Influence of microthreads and platform switching on stress distribution in bone using angled abutments

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Abstract

Purpose: To evaluate the stress distribution in peri-implant bone by simulating the effect of an implant with microthreads and platform switching on angled abutments through tridimensional finite element analysis. The postulated hypothesis was that the presence of microthreads and platform switching would reduce the stress concentration in the cortical bone.

Methods: Four mathematical models of a central incisor supported by an implant (5.0 mm × 13 mm) were created in which the type of thread surface in the neck portion (microthreaded or smooth) and the diameter of the angled abutment connection (5.0 and 4.1 mm) were varied. These models included the RM (regular platform and microthreads), the RS (regular platform and smooth neck surface), the SM (platform switching and microthreads), and the SS (platform switching and smooth neck). The analysis was performed using ANSYS Workbench 10.0 (Swanson Analysis System). An oblique load (100 N) was applied to the palatine surface of the central incisor. The bone/implant interface was considered to be perfectly integrated. Values for the maximum ($\sigma_{\text{max}}$) and minimum ($\sigma_{\text{min}}$) principal stress, the equivalent von Mises stress ($\sigma_{\text{vM}}$), and the maximum principal elastic strain ($\varepsilon_{\text{max}}$) for cortical and trabecular bone were obtained.

Results: For the cortical bone, the highest $\sigma_{\text{max}}$ (MPa) were observed for the RM (55.1), the RS (51.0), the SM (49.5), and the SS (44.8) models. The highest $\sigma_{\text{vM}}$ (MPa) were found for the RM (35.4), the SM (42.1), the RS (38.7), and the SS models (37). The highest values for $\sigma_{\text{min}}$ were found for the RM, SM, RS and SS models. For the trabecular bone, the highest $\sigma_{\text{max}}$ values (MPa) were observed in the RS model (65.5), followed by the RM (63.7), SS (5.6), and SM (5.2) models.

Conclusion: The hypothesis that the presence of microthreads and a switching platform would reduce the stress concentration in the cortical bone was partially rejected, mainly because the microthreads increased the stress concentration in cortical bone. Only platform switching reduced the stress in cortical bone.

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1. Introduction

As a result of the significant technological advancement in the field of osseointegrated implants, some of the parameters, such as implant design, materials, and surgical techniques, have allowed greater predictability of success for restorations, achieving an esthetic clinical solution in situations that were considered complex in the past [1].

Preservation of the bone crest around implants and maintenance of the gingival papilla are of fundamental importance in obtaining satisfactory esthetic results. Conversely, occlusal overload, the type of implant, and the type of prosthetic platform may influence peri-implant bone stability. Bone loss is characterized as "early" or "late," depending on the time of occurrence [2–4]. Early bone loss is loss detected upon reentry surgery after the healing time or prosthetic

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appliance connection [5]. Late bone loss arises due to the implant/prosthesis wear or function [4,6–8].

The precise mechanism of marginal bone resorption is not fully understood, but it has been postulated that some factors may influence this process [9]. While late marginal bone loss has been associated with peri-implantitis and occlusal overload [4], early marginal bone loss has been associated with the implant’s design (macro and microdesign) and the process of the biologic seal establishment and stabilization. This process can be exacerbated by the microgap, the implant crest module, reformation of biologic width, and surgical trauma [4,5].

To overcome the function and esthetic problems associated with early bone loss and accommodate the new clinical applications of modern implant dentistry, manufacturers have modified both the macro and the microstructures [10] of implants, such as the shape and type of the implant–abutment connection, the presence of threads, thread design, and surface treatment [11,12].

For this reason, the concept of platform switching has been used to a large extent [13], as it allows bone remodeling around the implant, favoring the maintenance of the bone crest with a reduction in stress in the cervical region of the implant [14,15]. Also, other authors have performed several clinical [16–18] and histological [4,19,20] studies in implants with microthreads in the neck portion, with positive results with regard to the bone crest. Furthermore, finite element studies have showed great biomechanical behavior of implants with microthreads in comparison to the conventional smooth neck surface [21–23]. Although the combination of platform switching and microthreads has also been evaluated in a finite element study for implants placed in an ideal position [22], the effect of such a combination in a situation where less bone quantity requires angled abutment is not understood.

Thus, the aim of this study was to evaluate through three-dimensional (3D) finite element analysis (FEA) the effect of implants with microthreads and platform switching on stress distribution in the cortical and trabecular bone using angled abutments. The postulated hypothesis was that the presence of microthreads and platform switching would reduce the stress concentration in the cortical bone.

2. Materials and methods

The study was approved by the local Human Research Ethics Committee at the School of Dentistry of Araçatuba, São Paulo State University – UNESP (process #2008/01845). All procedures were conducted and used in accordance with and guided by the ethical statements of the Declaration of Helsinki developed by the World Medical Association.

2.1. Modeling the finite element models

A tomographic exam of the patient’s maxilla was performed to obtain tomographic images in dicom format. Four (4) mathematical models representing the anterior segment of the maxilla were elaborated using the Mimics 13.1 (Materialise, Leuven, Belgium) and Solid Works 2009 (Inovart, São Paulo, Brazil) software programs.

To model the implants and all prosthetic components (abutments, screw, crown), the dimensions and designs were obtained from each component using a digital caliper, photographs, and images obtained from a light optic microscope (Axiophot, Zeiss DSM-940 A, Oberkochen, Germany) by using AxioVision 4.6 software (ZEISS DSM-940 A, Oberkochen, Germany). In addition, X-ray images were made to verify the internal relationships among the components. Following this, each structure was modeled using a graphics software (Solid Works 2009, Inovart, São Paulo, Brazil).

All models were simulated as restored with a crown cemented on the angled abutment, varying the type of thread surface in the neck portion (microthreads and smooth surface) and the diameter of the abutment connection (5.0 mm for the regular model and 4.1 mm for the switching model), simulating 2 regular situations. These models included the RM (regular platform and microthreads), the RS (regular platform and smooth neck surface), the SM (platform switching and microthreads), and the SS (platform switching and smooth neck).

To fit and connect all prosthetic structures, a Boolean subtraction operation was performed using the graphics software (SolidWorks 2009, Inovart, São Paulo, Brazil). To simplify the mathematical calculations, immediate interfacial sliding inhibition (perfect interlocking), characterizing the implant–bone interface as completely osseointegrated (100% contact with surrounding structures) was assumed [15,22]. Similar integration of the abutment and implant was assumed, as the single unit thus formed eliminated any potential influence from friction caused by sliding movements [15,22].

2.2. Implant types and implant connection

The microthread implants (Nobel Replace™ Tapered Groovy, Nobel Biocare, Goteborg, Sweden) and the smooth neck implants (Replace™ Select Tapered, Nobel Biocare, Goteborg, Sweden) presented 5.0 mm × 13.0 mm and were restored with a feldspathic crown (Ivoclar Vivadent, Schaan, Liechtenstein). All crowns were cemented onto the angled abutment at 15° (4.1 mm and 5.0 mm in diameter) with resin cement (Panavia, Kuraray, Tokyo, Japan) in a layer 0.05 mm thick. After this, the assembly was inserted in the anterior segment of the maxilla with cortical and trabecular bone corresponding to the region of the right central incisor by a Boolean subtraction operation (SolidWorks 2010, Inovart, São Paulo, Brazil). The crown was 13.07 mm high, with a mesiodistal width of 8.8 mm and buccal-lingual width of 7.1 mm. The implant neck followed the approximate dimensions of commercial implants (Nobel Replace™ Tapered Groovy). The modeled microthread is shown in Fig. 1.

2.3. Stress measurements

After modeling elaboration, the models were exported to the finite element software (Ansys Workbench 10.0, Swanson
Analysis Inc., Houston, PA, USA) in iges files to determine the stress fields. The mechanical properties of the structures were based on the literature (Table 1) [24–26]. All materials were considered isotropic, homogeneous, and linearly elastic. A distributed load, in approximately 10 mm² [27] of 100 N, was applied to the lingual surface of the crown, near to the incisal edge, 45° to the long axes of the tooth for all models [28] (Fig. 2). The boundary conditions were constrained on the external surface of the maxilla bone segment (x = y = z = 0) (Fig. 2).

Parabolic tetrahedral elements were used for meshing. The refinement of the mesh was established through convergence analysis (6%) [27]. This technique allows for a balanced concentration of elements, avoiding the occurrence of excessive stress in small regions. The models presented a number of elements, ranging from 106,237 to 116,868, and a number of nodes, ranging from 170,880 to 189,786 (Fig. 2).

As output parameters, maximum (σmax) and minimum (σmin) principal stress, equivalent von Mises stress (σM), shear stress (σshear), and maximum principal elastic strain (εmax) were obtained for cortical and trabecular bone. Some authors [29] have suggested that the magnitudes of the concentrations should be presented in the σmax for evaluation of stress.
distribution in a non-ductile structure such as bone. Other authors have claimed that shear stress is the best parameter because it shows how the load diffuses into bone, and because the fixation strength of bone implants is commonly measured by interfacial shear strength by push-out and removal torque laboratory tests [30].

3. Results

3.1. Stress measurements of implants with microthreads

To evaluate the influence of microthreads on the stress distribution of cortical and trabecular bone, the results of the RM and RS models and of the SM and SS models were compared.

Considering the cortical bone of the regular models (RM and RS), it was observed that the RM model showed higher stress in comparison to the RS model for all parameters ($\sigma_{\text{max}}$, $\sigma_{\text{min}}$, $\sigma_{\text{M}}$, $\sigma_{\text{shear}}$, $\varepsilon_{\text{max}}$) (Table 2 and Figs. 3–6). The $\sigma_{\text{M}}$ showed an increase in 15% for the RM model in comparison to the RS model. This pattern of stress distribution was also noted for cortical bone when the models with platform switching (SM and SS) were compared, showing higher stress concentration for the SM model in comparison to the SS model (Fig. 4). The $\sigma_{\text{M}}$ showed an increase in 12.2% for the SM model compared to the SS model (Table 2).

In contrast, when the trabecular bone was evaluated, the regular models (RM and RS) showed higher stress concentration for all output parameters. For shear stresses, the peak occurs for the RS model. Also, greater $\sigma_{\text{max}}$, $\sigma_{\text{min}}$, and $\varepsilon_{\text{max}}$ were observed for the SS than for the SS model, and almost the same results for these two models were observed for $\sigma_{\text{M}}$. The SM model showed higher shear stress than did the SS model (Table 2 and Figs. 3–6).

3.2. Stress measurements of implants with platform switching

To evaluate the influence of platform switching on the stress distribution of cortical and trabecular bone, the results of the RM and SM models and of the RS and SS models were compared.

For cortical bone, comparing the results of the models with microthreads (RM and SM), higher stress concentration ($\sigma_{\text{max}}$, $\sigma_{\text{min}}$, $\sigma_{\text{M}}$, $\sigma_{\text{shear}}$) and $\varepsilon_{\text{max}}$ were found for the model with regular abutment than with platform switching (Table 2 and Figs. 2–5). The von Mises stress was about 7.3% higher for the RM model than for the SM model (Fig. 3). Also, comparing the results of the RS and SS models, $\sigma_{\text{max}}$, $\sigma_{\text{min}}$, $\sigma_{\text{M}}$, $\sigma_{\text{shear}}$, and $\varepsilon_{\text{max}}$ were found to be higher for the model with regular abutment (Table 2 and Figs. 3–6). The von Mises stress was about 4.4% higher for the RS model than for the SS model.
For trabecular bone, comparing the RM and SM models, the peak of $\sigma_{sM}$, $\sigma_{smin}$, $\sigma_{shear}$, and $e_{max}$ occurred for the SM model. Only $\sigma_{max}$ was higher for the RM model (Table 2 and Figs. 3–6). Comparing the RS and SS models, higher stress concentration and maximum strain were found for the SS model (Table 2).

4. Discussion

The clinical longevity of these implant systems relies on the mechanical integrity of the prosthesis and implant as well as the ability of peri-implant structures to withstand and positively adapt to the loading forces [31]. Excessive occlusal stress can cause bone resorption or even failure of the implant–bone interface, whereas lack of stress may lead to atrophy or even bone loss [22,32].

In the present study, it was observed that the presence of platform switching reduced the stress on the cortical bone, similar to other studies in which the authors found a decrease in the peri-implant bone loss [13,14]. In a related prospective study, platform switching was effective in bone preservation for delayed and immediate implants placed in fresh extraction sockets [33]. Another reason that might explain the efficacy of
the platform switching configuration is the distance between the bone surfaces to the stress-concentrated area on the implant surface [15,34].

Excessive loading can trigger bone resorption caused by bone microdamage, resulting in craterlike bone defects lateral to the implants. This microdamage to the bone may be initiated by stress concentrations at the implant–abutment joint [34]. With the platform switching, there is little stress concentration around the implant platform that is more closely attached to bone than with regular implant–abutment [34]. The platform switching better distributes the stress in the medial region of the implant.

Some studies have suggested that bone preservation with the platform switching may occur due to the alteration of the micro-gap location between the abutment and the implant [15].

Another theory suggested that a minimum space is required to restore the biological space of the implant–abutment, and this space is created 1 mm from the implant–abutment joint [35]. So, medializing the implant–abutment connection increases the space for the creation of long biological space, and it is supported over the external margin of the platform [35]. With this kind of implant–abutment connection, the inflammatory infiltrate stays away from the crestal bone margin, consequently decreasing the crestal bone resorption [15,21,22,33,35,36].

In current study, the models of implants with microthreads on the cervical neck have demonstrated higher stress concentration, particularly in cortical bone, where the presence of microthreads increased the values by 15% for the models of the regular platform, and 12% for the models of platform switching.

The hypothesis that the presence of microthreads and switching platform would reduce the stress concentration in the cortical bone was partially rejected, mainly because the microthreads increased the stress concentration in cortical bone.

In a two-dimensional finite element study, similar results with the addition of microthreads to the crestal module of an implant were found [22]. The authors found greater stress concentration on the bone crest for implants with microthreads and less stress when the abutment diameter was reduced, simulating a switching platform situation [22]. Although these authors had simulated straight abutments [22], the present study found similar results, simulating the angled abutments.

However, the simulated implants used in the current study and by Schrotenboer et al. [22] used different microthreads and implant designs, suggesting different results.

Using a canine model [37,38] and human retrospective analyses [39,40], other researchers have noted that the presence and location of the polished neck in relation to the bone crest influences the amount of bone loss during the early phases of the implant’s function.

The literature shows that implants with microthreads enhanced bone apposition and improved bone-to-implant contact versus implants without microthreads [19]. Higher bone-to-implant contact on the surface of a microthread implant can theoretically help the proximal bone resist resorption [19].

In the present study, higher stress/strain concentration was observed for the microthread implants, which may be explained by the horizontal profile of the microthread [30]. However, in this study the thread design of both modeled implants with or without microthreads had the upper region of the implant with a smooth surface. In fact, the peak of stress concentration occurs for both types of implants in this smooth region.

The effect of the micro-design of retention elements on the bone loss rate is not yet fully understood [9]. Hansson et al. [30] showed that retention elements in the implant neck increase an implant’s ability to resist an axial load 2.64–4.79 times higher than the load that can be resisted by an implant with a smooth neck [30].

Insufficient mechanical stimulation has been suggested by some authors as a major etiological factor behind marginal bone loss. In this study, the difference in the concentration observed between the microthread and smooth models may act as a bone stimulus [30], since the bone strength acts as a physiological limit. Local overloading in cortical bone occurs in compression when the maximum compressive principal stress exceeds 170–190 MPa in modulus, and in tension when the maximum tensile principal stress exceeds 100–130 MPa [28,32]. In the present study, these stresses were up to 54.6 MPa in compression and 55 MPa in tension.

In addition, some authors support that apposition of bone around an oral implant is the biological response to a mechanical stress below a certain threshold, so with slightly increased strain, the bone becomes mildly overloaded and compensates by forming more bone [41–43]. Loss of marginal bone may be the result of mechanical stress beyond this threshold. Consequently, bone apposition was most frequently found when the calculated strain varied between 3400 and 6600 microstrain, but when the strain exceeded 6700 microstrain, the remodeling of the bone resulted in a net loss of bone [41–43]. If the strain went beyond a threshold, which exceeds the bone’s capacity fatigue, then fracture could occur [41–43].

In the present study, for all models the strain generated occurred at levels below 3940 microstrain, suggesting bone apposition unlike bone damage or loss. However the difference between the both studies, regards the methodology, should be considered.

Currently, implant companies have great interest in developing an ideal crest module [44]. Besides the advantages of decreased bone resorption, due to the great area of bone available, it would be helpful to achieve or maintain an implant’s primary stability [44]. Implant thread design (height and width) is one of the most fundamental elements that affect an implant’s primary stability and its ability to resist static and dynamic loading [44].

However, there is a lack of sufficient information about the primary stability evaluated for implants with or without microthreads. In a study using a pig model and resonance frequency, the authors did not find statistically significant results for implant stability in implants with or without microthreads. The measurements were done immediately after the implant placement (primary stability) and repeated weekly for 70 days [45].
From the results of the current study only models with platform switching were able to reduce the stress and strain in cortical bone. The models with microthreads only reduced the stress and strain in trabecular bone. Perhaps this reduction on the stress concentration in the trabecular bone has an effect on maintaining the cortical crestal bone level.

Although additional information about bone stress behavior was obtained in this study for a maxillary central incisor influenced by one type of microthread and platform switching using an angled abutment, there are some limitations that should be noted. The bone was modeled as an isotropic and linearly elastic material, when in fact it is an anisotropic material and has viscoelastic properties [30,46]. Furthermore, after the osseointegration, the implants exhibited some micro-movements, which indicated that the interface was not fully bonded [30,46]. If a similar simulation were done for a posterior tooth, the results might change due to the load magnitude and bone characteristics. Further laboratory and clinical studies should be conducted to clarify the effect of microthreads on bone stability. The platform switching concept showed results for bone preservation similar to those of other studies. However, the same benefits should be evaluated for the prosthetic components, since reducing the size of the platform can increase the demand for these structures. The results for the microthreads are not fully understood and need more research, since different results were found in the literature.

5. Conclusion

Within the study limitations and according to the methodology used, it is possible to conclude:

1. The platform switching concept was able to reduce the stress and strain concentration for cortical bone compared with the regular platform. However, the switching platform showed higher stress for trabecular bone.
2. The implant with microthreads showed higher stress concentration for cortical bone in comparison with the smooth implant, and lower stress concentration for trabecular bone.
3. The implant with platform switching and smooth neck surface showed the lowest stress/strain concentration on the cortical bone, while the implant with a regular platform and microthreads showed the highest stress/strain concentration for cortical bone.

Conflict of interest statement

The authors do not have any conflict of interest.

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