

Dental Implant Design and Biological Effects on Bone-Implant Interface

Linish Vidyasagar, Peteris Apse

SUMMARY

The traditional protocol of dental implants has been based on a two-stage submerged surgical protocol, allowing a 3-6 months bone healing period. Thus within a treatment time-frame, implant-supported prostheses may take up to 7-8 months to complete, which from the patient's perspective may be unsatisfactory. In an attempt to shorten treatment periods, there is a trend towards using a one-stage non-submerged surgical procedure along with an early/ immediate loading protocol. Consequently, primary implant stability becomes a prerequisite for successful bone integration of dental implants. Primary implant stability has been reported to be influenced by the bone quality and quantity, the implant geometry, and the site preparation technique. This review identifies the role of surface roughness and aspects of implant design on the initial implant stability and bone responses to these factors. Although clinical evidence is unclear on the effects of implant thread shape on initial implant stability, it may be deduced that thread design may be influential in poor quality bone, and not be as significant in good quality bone. It is concluded that to make early/ immediate loading a predictable treatment modality in a low-density bone, technical modifications should be made to adapt to different clinical situations in the establishment of biologic width and optimize initial stability and maximize the crestal cortical bone preservation by translating shear strains at the interface to a more compressive component.

Key words: dental, implant design, bone, interface

INTRODUCTION

Although dental implants have become a predictable aspect of tooth replacement in prosthodontic treatment [1, 2, 3, 4, 5, 6], failures of up to 10% are still encountered. Furthermore these failures have been more associated with "soft" bone quality [7], 1985) such as encountered in the maxillary posterior area [8, 9, 10, 11, 12]. In a review article by Esposito et al [13], bone quality and volume were cited as major determinants for both early and late implant failures.

Primary implant stability is considered to play a fundamental role in obtaining successful osseointegration [14, 15]. Friberg et al [15] reported an implant failure rate of 32% for those implants which showed inadequate initial stability. Major contributors to initial implant stability have been suggested to be implant length, diameter, surface texture, and thread configuration.

Primary implant stability in dense mandibular bone, measured with resonance frequency analysis, was similar to the implant stability measured after 3-4 months [16, 17]. However, initial stability can be significantly less in bones of low density increasing the risk of failure [18]. Although bone density and quantity are local factors and cannot be controlled, the implant design and surgical technique may be adapted to the specific bone situation to improve the initial implant stability [19]. While different implant designs have shown similar initial stabilities in dense bone [20], implant stability in soft low density bone may be influenced by the implant design [21, 22]. It has been suggested that a combination of microscopic surface topography and macroscopic levels of implant design (e.g., screw thread profiles) may be

essential to create a stable bone-implant interface in a low density bone [23].

This article reviews the literature on aspects of implant design on the initial implant stability and bone responses to these factors. PubMed search was conducted using various keywords and the 'related article' feature. All articles up to June 2003 were reviewed; and weighted according to their scientific basis.

Role of implant surface roughness in low-density bone

Enhancing bone growth towards the implant surface has been regarded essential in cases with poor bone quality [15, 24]. Cooper [25] suggested that surface topography may affect the amount of bone formed at the interface.

A number of in vivo studies have demonstrated that increased surface topography results in increased bone-to-implant contact early after implant placement [26, 27, 28, 29, 30, 31]. However, increased bone-to-implant contact, gained by increasing surface roughness, may not always increase biomechanical interaction with bone [25, 32]. The character of surrounding bone and/ or the nature of the formed interface may be more of a factor to develop a positive biomechanical interaction [33].

It is important to differentiate the initial implant stability gained from surface topographical features from that gained by intimate implant-bone contact gained from dense bone. Higher failure rates after loading have been reported for implants with relatively smooth surfaces [10, 34, 35, 36, 37, 38], in comparison with rough-surfaced implants [24, 39, 40, 41]. However, in a meta-analysis by Cochran [42], the maxillary arch success rates for rough-surface implants were observed to be significantly greater than the success rate in mandible for these implants, which may suggest that difference in success rates due to implant surface characteristics are more likely to be found in lower bone densities.

In biomechanically challenging situations like early/ immediate loading of dental implants, achieving good primary stability is critical. Even so, it appears that post-operative complications associated with early loading dental implants occur in the early stages. Thus an essential factor

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may also be to maintain/increase the obtained initial stability over time (secondary implant stability). Secondary implant stability is determined by the bone tissue response to surgery and the implant surface [43]. Glauser et al [41] in a clinical study compared the implant stabilities of machined and oxidized implants subjected to immediate loading in the posterior maxilla during 6 months by means of Resonance Frequency Analysis (RFA). The results found surface-modified implants to maintain implant stability during the first 3 months of healing in contrast to the machined surface implants. In a clinical prospective study on immediate loading of machined implants placed in all jaw regions, Glauser et al [44] reported a failure rate of 17.3 % after 1 year and analysis of the losses showed that most failures occurred in the posterior maxilla. In a recent study [45] used oxidized implants (increased surface roughness) with a similar protocol and experienced only 3 % failures attributing the improved success to the surface textural changes. Rocci et al [46] also reported more failures with machined implants than with oxidized implants when subjected to immediate loading in the posterior mandible (14.4 % versus 4.7 % failures). Losses of machined implants occurred predominantly in quality 4 bone and in smokers, a pattern that was not observed for the oxidized implants. In contrast, some studies with immediately/ early loaded machined implants also report high survival rates when placed in challenging situations, such as in the maxilla [47, 48, 49]. However the good results may be partly explained due to stricter inclusion criteria, surgical adaptation, and using reduced or no occlusion.

It may be that although surface texturing of implants do not directly contribute to initial implant stability, it may reduce the risk of stability loss and consequently facilitating wound healing (secondary osseointegration).

Role of implant design in initial implant stability

A common factor between early loading and delayed loading of dental implants is the initial stability of the implant, implying that close apposition of bone at the time of implant placement from factors such as bone quality and surgical technique, may be the fundamental criterion in obtaining osseointegration [21, 50]. Such "anchorage" of an implant in bone may also be influenced by the implant design with such factors as overall surface area, length and thread configuration. This may be significant when anticipating immediate or early loading in order to reduce micromotion of greater than 150µm.

The following would be the design principles, one would want to achieve through an implant design:

a) Gain initial stability that would reduce the threshold for the 'tolerated micromotion' and minimize the waiting-period required for loading the implant.

b) Incorporate design factors, that would diminish the effect of shear forces on the interface (such as surface roughness related and thread features) so that marginal bone is preserved).

c) Design features that may stimulate bone formation, and/ or facilitate bone healing (secondary osseointegration).

Implant thread

Duyck et al [51] demonstrated that the application of excessive dynamic loads might cause crater-like bone defects around the marginal part of the implant. However, despite the crater shaped defects, the amount of

bone in contact with the implant did not significantly change, thus suggesting a role of implant design in protecting the bone from excessive stresses and strains [52, 53].

Threads have been incorporated into implants to improve initial stability [54, 55], enlarge implant surface area, and distribute stress favorably [56, 57] (Figure 1). Kohn et al [52] demonstrated the presence of a bone-bridge from the depth of one thread to another, when the implants were laterally loaded. They concluded that the strain is more concentrated in the area where bone contacts the crest of the thread and the strain decreased from the crest to the root of the thread. It has been proposed that threads, due to their uneven contour will generate a heterogeneous stress field, which will match the 'physiologic overload zone', thus prompting new bone formation [58](Figure 2) which may support the 'cuplike bone formation' at the crest of the implant thread [59](Figure 3).

The shape of the thread profile may affect the magnitude of stresses in the bone. The original Brånemark screw (introduced in 1965) had a V-shaped threaded pattern [1, 60]. While some manufacturers modified the basic V thread, others used a reverse buttress with a different thread pitch for better load distribution [61, 62]. Knefel [63] investigated 5 different thread profiles, and found the most favorable stress distribution to be demonstrated by an 'asymmetric thread', the profile of which varied along the length of an implant.

Recently it has been proposed that a square crest of the thread with a flank angle of 3 degrees decreases the shear force and increases the compressive load (BioHorizons Maestro Implant Systems Inc., Birmingham, Alabama)[64]. Furthermore, the thread pitch and depth of the square thread was varied in each of the four known bone densities, in

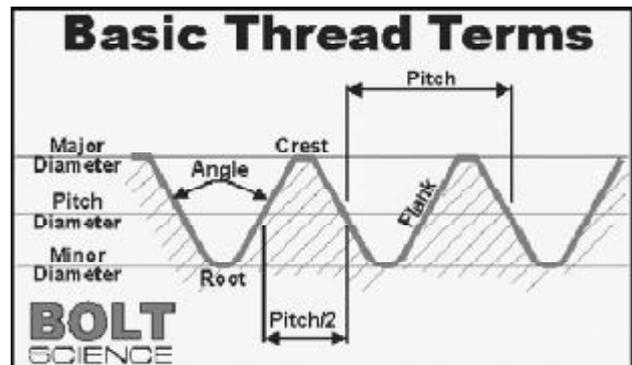


Figure 1. Basic thread terminology.

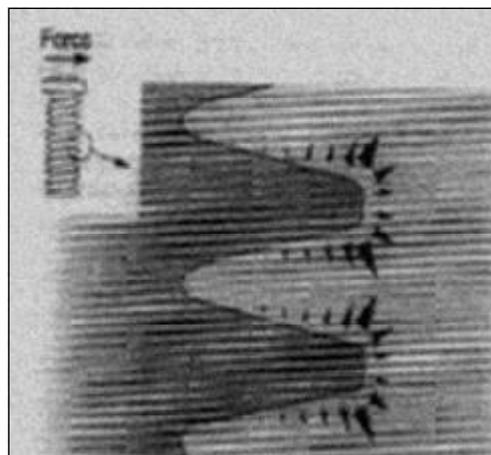


Figure 2. The discrete levels of stresses created may match the 'physiologic overload zone', thus prompting new bone formation (reprinted with permission from Wiskott and Belser; 1999).

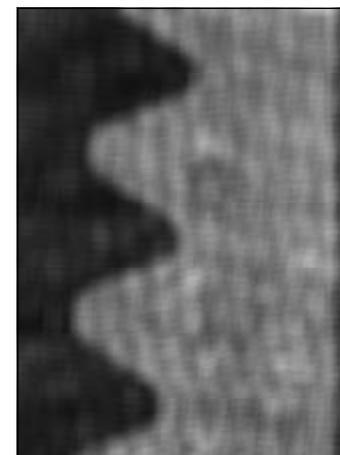


Figure 3. Cuplike bone formation on crest of implant threads (reprinted with permission from Wehrbien and Diedrich; 1993)

order to obtain a similar microstrain in all bone densities [65]. Although theoretical mathematical models and short-term clinical reports [66, 67, 68, 69] demonstrate a more functional load distribution, more prospective clinical trials are needed to support these observations.

Thread patterns in dental implants currently range from microthreads near the neck of the implant (Astra Tech, Lexington, MA) to broad macrothreads on the mid-body (Biohorizons, Birmingham, AL; Steri-Oss, Nobel Biocare) and a variety of altered pitch threads to induce self-tapping and bone compression (Implant Innovations, Palm Beach Gardens, FL; Nobel Biocare)[70]. Thus a plethora of modifications have been employed by implant companies to accentuate the effect of threads. However, very few have been scientifically documented. More than one implant design might work equally well in treating a patient, and the determination of which design is "best" may depend on how one prioritizes different objectives of treating the patient [71].

Although clinical evidence is unclear on the effects of implant thread shape on initial implant stability, it may be deduced that thread design may be influential in poor quality bone, and not be as significant in good quality bone.

Implant neck (crest module)

The highest bone stresses have been reported to be concentrated in the cortical bone in the region of the implant neck as demonstrated in Finite Element Analysis (FEA) of loaded implants with or without superstructure [72, 73, 74, 75, 76, 77, 78]. This is consistent with findings from experiments and clinical studies that demonstrated that bone loss begins around the implant neck [1, 74, 79, 80, 81, 82].

It has been suggested that the implant neck should be smooth/ polished, supporting the belief that the crest module should not be designed for load bearing [83].

However, significant loss of crestal bone has been reported for implants with 3 mm long smooth polished necks [84]. Following the placement of an endosseous implant, there is an initial bone modeling/ remodeling during healing and the establishment of a biological seal around the neck of the implant. This bone modeling for biologic seal is a combination of a 1.0-1.5 mm junctional epithelium and a 1.5-2.0 mm connective tissue region that is established superior to the alveolar crest [85]. Evidence from in vivo studies supports the observation of establishment of a biologic seal. Hammerle et al [86] did not observe crestal bone to be maintained above the junction of the Titanium Plasma-sprayed Surface (TPS) and machined neck with ITI implant system, and they concluded that polished implant collars do not integrate, as Buser et al [26] demonstrated in his mini-pig model. Similarly, bone modeling occurs to the level where the porous surface begins, with the Endopore implants [87, 88]. Disuse atrophy, due to sub-normal mechanical stimulation, has been speculated to be an etiologic factor for this marginal bone resorption [89].

It appears that when the implant heads have been placed at the crest of the alveolar bone cortical bone will change in the process of establishing a biologic width, and that this modeling/ remodeling behavior typically occurs to the level where the screw threads start and/ or the roughened surface topography begins [26, 90]. Implant design should therefore take into consideration the bone remodeling in establishing the biological width. The use of a roughened crest module that is level with the crest of the bone may provide a positive stress stimulus to the bone and decrease bone loss in this area, while the smooth part of the crestal module,

above the level of crestal bone, should provide an area for connective and epithelial tissue contact [23].

Mihalko et al [91] using FEA, demonstrated that the mechanical conditions for maintaining bone in the crestal region may be improved if the implant is provided with circumferential grooves. Al-Sayyed et al [92] in an animal study with loaded porous-coated dental implants had smooth machined necks of two different heights, demonstrated significantly more bone loss adjacent to implants with long machined necks than to implants with a short necks. The advantage of rough surfaces in the reduction of crestal bone loss has also been demonstrated by Hermann et al [93]. In their study two different one-part implant bodies were compared; the first group of implant had the rough/ smooth junction placed at the bone crest at surgery, while the second group had the rough/ smooth junction placed 1.5 mm below the bone. After 6 months, the bone level remained at the original height of the first implant group, while bone loss of 1.5 mm occurred on the second group, with a reduction of bone levels to the region of transition between the rough and smooth surface.

The results of the study by Hansson [94] also supported the concept that an improved mechanical stimulation of the marginal bone can be brought about by providing the neck of the implant with rough elements. Norton [95] evaluated radiographically 33 single tooth implants for up to 4 years and reported significantly lower amounts of bone loss, 0.32 mm mesially and 0.34 mm distally with an implant system that incorporates microthread retention elements at the implant neck (Astra Tech Dental Implant). A 5-year prospective study of the same implant system on single tooth implants also revealed minimal marginal bone loss and bone maintenance in the transcortical region [96].

Evidence seems to suggest that functionally loading the bone at the crest with a rough implant neck induces a favorable stress on the bone and effectively reduces disuse atrophy [88, 92].

It would appear that, for a low density bone, implants should be selected on a

bioengineering principle that the implant body has a thread profile which maintains strain levels at the 'steady state zone' and an implant neck (the part in contact with the cortical bone) with a thread profile that stimulates bone preservation. As cortical bone is quite minimal in areas of low-density bone, the crest module thread or roughness configuration should be such that it reduces the shear component of forces on the bone crest.

CONCLUSION

Currently, there is a trend towards using a one-stage non-submerged surgical procedure along with an early/ immediate loading protocol. A close contact between bone and implant may be the essential feature that permits the transfer of stress from the implant to the bone without any appreciable relative motion and thus providing a physiological stress to induce bone remodeling/ modeling.

However, to make it a predictable treatment modality in a low-density bone, considerations should be made to accommodate changes occurring in the establishment of a biologic width and incorporate design features that optimize initial stability and maximize the crestal cortical bone preservation by translating shear strains at the interface to a more compressive component.

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