tests evaluating the primary stability of dental implants using bone spreaders and the osseodensification method in artificial bone (polyurethane resin blocks simulating type III and type IV bone density) showed that chisel-shaped bone spreaders and noncutting tapered drills seem to offer improved implant stability in artificial type III resin bone. However, in soft bone, no condensation method significantly improved implant stability for implants with a progressive thread design.[83] However, in vitro tests compared the effect of the osseodensification technique using natural bone specimens and artificial bone simulants. Specifically, porcine tibia head specimens and a new artificial bone simulant were used. The results showed that osseodensification is a reliable technique for improving bone density at the bone-implant interface. Owing to the elasticity and plasticity of the bone, the osseodensification method significantly increased implant stability. Newly tested artificial bone models presented similarities to the natural bone.[84]

The peri-implant bone density is changing over period considering the original bone density at the stage of the osteotomy, using different instrumentation techniques to condense the bone and continues to improve bone density stimulating the surrounding bone using functional loads. This stimulation of the bone (bone training) establishes a dynamic equilibrium and final homeostasis under loading conditions, as has been proven histologically in animals and humans.[60,85-87]

4 | RESTORATION-RELATED COMPLICATIONS: DENTAL CEMENT, CROWN CONTOURS

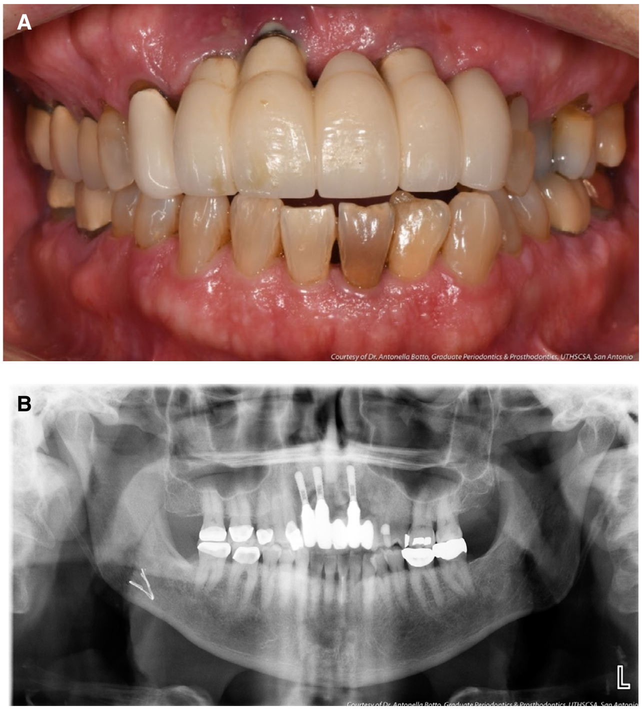
Edentulous patients do not seek implants; rather, they seek tooth replacements. Therefore, the time of implant loading is a critical aspect of implant rehabilitation. Nevertheless, implant restorations are not merely esthetic substitutes for teeth but are important determinants of peri-implant health. The two major complications that arise from restoration are (a) the presence of excess cement and (b) inappropriate contours.

Though these risk factors for complications are discussed in separate chapters in more detail, it is critical that they are mentioned in relation to implant site preparation complications. This is because the presence of excess cement is directly linked to the depth and apicocoronal position of the implant osteotomy, whereas the crown contours are affected by the three-dimensional position of the implant osteotomy. For instance, if an immediate implant is placed 5 or 6 mm below the gingival margin in an effort to overcome challenges with obtaining initial stability in a case when buccal bone dehiscence is present, then the placement of the implant-abutment interface at such a deep apical position would hinder any access for appropriate cement detection and removal. Frequently, even with careful treatment planning of the implant position ahead of time, lack of experience, aggressive implant self-threading designs, and/or deformed osteotomy preparation drills can lead to osteotomy drifting and associated positional complications.

A multitude of large-scale epidemiologic investigations have shown that selection of cement-retained vs screw-retained implant-supported prostheses does not have any major effect in future risk for peri-implantitis or implant failure, with one exception. The use of resin-based or methacrylate cements can have detrimental biologic effects if not carefully removed. Resin-type cements are generally hydrophobic and viscous, resulting in thin films of material that can slide in the peri-implant sulcus and persist, relatively immune to hydrolysis or degradation.[88] Further, in vitro evidence suggests that resin-based cements are conducive to the proliferation of potential peri-implant pathogens and support their rapid growth compared with zinc-based cements.[89] In corroboration with these preclinical findings, Korsch et al[90] found that the presence of a resin cement was associated with peri-implant bleeding on probing in 100% of cases and suppuration in 86% of cases in a sample of over 30 implant subjects. Interestingly, the peri-implant inflammation was reversed by the simple action of recementing the restorations with a zinc-based cement.

Based on the large body of preclinical and clinical data suggesting that resin-based cements are challenging to remove, may leave excess cement, and that this cement attracts bacteria and causes biologic complications, their use should be avoided. In comparison, zinc-based cements seem to have favorable properties for cementation of implant-supported restorations, perform well clinically,[91] and are radiopaque, which facilitates the early identification of excess. Their use should be coupled with specific techniques that aim to avoid residual excess cement, and the removal of excess cement should always be confirmed radiographically and clinically. A technique utilized by Wilson[92] based on the use of an endoscope for detection of excess cement and the technical report published by Romanos[93] are examples of clinical approaches to eliminate subgingival cement remnants in implant-supported restorations that may be of additional help to practitioners.

The second complication related to implant restorations may be caused by inappropriate contours. The contours of natural teeth are dictated by genetics and function, but the restorative contours of implant-supported restorations are determined by surgical placement and restoration design (Figure 5). Katafuchi et al[94] recently assessed the effect that restoration emergence angles have on risk for developing peri-implantitis in a sample of nearly 100 implant subjects. Their results found that, when bone level implants were used, the presence of an emergence angle greater than 30° significantly correlated to increased peri-implantitis prevalence compared with an emergence angle of up to 30°. Notably, convex restoration profiles conferred augmented risk for peri-implantitis.[94] These results are very important for preventing biological complications during implant placement. With digital treatment planning, the appropriate implant placement and restoration design can be visualized during the treatment planning stage, and any necessary pre-restorative surgical procedures should be planned accordingly to reduce risk for complications.



Courtesy of Dr. Antonella Botto, Graduate Periodontics & Prosthodontics, UTHSCSA, San Antonio

Courtesy of Dr. Antonella Botto, Graduate Periodontics & Prosthodontics, UTHSCSA, San Antonio

FIGURE 5 Clinical image showing suppuration of implant #8 associated with 5-8 mm probing depths. A, The excessive apical positioning of these tissue-level implants can be appreciated by the distance between the restorative margin and the desired cemento–enamel junction location as designed on the prosthesis; B, the panoramic radiograph depicts a large apicocoronal discrepancy between the cemento–enamel junction of adjacent teeth and the implant platforms that contributes to this complication

5 | POSTINTEGRATION COMPLICATIONS

5.1 | Titanium particles and tissue homeostasis

The success of implant biomaterials lies in the ability of titanium to form a robust oxide layer upon contact with oxygen in aqueous solutions that prevents further rapid oxidation of the titanium surface. This oxide layer is primarily composed of titanium dioxide (greater than 95% for titanium grades IV and V) and is commonly referred to as the titanium "passivation layer." Contrary to common belief, this layer is not as resilient prior to function, and when first placed it has a thickness of approximately 100 Å,[95] which increases over time with functional loading. This passivation layer confers the ability to resist corrosion. In fact, the dissolution rate of titanium from dental implants is considered to be in the region of 20 µm per year.[96] Nonetheless, the friction between the implant surface passivation layer and dense bone has recently arisen as a potential mechanism related to titanium release during implant insertion.[53] Delgado-Ruiz and Romanos[53] comprehensively assessed the literature related to titanium release in the oral tissues during implantation and identified two main sources of metal release: from osteotomy instrumentation and during implant insertion.

While we comprehend our world on a macrolevel and, for instance, do not observe any changes to osteotomy drills after 100 implant placement procedures, science examines events at a much higher magnification. Apparently, implant osteotomy drills release vast amounts of metal, including titanium, as the number of uses and number of sterilization cycles increase.[53,97] Because these metals are traceable in the irrigation fluid, it is highly advised to conduct ample irrigation and flushing of the osteotomy to maximize titanium debris removal. To put the rate of wear into perspective, a titanium drill used 10 times exhibits 18% deformation, whereas the deformation exceeds 30% after 50 uses.[98]

New clinical data from human peri-implantitis implicate titanium particles in peri-implant inflammatory disease.[99] Safioti et al[99] found that the presence of titanium particles was nearly nonexistent in peri-implant plaque in health but rose to substantial concentrations of over 100 ppm during peri-implant disease. While these findings of titanium implication in peri-implant inflammation are gaining attention, it is of interest to identify the causes of titanium release in the peri-implant environment. Titanium particle release during implant insertion is linked to wear, stimulating further immunological response and osteolysis. This seems to be associated with the frictional forces originating during implant insertion in dense bone.[53] It is long known that the placement of implants in the mandible, in which region the cortical bone is denser than the maxilla, leads to traceable titanium particles in the tissue.[100] This is further corroborated by findings that the particles released during implant insertion are concentrated at the cortical layer.[53] Thus, the release of titanium particles may become a consideration when implants are placed in cortical bone with very high insertion torques (Figure 6). In fact, Salerno et al[101] found that the tips of the threads on the coronal and mid portions of the implants are more affected by wear and particle loosening during insertion than the apices are, which is consistent with a higher placement torque for the coronal implant surface during final placement.

During insertion, the titanium passivation layer is removed, and it is thought that the implant will repassivate during healing, which, if successful, will lead to osseointegration. However, repassivation is not always feasible, because it is contingent upon oxygen availability and favorable environmental conditions. If large capillary distances or a local inflammatory hostile environment reduces oxygen availability then the implant passivation layer will fail to reform, leading to titanium corrosion.[95,102] Berbel et al[103] recently specifically assessed the effect of reduced oxygen availability for titanium repassivation in an electrochemical model of peri-implantitis and determined that reduced oxygen availability and inflammatory oxidizing conditions (eg, oxygen radicals) diminished titanium corrosion resistance. The hypothesis that titanium dissolution particles as products of corrosion, and not titanium wear particles due to implant insertion, are implicated in peri-implantitis is further supported by data from the orthopedic literature. A recent synchrotron X-ray micro-focus spectroscopy analysis of failed orthopedic implants revealed that titanium particles in the tissues were invariably found in both metallic and oxide forms, which indicates the presence of corrosion processes.[104]

6 | CONCLUSIONS

In summary, optimal bed preparation is required to improve anchorage of the implant macrodesign within the surrounding bone, and various bone condensation techniques can be used with caution in conjunction with implant insertion following manufacturer guidelines. Implant macrodesign and positioning, as well as prosthetic concept, have a fundamental impact on the crestal bone stability, but basic biologic principles of wound healing should also be followed.

In addition, instrumentation may be associated with material wear, and this phenomenon should be taken into consideration to control peri-implant inflammatory reactions that may lead to implant failures.

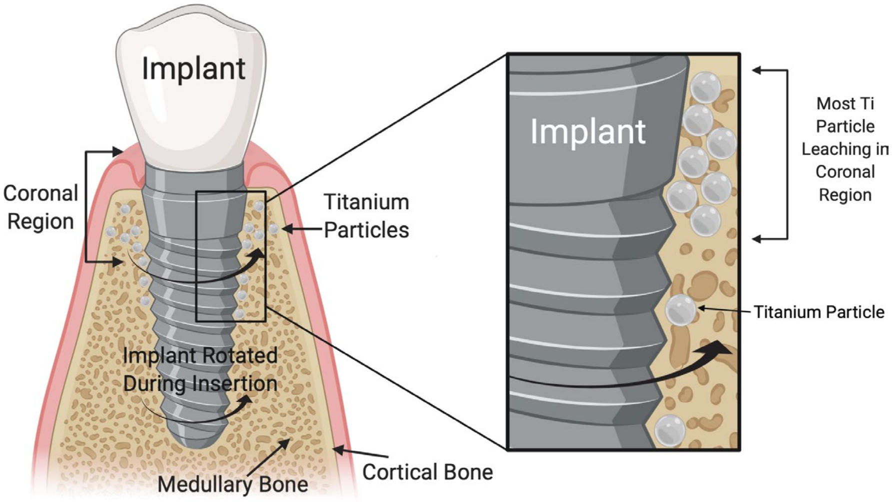


FIGURE 6 Illustration depicting the aggregation of presence of titanium particles on the coronal aspect of the osteotomy consistent with the cortical bone fraction. This finding, along with other corroborating findings, supports that frictional wear during the preparation and insertion causes particle wear and aggregation in the bone. Whether these lead to osseointegration failure is still a matter of investigation

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