Regular and Switching Platform: Bone Stress Analysis With Varying Implant Diameter

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The aim of this study was to evaluate stress distribution of the peri-implant bone by simulating the biomechanical influence of implants with different diameters of regular or platform switched connections by means of 3-dimensional finite element analysis. Five mathematical models of an implant-supported central incisor were created by varying the diameter (5.5 and 4.5 mm, internal hexagon) and abutment platform (regular and platform switched). For the cortical bone, the highest stress values (σ_{max} and σ_{vm}) were observed in situation R1, followed by situations S1, R2, S3, and S2. For the trabecular bone, the highest stress values (σ_{max}) were observed in situation S3, followed by situations R1, S1, R2, and S2. The influence of platform switching was more evident for cortical bone than for trabecular bone and was mainly seen in large platform diameter reduction.

Key Words: implant dentistry, finite analysis, bone, stress, loading

INTRODUCTION

Early peri-implant bone loss has been observed in many implant systems and through use of different surgical techniques, commonly in the first year of the implant in function and potentially compromising the esthetics of restorations.[1–4] A possible cause of this bone loss may be excessive occlusal force and the mechanical properties of the implant, such as its interaction with the bony structure.[3,5–8]

The implant geometry and type of implant/abutment connection are important factors for maintaining osseointegration because they influence force transmission to the bone.[9] For this reason, clinical situations that improve stress distribution in bone are increasingly sought to minimize peri-implant bone loss.

The term "platform switching" refers to the use of an abutment with a reduced diameter in relation to the diameter of the implant platform, leading to the creation of a horizontal gap at the abutment/implant junction.[10] Based on this principle, the abutment/implant junction is moved medially, so that it is further from the peri-implant bone, which may minimize the impact of the inflammatory cell infiltrate.[11,12]

Many clinical, histologic, and laboratory studies have suggested that this procedure appears to reduce crestal bone resorption.[8,13–15] However, there is still no conclusion as to which abutment and implant diameters best favor stress distribution in the bone when platform switching is used.

Therefore, the aim of this study was to evaluate the stress distribution in the peri-implant bone by simulating the influence of different implant diameters with regular and platform-switched connec-

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Table 1

Characteristics of the models used in the study

Models	Implant Diameter	Abutment Diameter	% Switching	Reduction/Diameter
Regular 1 (R1)	4.5 mm	4.5 mm	0%	0 mm
Regular 2 (R2)	5.5 mm	5.5 mm	0%	0 mm
Switching 1 (S1)	4.5 mm	3.8 mm	15.55%	0.7 mm
Switching 2 (S2)	5.5 mm	4.5 mm	18.18%	1.0 mm
Switching 3 (S3)	5.5 mm	3.8 mm	30.90%	1.7 mm

tions. A tridimensional finite element method was used to assess the influence of various abutment and implant diameters on cortical and trabecular bone stress distribution when platform switching is used.

MATERIALS AND METHODS

After getting approval by the Human Research Ethics Committee (Process # 2008/01845) and informed consent, a tomographic exam was performed in the maxilla of a patient to obtain tomographic images in dicom format. Five mathematical models were constructed, representing the anterior segment of the maxilla, using the Mimics 11,11 (Materialise, Leuven, Belgium) and Solid Works 2010 (Inovart, São Paulo, Brazil) programs. All the models were restored with a cemented crown on an intermediate abutment varying the implant diameter (4.5 and 5.5 mm) and the prosthetic platform (3.8, 4.5, and 5.5 mm), simulating 3 switching situations (S1, S2, and S3) and 2 regular situations (R1 and R2) (Table 1; Figure 1).

The SIN implants (4.5 × 11.5 mm and 5.5 × 11.5 mm; Sistema de Implante, São Paulo, Brazil) with an internal hexagon, received an IPS e-max Press crown (Ivoclar Vivadent, Schaan, Liechtenstein) cemented on the abutment with Variolink II cement (Ivoclar Vivadent) at a 0.05 mm in thickness (Figure 2a). Afterward the set was inserted into the anterior segment in the maxilla with cortical and trabecular bone corresponding to the region of element #11 (Figure 2b). The crown height was 13.0 mm, with a mesiodistal width of 8.8 mm and a buccal-lingual width of 7.1 mm.

After the models were made, they were transported to the finite element program Ansys Workbench 10.0 (Swanson Analysis Inc, Houston, Pa) to determine the regions of interest and generate the finite element mesh.

The mechanical properties of the structures were based on previously published studies and manufacturer's data (Table 2).[16,17] All materials were considered isotropic, homogeneous, and linearly elastic. The bone/implant interface was considered perfectly integrated.[18,19] One oblique load (45°) was applied to the palatine surface of the crown of element #11 (100N).[20]

Tetrahedral parabolic elements of 0.45 mm were used for the mesh (Figure 3). Mesh refinement was adapted by an analysis of convergence (6%).[16] In the models, the number of elements ranged from 275291 to 280556 and the number of nodes ranged from 420030 to 426759 (Table 3). To characterize the boundary condition, a displacement equal to zero was established on the 3 Cartesian axes ($x = y = z = 0$), and these were fixed to the sides and top region of the models.

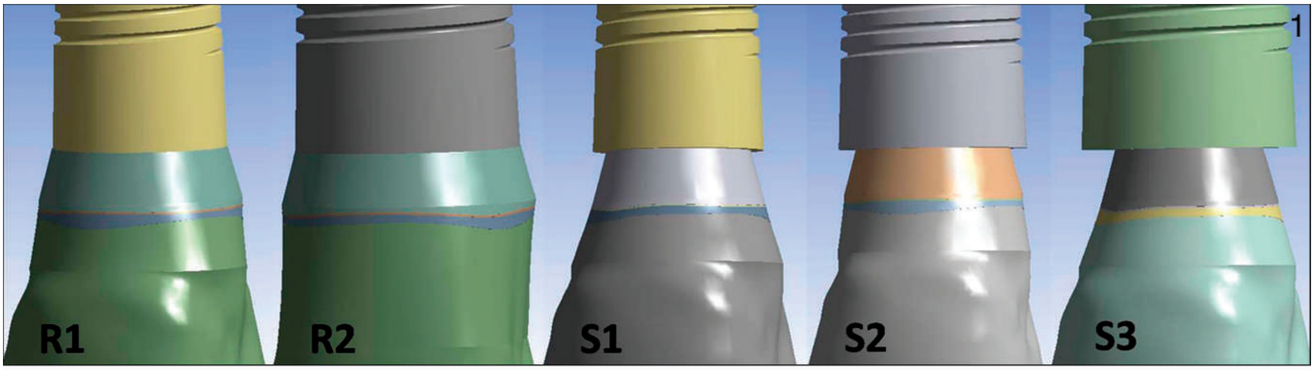
For the results, the maximum (σ_{max}) and minimum (σ_{min}) principal stress, equivalent von Mises stress (σ_{vm}), and maximum principal elastic strain (ε_{max}) were obtained for cortical and trabecular bone.

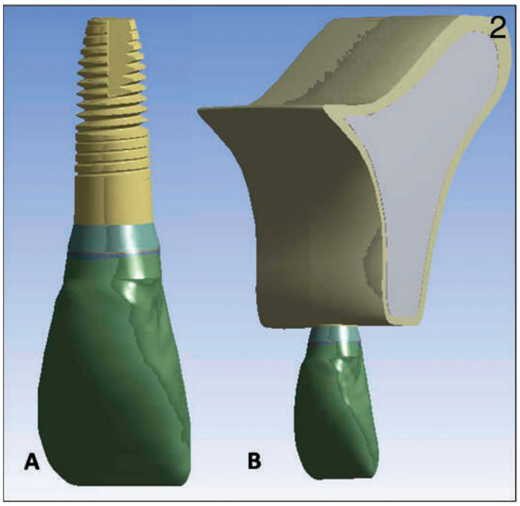
RESULTS

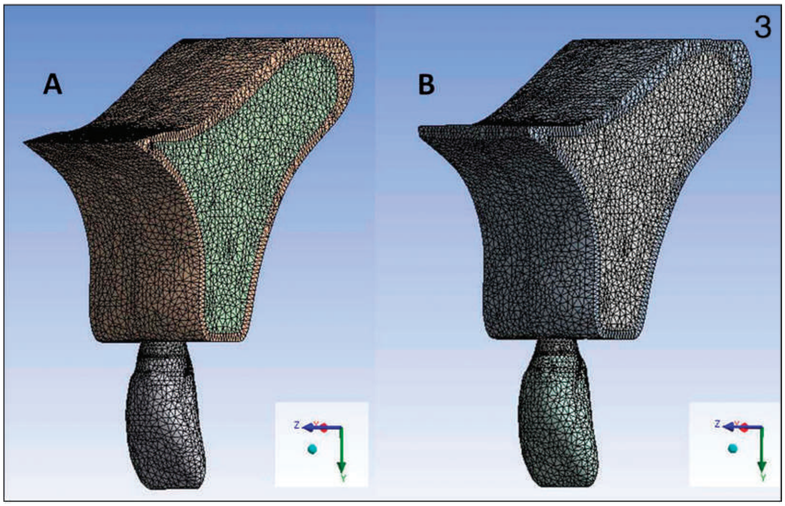
Irrespective of the analysis criterion adopted for evaluating the stress in cortical bone, maximum principal stress (σ_{max}) or equivalent von Mises stress (σ_{vm}), the models presented equivalent behaviors. In the trabecular bone, the stress values were more divergent.

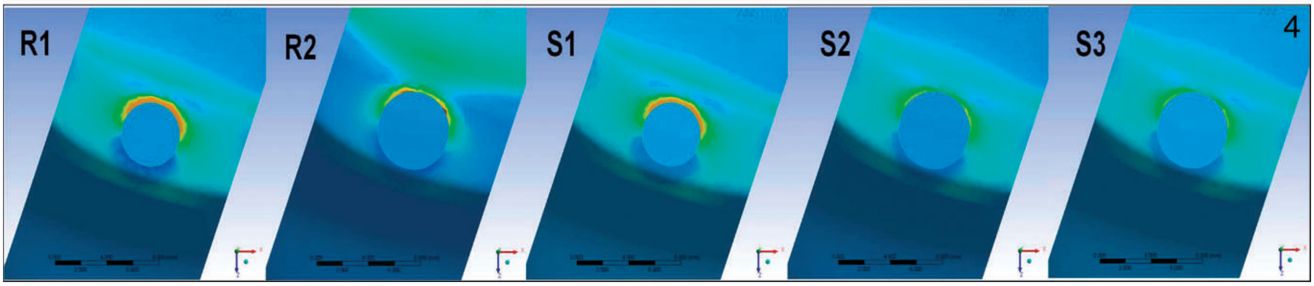
Cortical bone

For the cortical bone, the highest stress values (σ_{max} and σ_{vm}) were observed in situation R1 (105 and 87.1 MPa), followed by S1 (81.1 and 73.3 MPa), R2 (67.3 and 52.5 MPa), S3 (49.2 and 41.6 MPa), and S2 (46.1 and 39.8 MPa) (Table 4; Figure 4). The maximum principal stress (σ_{max}) and the equivalent









Figures 1–4. Figure 1. Platform simulated in the corresponding regular (R1 and R2) and switching (S1, S2, and S3) models. **Figure 2.** (a) Prosthetic crown cemented on the abutment of the implant simulating a regular platform condition. (b) Complete representative model with cortical and trabecular bone. **Figure 3.** Finite element mesh of the models. (a) Regular model (R). (b) Switching model (S3). **Figure 4.** Stress data of regular (R1 and R2) and switching (S1, S2, and S3) models after oblique loading.

von Mises stress (σ_{vM}) decreased by 56% and 54.3%, respectively with the switching model (S2) compared with the regular model (R1).

For the maximum principal strain (ε_{max}), R1 showed the highest stress (6.68e-003), followed by S1 (5.17e-003), R2 (4.29e-003), S2 (2.92e-003), and S3 (2.66e-003) (Table 4). Using this analysis criterion, the values for S3 decreased 60% compared with R1.

For all models (R1, R2, S1, S2, and S3) the maximum principal stress (σ_{max}) was concentrated on the lingual region of the cortical bone near the platform (Figure 4). The regular models (R1 and R2) and the switching model S1 showed more concentrated stress than the switching models S2 and S3 (Figure 4).

Trabecular bone

For the trabecular bone, the highest stress values (σ_{max}) were observed in situation S3 (11.8 MPa), followed by R1 (7.32 MPa), S1 (6.28 MPa), R2 (5.19

TABLE 2

Properties of materials used in the model

Material	Elastic Modulus (GPa)	Poisson Ratio	References
Cortical bone	13.8	0.26	Huang et al[16]
Trabecular bone (Type III)	1.6	0.3	Kao et al[17]
Implant	110.0	0.35	Huang et al[16]
Abutment	110.0	0.35	Huang et al[16]
Cement	8.3	0.3	Manufacturer
IPS e-max Press	95.0	0.3	Manufacturer

MPa), and S2 (4.09 MPa) (Table 4; Figure 4). The switching model S2 had a decrease of 63% in the $\sigma_{max,}$ compared with S3.

For the equivalent von Mises stress (σ_{vM}), S2 showed the highest stress values (9.94 MPa), followed by R2 (9.56 MPa), S1 (8.14 MPa), S3 (6.93 MPa), and R1 (6.22 MPa) (Table 4). With this criterion, no difference was found in the excessively high stress values in the trabecular bone. Little difference was also found in the stress values between the models for the maximum principal strain (ε_{max}) (Table 4).

DISCUSSION

The results of this study suggest that the use of platform switching reduced bone stress in the cortical bone when an implant with a larger diameter was used, irrespective of the amount of reduction between the abutment and implant diameters.

Many studies have indicated that platform switching reduces crestal bone resorption.[7,10,11,14,21–23] Schorotenboer et al[7] suggested that when the abutment was reduced by 10% or 20%, it resulted in less stress transferred to the crestal bone (<10%). In the present study, when there was a reduction of 18.18% between implant and abutment, there was a reduction in stress of approximately 31.5% compared with the regular prosthetic platform.

TABLE 3

Number of nodes and elements of the regular (R1 and R2) and switching (S1, S2, and S3) models

Models	Nodes	Elements
R1	426943	280556
R2	426759	279125
S1	421913	277696
S2	425093	278180
S3	420030	275291

It has also been shown that platform switching may increase the distance between the abutment inflammatory cell infiltrate and the alveolar crest, thus reducing the bone resorptive effect of the abutment design.[24] Therefore, the effect of platform switching can be clinically relevant in several situations. When anatomic structures such as the sinus cavity or the alveolar nerve limit the residual bone height, the platform-switching approach may minimize bone resorption, thereby increasing the biomechanical support available to the implant.

The effect of platform switching on esthetics around dental implants is another advantage of this concept. Baumgarten et al[25] describe the platform-switching technique and its usefulness in situations when shorter implants must be used, when implants are placed in esthetic zones, and when a larger implant is desirable but prosthetic space limited.

The decrease in crestal bone stress induced by increasing the diameter was also confirmed in the maxilla by Huang et al.[16] Therefore, based on biomechanics, a large-diameter implant may be beneficial for single implant placement, especially with immediate loading. These larger-diameter implants are recommended for clinical use because they increase the contact surface between the bone and implant and reinforce implant stability.[26]

Canullo et al[12] speculated that the reduced bone-level alterations in platform-switched implants may be related to their increased implant diameter rather than to the platform. However, comparative retrospective studies of implants with different diameters with regards to marginal bone loss did not show different outcomes.[27]

In contrast to the aforementioned advantages,

Table 4

Values of σ_{max}, σ_{min}, σ_{vM} (MPa) and ε_{max} for the cortical and trabecular bone for regular (R1 and R2) and switching (S1, S2, and S3) models*

Models	α_{max} Cortical	α_{min} Cortical	σ_{vM} Cortical	ε_{max} Cortical	α_{max} Trabecular	α_{min} Trabecular	σ_{vM} Trabecular	ε_{max} Trabecular
R1	105	–105	87.1	6.68e-003	7.32	–4.04	6.22	3.65e-003
R2	67.3	–49.6	52.5	4.29e-003	5.19	–9.56	9.54	5.06e-003
S1	81.1	–76.7	73.3	5.17e-003	6.28	–3.72	8.14	3.6e-003
S2	46.1	–39.8	39.8	29.2e-003	4.09	–3.03	9.94	2.56e-003
S3	49.2	–34.1	41.6	2.66e-003	11.8	0.681	6.93	3.3e-003

*σ_{max} indicates maximum principal stress; σ_{min}, minimum principal stress; σ_{vM}, equivalent von Mises stress; ε_{max}, maximum principal elastic strain.

this technique also has limitations. Platform switching can only be used when the components are of a similar design; that is to say, the access of the screw and hexagon of implants with different diameters must be compatible with those of the prosthetic components.[28] Furthermore, although the stress on the peri-implant bone is reduced, some authors have reported that there is an added stress on the abutment and abutment screw,[13] which could lead to screw fracture.

The methodology used in this study defined the models as isotropic, homogeneous, and linearly elastic, which is not clinical reality. In addition, the connection between the implant and bone was considered 100%.

Therefore, it is suggested that further mechanical investigations be conducted with nonlinear simulations as well as microbiological and clinical research to confirm the findings suggested in the present study.

CONCLUSIONS

1. The influence of platform switching was more evident for cortical bone than trabecular bone, mainly for large reductions in platform diameter.
2. Implants with a large diameter showed less stress concentration when associated with platform switching.

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