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Regular and Platform Switching: Bone Stress Analysis Varying Implant Type

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Abstract

Purpose: This study aimed to evaluate stress distribution on peri-implant bone simulating the influence of platform switching in external and internal hexagon implants using three-dimensional finite element analysis.
Materials and Methods: Four mathematical models of a central incisor supported by an implant were created: External Regular model (ER) with 5.0 mm × 11.5 mm external hexagon implant and 5.0 mm abutment (0% abutment shifting), Internal Regular model (IR) with 4.5 mm × 11.5 mm internal hexagon implant and 4.5 mm abutment (0% abutment shifting), External Switching model (ES) with 5.0 mm × 11.5 mm external hexagon implant and 4.1 mm abutment (18% abutment shifting), and Internal Switching model (IS) with 4.5 mm × 11.5 mm internal hexagon implant and 3.8 mm abutment (15% abutment shifting). The models were created by SolidWorks software. The numerical analysis was performed using ANSYS Workbench. Oblique forces (100 N) were applied to the palatal surface of the central incisor. The maximum (σ_{max}) and minimum (σ_{min}) principal stress, equivalent von Mises stress (σ_{vM}), and maximum principal elastic strain (ε_{max}) values were evaluated for the cortical and trabecular bone.
Results: For cortical bone, the highest stress values (σ_{max} and σ_{vm}) (MPa) were observed in IR (87.4 and 82.3), followed by IS (83.3 and 72.4), ER (82 and 65.1), and ES (56.7 and 51.6). For ε_{max}, IR showed the highest stress (5.46e-003), followed by IS (5.23e-003), ER (5.22e-003), and ES (3.67e-003). For the trabecular bone, the highest stress values (σ_{max}) (MPa) were observed in ER (12.5), followed by IS (12), ES (11.9), and IR (4.95). For σ_{vM}, the highest stress values (MPa) were observed in IS (9.65), followed by ER (9.3), ES (8.61), and IR (5.62). For ε_{max}, ER showed the highest stress (5.5e-003), followed by ES (5.43e-003), IS (3.75e-003), and IR (3.15e-003).
Conclusion: The influence of platform switching was more evident for cortical bone than for trabecular bone, mainly for the external hexagon implants. In addition, the external hexagon implants showed less stress concentration in the regular and switching platforms in comparison to the internal hexagon implants.

The longevity of dental implants depends on integration between the implant components and hard and soft tissues;[1] however, bone resorption has been frequently reported after 1 year of implant function.[2-39] The most common factors for bone loss are occlusal overloading,[2-18] contamination in the gap between the abutment and the implant,[19-26] biological width formation,[27-33] design of the implant neck,[34-37] surgical trauma,[1] peri-implantitis,[1] and gingival biotype.[38]

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Although there is no consensus in the literature for the main cause of peri-implant resorption, it is important to determine a stable level of peri-implant bone loss since preservation of the supporting bone is essential for soft-tissue esthetics.[35,39] Considering patients' increasing requirement for esthetics, natural-looking restorations have been a challenge for clinicians.

Minimal or no bone loss would be ideal. Thus, Lazzara and Porter[40] suggested alteration of the horizontal relation between the implant and prosthetic component diameters, introducing the concept of platform switching. This technique is characterized by a reduced diameter of the prosthetic component in comparison to the implant diameter,[40,41] which has been widely studied and reported in the literature.

Clinical, radiographic, and histological studies have shown reduced peri-implant bone loss with platform switching.[26,35,36,42,43,44,45-49] Some studies using the finite element method demonstrated more uniform stress distribution on the peri-implant bone with platform switching than with the traditional technique.[11,13,15,16,50] The literature demonstrates that internal connections present better performance in laboratory tests and superior structural integrity of the implant,[51,52] antirotational stability,[51,52] reduced rate of abutment screw loosening,[53,54] and lower stress transfer to the bone[10,55,56] than do external hexagon connections; however, there is no study evaluating the performance of external hexagon implants associated with platform switching.

Considering the effect of platform switching to reduce bone loss, the aim of this study was to evaluate stress distribution on the peri-implant bone, simulating the influence of platform switching in external and internal hexagon implants using three-dimensional finite element analysis.

Materials and methods

This study was approved by the Human Research Ethics Committee (process #2008/01845) at the Araçatuba School of Dentistry, São Paulo State University (UNESP), Brazil. After the patient signed the informed consent, a tomographic examination of the maxilla was conducted to obtain tomographic images in *dicom* format. The mathematical models representing the anterior segment of the maxilla were fabricated using Mimics 11.11 (Materialise, Leuven, Belgium) and Solid Works 2010 (Inovart, São Paulo, Brazil) software.

All models were restored with a crown cemented on the abutment varying the type of implant (internal and external hexagon implants) and the platform diameter (regular—4.5 mm; switching—4.1 mm) to simulate two regular situations (IR—internal regular platform; ER—external regular platform) and two switching situations (IS—internal platform switching; ES—external platform switching). The four models obtained are described in Table 1 and represented in Figure 1.

The external hexagon implants SIN Revolution (5.0 mm × 11.5 mm, Sistema de Implante, São Paulo, Brazil) and internal hexagon implants SIN Strong (4.5 mm × 11.5 mm, Sistema de Implante) were restored with an IPS e-max Press crown (Ivoclar Vivadent, Schaan, Liechtenstein) cemented on the abutment (5.0-, 4.5-, 4.1-, and 3.8-mm diameter) with 0.05-mm thick Variolink II cement (Ivoclar Vivadent) (Fig 2). Then, the assembly was inserted in the anterior segment of the maxilla with cortical and trabecular bone corresponding to the region of the

Table 1 Characteristics of the models used in the study

Characteristic Connection	External regular (ER) External hexagon	Internal regular (IR) Internal hexagon	External switching (ES) External hexagon	Internal switching (IS) Internal hexagon
Implant diameter	5.0 mm	4.5 mm	5.0 mm	4.5 mm
Abutment diameter	5.0 mm	4.5 mm	4.1 mm	3.8 mm
Implant length	11.5 mm	11.5 mm	11.5 mm	11.5 mm

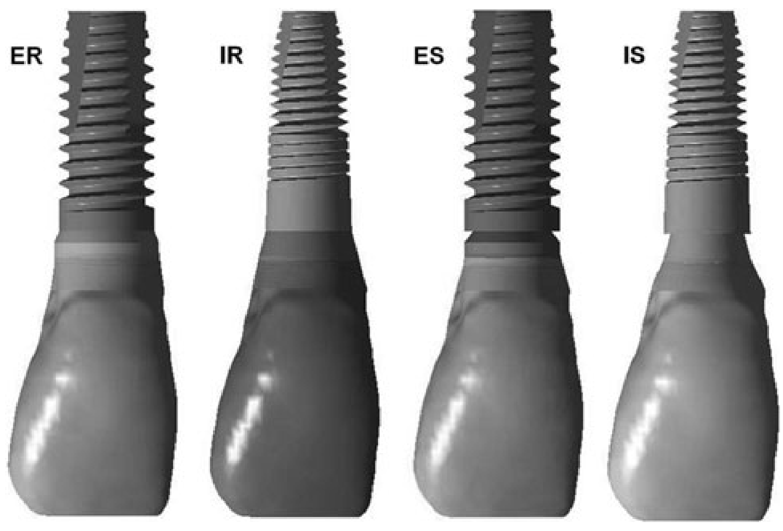

Figure 1 External regular (ER), internal regular (IR), external switching (ES), and internal switching (IS) models.

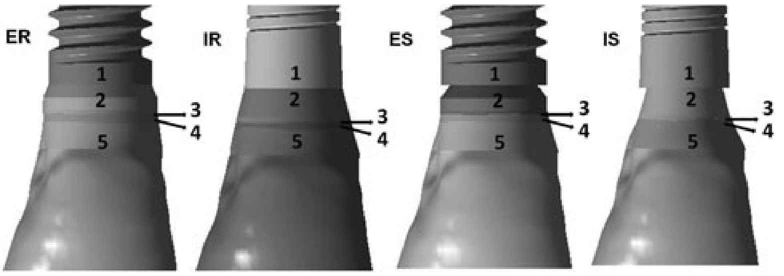

Figure 2 Components of the four models: implant (1), abutment (2), cementation line (3), coping (4), and crown (5).

right central incisor. The crown was 13.0 mm high, 8.8 mm in mesiodistal width, and 7.1 mm in buccal-lingual width.

After fabrication, the models were transfered to the finite element software Ansys Workbench 10.0 (Swanson Analysis Inc., Houston, PA) to determine the regions and generate the finite element mesh. The mechanical properties of Young's modulus (E) and Poisson's ratio (ν) of each structure were used to consider the study as homogeneous, isotropic, and linearly elastic (Table 2).[5,6,10,15,57] The mechanical properties referred to a Lekholm and Zarb classification bone type III,[58] which is more frequent in the anterior region of the maxilla.[57,59] The bone/implant interface was considered as completely osseointegrated.[5,6,10,13,15,57]

Oblique loading (100 N, 45°) was applied on the palatal surface of the crown of the right central incisor (Fig 3).[5,10,13,15] The fixed support was determined in the three cartesian axes ($x = y = z = 0$) to characterize the boundary condition.

A solid element with parabolic tetrahedral interpolation[60] and a mesh composed of elements with 0.2 mm in dimension were used (Fig 4). The refinement of the mesh was established through convergence analysis (6%).[14] The quantity of nodes and elements presented by each model is described in Table 3.

For analysis of 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}) values for the cortical and trabecular bone were obtained. According to Dejak and Mlotkowski,[61] principal stress is the most appropriate analysis criteria for predicting failures in nonductile materials.

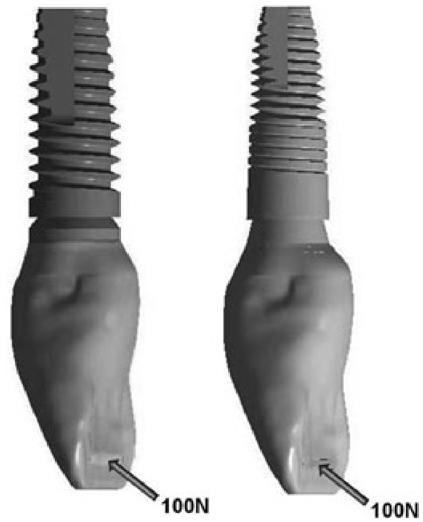

Figure 3 Oblique loading on the palatal surface of the maxillary central incisor.

Results

Irrespective of the analysis criterion adopted to evaluate the stress in cortical bone, σ_{max} or σ_{vm}, the models presented similar behaviors (Table 4). In the trabecular bone, the stress values were more divergent.

Table 2 Elastic properties described for the materials used in the models

Material	Young's modulus (GPa)	Poisson's ratio
Cortical bone[14]	13.8	0.26
Trabecular bone (type III)[62]	1.6	0.30
Implant[14]	110.0	0.35
Abutment screw[14]	110.0	0.35
Abutment[14]	110.0	0.35
Variolink II*	8.3	0.30
IPS e-max Press*	95.0	0.30

*Information provided by manufacturer.

Cortical bone

For the cortical bone, the highest stress values (σ_{max} and σ_{vm}) (MPa) were observed in IR (87.4 and 82.3), followed by IS (83.3 and 72.4), ER (82 and 65.1), and ES (56.7 and 51.6) (Fig 5). In both situations, the switching models decreased the stress in relation to the internal hexagon (4.6% for σ_{max}, 12% for σ_{vm}), mainly in relation to the external hexagon (30.8% for σ_{max}, 20.7% for σ_{vm}).

Considering the type of implant, the external hexagon showed less stress in both situations (regular: 6.1% for σ_{max} and 20.8% for σ_{vM}; switching: 31.9% for σ_{max} and 28.7% for σ_{vM}) than did the internal hexagon implants. For the maximum principal strain (ε_{max}), IR showed the highest stress, followed by IS, ER, and ES (Table 4). The decrease in the values of the switching model in comparison to the regular model was 4.2% for the internal hexagon and 29.6% for the external hexagon.

Trabecular bone

For the trabecular bone, the highest stress values (σ_{max}) (MPa) were observed in ER, followed by IS, ES, and IR. For the σ_{vM}, the highest stress values (MPa) were observed in IS, followed

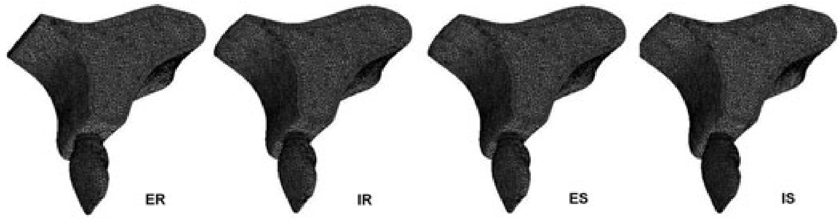

Figure 4 Finite element mesh of the ER, IR, ES, and IS models.

by ER, ES, and IR (Table 4). The internal regular platform (IR) showed the lowest stress in the trabecular bone for both analysis criteria in comparison to the other models.

For the maximum principal strain (ε_{max}), ER showed the highest stress, followed by ES, IS, and IR (Table 4). The decrease in the value for the switching model in comparison to the regular model was 1.27% for the external hexagon implant. For the internal hexagon implant, a decrease of 16% occurred from the switching to the regular model.

Discussion

The results observed in cortical bone demonstrated that the implant with external connection associated with platform switching presented the best behavior, because the values for the σ_{max}, σ_{vM}, and ε_{max} were the lowest. On the other hand, the implant with internal hexagon and regular platform showed the worst performance in this study.

As in this study, the simulated structures (implants and prosthetic components) were an exact copy of those commercially distributed by the manufacturer; the external hexagon implants were 0.5 mm larger than the internal hexagon implants. Considering that some authors have suggested that a higher diameter of the implant should reduce the stress transferred to the cortical bone,[5,14,17,18] this could explain the favorable results of the external connection. Thus, the external switching implants transferred less stress to the cortical bone (31.9% for σ_{max} and 28.7% for σ_{vM}) than did the internal switching group.

Comparing ER and ES, σ_{vM} decreased 20.7% in the cortical bone. Rodriguez-Ciurana et al[50] reported similar results with a 26.6% decrease between models with the same characteristics. The difference of about 6% between the studies may result from different cortical thicknesses (2 mm in that study, 1 mm here), as Okumura et al[18] said that thinner cortical bone on the alveolar crest leads to highest stress concentration around the implant neck.

The ε_{max} analysis revealed that large-diameter implants (ER and ES) presented lower values than narrower implants (IR and IS). This result is in accordance with Ding et al,[17] who found reduced strain when the implant diameter increased. In addition, using switching models, this analysis showed that ε_{max} can be 4.2% lower for the internal hexagon and 29.6% lower for the external hexagon implants.

When switching platform was used by Maeda et al,[11] Quaresma et al,[13] and Rodríguez-Ciurana et al,[50] lower stress concentration in peri-implant bone was found in comparison to regular models. This is in agreement with the results of this study, since both external and internal hexagon-switched groups presented lower values for all analysis criteria in comparison to the regular groups.

The situation simulated in this study required incidence of oblique load in relation to the implant long axis in the anterior maxillary region,[13,57] according to a physiological situation. For the oblique loading, the highest stress is generated in the cortical bone surrounding the implant platform.[5,6,9,10,11-18,62] Similar performance was observed in this study where all models had the stress located in the buccal region, except for the regular internal hexagon model where stress was exhibited in the proximal region. This situation confirms the worst performance of the IR group, since bone loss in the proximal region leads to loss of papilla and esthetic damage. In all models, the maximum σ_{vM} in the cortical bone was about 6 to 14 times

Table 3 Nodes and elements of the models

Models	Nodes	Elements
ER	518,220	341,601
IR	539,366	356,679
ES	520,559	343,553
IS	528,776	350,298

Table 4 Maximum (σ_{max}) and minimum (σ_{min}) principal stress, equivalent von Mises stress (σ_{vM}) (all in MPa), and maximum principal elastic strain (ε_{max}) distributions in cortical and trabecular bone in the regular (external regular—ER, and internal regular—IR) and switching (external switching—ES, and internal switching—IS) models

Models	α_{max} cortical	α_{min} cortical	α_{vM} cortical	ε_{max} cortical	α_{max} trabecular	α_{min} trabecular	α_{vM} trabecular	ε_{max} trabecular
ER	82	−82.1	65.1	5.22e−003	12.5	−5.8	9.3	5.5e−003
IR	87.4	−112	82.3	5.46e−003	4.95	−5.36	5.62	3.15e−003
ES	56.7	−59.5	51.6	3.67e−003	11.9	−8	8.61	5.43e−003
IS	83.3	−84.5	72.4	5.23e−003	12	−4.49	9.65	3.75e−003

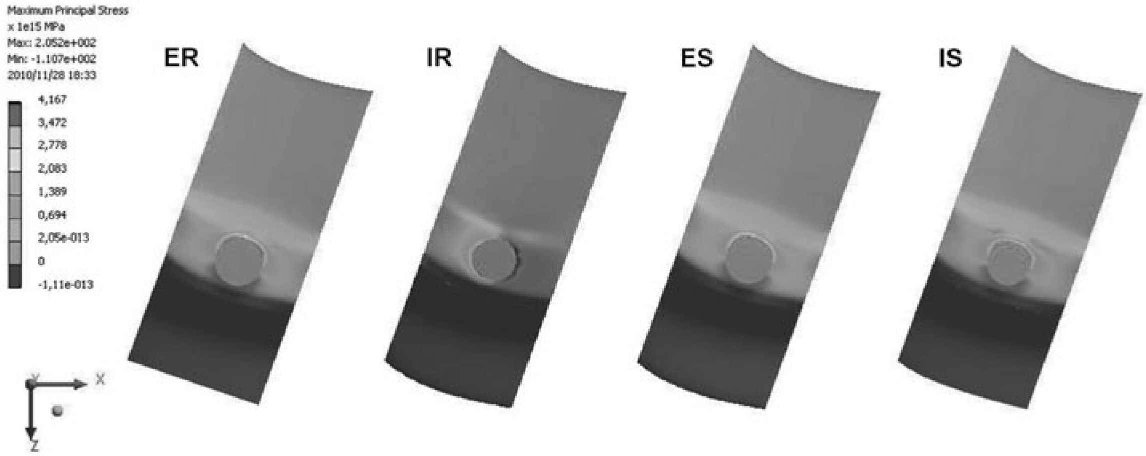

Figure 5 Stress distribution (σ_{max}) in the cortical bone of the ER, IR, ES, and IS models.

higher than that in trabecular bone, in accordance with the findings of Okumura et al.[18]

The evaluation of the trabecular bone demonstrated that, in the regular models, stress values (σ_{max} and σ_{vM}) were higher for the external hexagon implant (ER = 12.5 and 9.3 MPa, respectively) than for the internal hexagon group (IR = 4.95 and 5.62 MPa, respectively), similar to the findings of other authors.[5,13,17] This may result from the reduced quantity of trabecular bone when the implant diameter increases.[17] According to Holmgren et al,[5] this result demonstrates that the implant with higher diameter is not always the best alternative, since the stress distribution to bone is unfavorable for cases with morphological limitations; however, considering the cortical bone, the higher implant diameter usually presents lower bone stress.[5,14,17,18]

Ding et al[17] stated that an implant with higher platform diameter allows better transference of masticatory forces, decreasing the bone loss. Thus, according to biomechanics, these authors suggested that the highest implant diameter should be selected considering the anatomy of the region.

Considering the hexagon type, this study demonstrated that the internal connection generated 60.4% less stress in the trabecular bone than the external connection in the regular models. This is in accordance to the results of Baggi et al,[16] who demonstrated that the external hexagon implant generated higher bone stress than the internal hexagon.

The lowest stress values were observed in the regular internal hexagon model. This finding in trabecular bone may result from a greater distance between this bone type and loading position associated with its lower Young's modulus in comparison to the cortical bone.

Even considering that the methodology used in this study defined the models as isotropic, homogeneous, and linearly elastic, which is not realistic, and that the connection between the implant and bone was considered completely osseointegrated; it can be suggested that external hexagon implants should be associated with platform switching for better esthetics and function in the anterior region of the maxilla. However, additional nonlinear FEA can confirm these data, and clinical and histological studies are necessary to confirm this clinical hypothesis.

Conclusion

Within the limitations of this study, the following conclusions may be drawn:

1. The influence of the switching platform was more evident for the cortical bone in comparison to the trabecular bone, mainly for the external hexagon implants;
2. The external hexagon implants showed less stress concentration in the regular and platform switching compared to the internal hexagon implants.

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