Biomechanics and Peri-implantitis: The Effect of a Subcrestal Wing-Thread to Decrease Alveolar Crestal Bone Strain. Theory, Finite Element Analysis, and Clinical Application

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Purpose: This study used finite element analysis and a clinical case example to test the hypothesis that a wing-thread placed 4 mm below the top of an implant would decrease crestal bone loss in function. Materials and Methods: Finite element analysis was used to compare standard and wing-thread implants subjected to axial and off-axis forces based on the hypothesis that decreasing bone strain at the alveolar crestal margin improves peri-implant bone stability. A clinical case example of the wing-thread implant was followed for 30 months. Results: Stress concentration was diminished at the crest when a wing-thread was used compared to a standard implant body. Ninety-degree lateral forces were diminished by a factor of 10 in the wing-thread implant. A patient followed for 30 months showed stable bone levels around the wing-thread implants. Conclusion: The wing-thread hypothesis appears to have some support for increasing bone stability based on finite element analysis and early clinical results. ORAL CRANIOFAC TISSUE ENG 2012;2:327–333. doi: 10.11607/octe.0015

Key words: biomechanics, bone loss, bone strain, mechanostat, peri-implantitis, wing-thread

The etiology of peri-implantitis is multifactorial, leading to end-stage peri-implant lesions similar to those found in periodontitis with attendant crestal bone loss and loss of osseointegration.¹⁻⁸ The absolute cause of peri-implantitis is unknown, but biomechanical factors, especially those affecting the alveolar crest at the neck of the implant, cannot be eliminated. Despite the fact that the vast majority of implants maintain crestal bone levels, there are still an unexplained number of implants that fail to osseointegrate or lose crestal bone early or late in the restorative period.⁹ The etiology of these events remains unclear but may, in part, have a biomechanical basis.

Figure 1 shows a radiograph 2 years after an implant was restored. The implant crown had become loose and was tightened back into place after some weeks of malfunction. However, the toggling of the crown while it was loose appeared to have led to fracture of the implant collar and subsequent peri-implant bone loss. An adjacent implant placed at the same time had maintained its bone and showed no evidence of peri-implantitis. The question therefore arises: Did mechanical failure of the bone contribute to the peri-implantitis?

Oh et al suggested six plausible causes for peri-implant bone loss, which included primary surgical trauma and occlusal overload.¹⁰ A biomechanical causation remains a common theory for peri-implantitis.

The purpose of this paper is to suggest a biomechanical cofactor hypothesis for peri-implant bone loss leading to peri-implantitis. A finite element analysis (FEA) coupled with early clinical findings for the use of a relatively new dental implant design with a wing-thread placed 4 mm below the alveolar crest to decrease crestal bone stress will be presented. The working hypothesis was that, since biomechanical stress concentrations in bone are most pronounced at

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the neck of an osseointegrated implant, the addition of an expanded wing-thread 4 mm apical to the platform of a dental implant would move stress concentration away from the neck, potentially reducing microdamage to the alveolar crest and decreasing the risk of peri-implantitis.

MATERIALS AND METHODS

FEA was used to compare standard and wing-thread implants in an empty socket model to differentiate stress distributions and elucidate the bone strain patterns around the implant neck. The analysis studied the possible strain-reducing effect of adding an expanded wing-thread placed 4 mm below the top of the implant.

A three-dimensional model of an implant placed in a standard cross section of jawbone was developed using the finite element method. This model was used to investigate the stress distribution induced in the contact area between the implant and the bone, as well as implant displacement caused by application of vertical and oblique loads to the implant platform. The model consisted of a mandibular segment (cortical and cancellous bone) containing one implant unit. The bone was modeled as a cancellous core surrounded by a 2-mm-thick cortical layer. A blood clot was also modeled in the coronal portion of the bone to compare the effect of the expanded wing-thread geometry with that of a regular cylindrical implant. The implant was modeled as a cylinder with a diameter of 3.75 mm and length of 10 mm. The virtual dental implant was made of titanium with a Young’s modulus of 110 GPa. All bone was assumed to be isotropic and linearly elastic. Young's moduli employed in the model were 14 GPa for cortical bone, 1.4 GPa for cancellous bone, and 0.14 GPa for the blood clot. Bone densities were 1,800 kg/m³ for cortical bone and 1,200 kg/m³ for cancellous bone.

The three-dimensional models were built with MSC Nastran software and consisted of 10,000 solid hexagonal elements. Figure 2 shows a cross section of one model. Boundary conditions were applied to the sides of the models such that all forms of translational movements were constrained. An occlusal load of 200 N was applied to the top of the implant. Three types of implants were modeled: a classical cylinder (the reference model), a cylinder with three wings, and a cylinder with a wing around its entire circumference (Fig 3). Implant stability was also calculated under 20 kg of lateral loading at an angle of 20 degrees.

RESULTS

FEA Findings
The von Mises stress distribution within the cortical bone/implant interface under 200 N of axial compression loading of the implant is shown in Fig 4 for the three types of implants analyzed. The stress magnitude was relatively low for all implant types in the blood clot area. However, in the cortical bone, the stress magnitude around the “winged implants” was lower than around the classical cylindrical implant. The implant with a full circumferential wing showed the most balanced stress distribution at the cortical bone/implant interface. At the junction point of the blood clot and the cortical bone edge, the computed pressure decreased from 2.58 kg/mm² for a regular implant to 1.54 kg/mm² for a winged implant, a difference of approximately 40%.

Figures 5 and 6 demonstrate the calculated stress distributions and displacement under lateral loading. The maximum displacement of the winged implant was 5.2 μm (Fig 6), compared to 8.5 μm for a regular implant (Fig 5), a difference of approximately 60%.

The FEA model therefore demonstrated that the added wing considerably reduced the stress distribution at the implant neck, thus reducing the potential...
for bone loss at the crest. It was also shown that the winged implant was more stable when subjected to axial and oblique loads.

Figures 7 and 8 show the results of applying a 90-degree lateral force of 80 N to an implant crown. In this setting there was a very significant difference in the amount of displacement between regular (Fig 7) and wing-thread implants (Fig 8) from the vertical cantilever of the restoration. The regular implant showed 0.214 mm of displacement at the neck area (Fig 7),
versus 0.029 mm for the winged implant (Fig 8); the amount of displacement therefore differed by a factor of about 10.

**Clinical Application**

Two wing-thread implants (Saturn Implant, Cortex Inc) were placed into previously grafted premolar sites (Figs 9a and 9b). A regular threaded implant was inserted in the first molar site. At the time of definitive restoration, the graft was still not consolidated radiographically (Fig 9c). At 2 years (30 months after graft placement), clinical and radiographic examinations showed a well-consolidated bone graft and stable bone levels around the implants (Figs 9d and 9e).
DISCUSSION

Bone strain is the governing stimulus for maintenance of mechanical strength mediated by primary cilia in bone-forming cells. Biomechanical feedback within the set points of what Frost termed the mechanostat of bone slowly increases bone stiffness around a dental implant via a modeling and remodeling response to optimize bone architecture in response to strain.  The mechanostat monitors this relationship between bone strength and the magnitude of the load to control the upper and lower limits of bone strength. Bone mineral density slowly increases around an implant in function, eventually resetting overall bone strain to a relatively narrow physiologic range. When bone strains are very high, e.g., 6,000 με, mechanostat modulation is unable to repair the area undergoing this amount of stress by forming new bone. Microdamage accumulates, followed by fatigue fracture, then fibrosis. Implants that are placed and immediately subjected to long cantilever function may exceed the reparative capacity of bone remodeling, preventing osseointegration. On the other hand, implants that are staged and then subjected to a long cantilever undergo peri-implant bone strain that is slowly reduced by the action of the mechanostat by increasing bone mineral density around the implants, so that there is little change in bone level over time. The question then arises: Could implant design features, such as the wing-thread, be beneficial in reducing bone strain in settings that might compromise osseointegration?

Most clinical situations will not feature extreme cantilevers; however, the use of angled implant strategies, such as the All-on-Four treatment with immediate function, is somewhat analogous to cantilever function with vertically placed implants. Interestingly, implants restored in axial hyperocclusion do not always show bone loss. Animal research has shown that peri-implant bone levels are usually maintained despite hyperfunction, presumably because bone stress compensation remains within the physiologic range.

In one study, dental implants placed into monkeys that were then restored into hyperocclusion with ligature-induced peri-implantitis showed no histologic evidence of peri-implant bone loss despite 16 weeks of repetitive occlusal trauma. Clinically, however, there appears to be evidence that occlusal factors are related to marginal bone loss around two-stage implants, but the reason for this remains unclear. Typically, crestral bone loss stabilizes to a minimum annual average bone loss of 0.2 mm or less per year, as reported in the literature, but in some settings of attributed occlusal overload, marginal bone loss occurs well in excess of this.

The influence of controlled occlusal loading was also studied in monkeys by Miyata et al, who placed a supraocclusal restoration in the presence of peri-implantitis for 8 weeks in Macaca fascicularis. Then, in one group, the supraocclusal prosthesis was removed and not replaced for 4 weeks and compared with a group that kept the supraocclusal restoration. Upon sacrifice, there was no difference in bone loss in the groups, and peri-implantitis did not improve upon correction of occlusal overload.

This contrasts with a study by De Smet et al, who used a guinea pig tibia model and in vivo computed tomography to evaluate implants loaded at high force but low frequency. They observed that bone mass increased significantly after 2 weeks, with a pronounced osteogenic effect observed by 4 weeks. The authors concluded that there is a strong correlation of bone response to acute conditions of loading. In this study, the mechanostat response led to bone gain from bone strains at the upper end of the physiologic limit. This correlates with a study done by Sugiyama et al that demonstrated that, despite the often-observed nonresponse to bone strain in experimental studies, in a sciatic neurectomized rat tibia model, there was a linear response to bone strain; this ranged from disuse atrophy associated with low strain (300 με) to bone gain associated with high strain (5,000 με). This conflict with the idea that there is a zone of unresponsiveness, a “lazy zone,” in which bone does not appear to respond to a broad range of bone strains. New bone formation, then, is a direct response to peak dynamic load and occurs as required to prevent fatigue failure. Thus, it appears that, at some dynamic load threshold around a dental implant, the bone mass/strength will increase, even though at some other level of bone strain, the response may appear relatively unchanged.

From a biomechanical point of view, there is some controversy concerning how bone reacts to bone strain. One study used human cortical bone to study strain in the development of microcracks leading to fatigue fracture. The study found that microdamage was inversely related to bone strain. That is to say, low bone strain rates showed more microcracking than high strain rates. After the yield point, there was much greater post-yield strain, which was thought to be caused by microcracking, not by a direct increase in strain rate. The authors conclude that low strain rates allow time for microcracking to develop, which increases bone “compliance.” This suggests a transition-phase response to biomechanical function. If during early healing there is significant localized damage, this leads to low postyield strains, which progress to failure by relatively low energy strains. However, during deformation, bone compliance prevents a rapid transition toward brittleness.
Szabo et al also observed no direct relationship between an increasing strain rate and the amount of microdamage or microdamage initiation in trabecular bone based on the mechanical properties of single bovine trabeculae. That is to say, trabeculae are unaffected by changes in strain rate; therefore, according to the study, strain rate can be ignored when characterizing trabecular bone.38

The thought process in the wing-thread hypothesis is that nonaxial cyclic forces at the neck of a dental implant may accumulate hard tissue microdamage within 4 mm of the alveolar crest, which may then contribute to an inflammatory response and subsequent peri-implantitis. This process would be enhanced by cofactors such as implant-abutment interface microleakage and adjacent periodontitis.4–6 In addition, mechanical damage inflicted on bone at the time of implant insertion may exceed the microdamage threshold for replacement repair, resulting in early or late peri-implant crestal bone loss.39,40 Therefore, damage to bone adjacent to the neck of an osseointegrated implant, whether acute or chronic, termed “overload,” could contribute to peri-implant bone loss and the formation of peri-implantitis.

The hypothesis that wing-thread implants may significantly reduce the stress from occlusal deflection forces, particularly in the now-common angled implant settings with distal cantilevers where lateral forces are magnified, remains unproven.11,41 In a recent canine study, axially placed wing-thread implants used in a delayed loading protocol showed favorable resonance frequency responses, removal torque values, and bone-to-implant contact after 8 weeks.42 However, the use of this implant for immediate function in angulated configurations may likewise provide a significant advantage for primary stability, especially in settings of poor bone quality.22

The present FEA was highly suggestive of a protective effect of the wing-thread reducing stress around the neck of the implant; the wing-thread also appeared to decrease overall implant displacement to lateral forces, a desirable feature for All-on-Four immediate-function implant schemes.11,21,22 Also, early implant restorations using the expanded wing-thread implants have demonstrated stable peri-implant bone for up to 3 years.11 This suggests that if mechanical injury to the crestal bone is a cofactor for the development of bone loss, then the wing-thread could potentially reduce or delay the development of peri-implantitis over the long term.

CONCLUSION

The use of a dental implant with a wing-thread placed 4 mm apical to the implant platform showed decreased stress at the neck of the implant in finite element analysis. Early clinical findings demonstrated stable crestal bone for up to 3 years in function with the use of this modified implant. If the initiation and progression of peri-implantitis has a biomechanical etiology—at least in part—it remains unproven whether a wing-thread will be preventative or have significant clinical consequences; long-term studies are required.

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Dr Laster is patent holder of the wing-thread implant.

REFERENCES


