Influence of abutment diameter for platform switching on the biomechanics of internal and external hexagon posterior implants

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***Abstract*— *Objective: The aim of this study was to evaluate the influence of the reduction of abutment's diameter for platform switching on stress distribution of single implant with external or internal connections using three-dimensional (3D) finite element analysis. Materials and Methods: A total of 8 virtual 3D models were constructed containing one single implant (5.0 × 11.0 mm) in a mandibular segment supporting a single first molar screwed crown. The implants presented external or internal hexagon connections with UCLA abutment with different diameters: 3.8, 4.2, 4.6 or 5.0 mm. All structures were considered perfectly bonded and each model received a 200 N oblique load on the occlusal surface distributed on 8 points. The maximum tensilestress (σ_{max}) and the maximum principal elastic strain (ε_{max}) were calculated for the cortical and trabecular bones and equivalent Von Misses (σ_{vM}) for dental implant and abutment using ANSYS Workbench software. Results: The reduction of abutment diameter produced a reduction of stress values in bone tissue up to 3,6% in internal hexagon. On the other hand, the smallest abutment diameter for external hexagon connection produced the highest stress in surrounding cortical bone(53 MPa).The reduction of abutment diameter increased the stress and strain in both theabutment (up to 360%) and implant (up to 200%), regardless of implant connection. External hexagon connection presented the highest stress and strain magnitudes. Conclusion: The reduction of abutment diameter improves stress distribution in bone tissue, regardless of implant connection type. However, it increases the stresses within the implant and abutment, which could compromise their mechanical resistance.*

***Keywords*— platform switching, dental implant, stress distribution, finite element analysis.**

I. INTRODUCTION

Bone resorption close to the first thread of Osseo integrated implants is frequently observed during initial loading. The mechanism of bone resorption has been attempted to be explained by formation of the biologic width as with the periodontal tissue around natural teeth (Berglundh et Lindhe, 1996) or by the mechanical stress to the bone– implant interface (Duyck et al., 2001).The bone loss observed after prosthetic load can be expected as 1.5–2 mm in the vertical axis and 1.4 mm in the horizontal axis (Tarnow et al., 2000).

Several hypotheses have been proposed for these changes observed in the bone crest region. Some authors indicate the influence of the microgap present in the

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implant-abutment interface (I/P). Bacterial microleakage through the I/P interface and colonization of the internal portion of the implants leads to an inflammatory infiltrate close to the I/P interface, thus hindering bone resorption close to the bone /implant junction (Hermann et al., 2001).

Shifting to a smaller diameter seems to be promising in the prevention of bone loss The platform switching (PS) concept was introduced in the literature by in 2006(Lazzara et Porter, 2006), referring to the use of a small diameter abutment on a larger diameter implant platform. The proposed difference between implant platform and abutment is an attempt to decrease the bone loss thought three different ways: microbiologicby shifting the implant–abutment interface medially, inflammatory infiltrate is moved away from the bone and the deleterious impact of the implant–abutment microgap on the peri-implant bone is reduced) (Lazzara et al., 2006); biologic by increasing the exposed horizontal area of the implant surface and allowing the connective component of biologic width to have more space to get attached preventing epithelial down-growth) (Farronato et al., 2012); and biomechanically by shifting the stress concentration area away from the cervical bone–implant interface, resulting in less post-loading bone resorption (Ackermann et al., 2020; Aslam et al., 2019; Gupta et al., 2019; Maeda et al., 2007; Maminskas et al., 2016)

The biomechanical advantage of PS suggested that the distance between the bone surfaces and implant/ abutment interface decrease the stress-concentrated area on the implant surface. The mismatch between implant and abutment to configurated a PS is not clear, studies shows that > 0.4mm mismatch can decrease the marginal bone loss. However, the current findings demonstrated that PS might risk the mechanical properties of abutments particularly of the ones with increased set-off distance and straight emergence.

The other factor may influence the distributed load on the bone is the implant connection. Internal connections have been introduced to lower or eliminate these mechanical complications and reduce stress transferred to the crestal bone(Finger et al., 2003; Norton, 1997). High strains and marginal bone loss have been found around the neck of implants with an external hexagon design(Hoshaw et al., 1994; J.-W. Lee et al., 2011).

The PS and different connections have been demonstrated effectiveness in reducing stress in the periimplant bone. However, there are no studies that evaluate different mismatch between abutment and implant diameters comparing the internal and external implant connections. The aim of this study was to evaluate, through the three-dimensional finite element analysis, the influence of abutment diameter and implant connection onbone tissue, implant and prosthetic components biomechanical behavior.

II. MATERIAL AND METHODS

Eight tridimensional virtual models of a first lower molar supported by animplant were constructed. The abutment diameter (3.8, 4.2, 4.6 and 5.0) and the implant connection (internal hexagon and external hexagon) were the study factors. Oblique occlusal loadwas applied and analyzed by the finite element analysis software to obtain the maximum tensile stress (σmax) and the maximum principal elastic strain (Ɛmax) for the cortical and cancellous bone and the von Mises stress (σvM) for the implant, abutment and the abutment screw.

Finite Element Models Design

Computerized tomographic images of a human edentulous mandible were used for the construction of the mandibular segment with cortical and cancellous bone. Likewise, a CT scan of a human lower first molar was used to provide the DICOM images, exported to the In Vesalius software for the 3D reconstruction of the implant-retained cemented crown, according to a previously published protocol (Camargos et al., 2020).

The modeling of the two implants were obtained by a generic construction of a cylindric 5 x 11 mm internal or external hexagon connection. Likewise the modeling of the eight abutments with four different diameter and two different connections, as based on the generic UCLA abutment. A computer-aided software (Solid Works, Concord) was used for the tridimensional modeling. The four abutments diameter were3.8, 4.2, 4.6, 5.0 mmas presented in Figure 1.The metal-ceramic cemented crown had a cement layer with 0,5mm of thickness. Then, the eight CAD models were exported to Ansys Workbench 10.0 FEA software (Swanson Analysis Inc) for the finite element analysis.

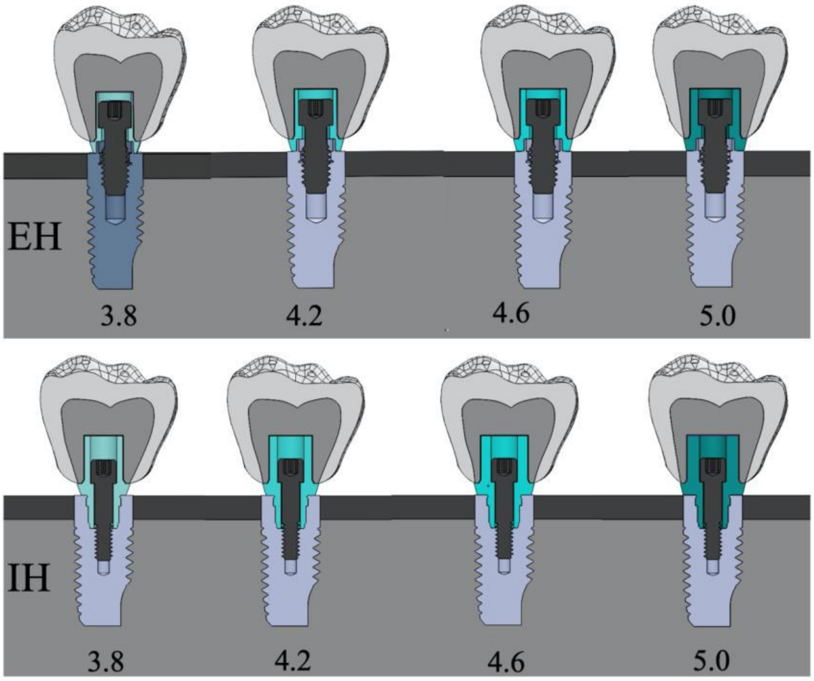

Fig.1: Axial visualization of the eight experimental models in external hexagon (EH) and internal hexagon (IH) 5 x 11 mm implants and 3.8, 4.2, 4.6 and 5.0 mm abutments. Implant body and dimensions were maintained, as only the connection type, screw and abutment diameters were altered in order to increase the platform switching effect.

Material Properties and mesh formatting

All structures were considered isotropic, homogeneous and linearly elastic. The elastic modulus and Poisson's ratio were obtained from the literature and are shown in Table 1. Convergence analysis of 5% was processed, (Geng WeiXu, Weiqi Yan, 2008)achieved using a tetrahedral mesh containing 0.6 mm elements (Figure 2).

Table 1: Mechanical properties of the materials

Material	Young's modulus	Poisson's ratio	Reference
Cortical bone	14.0	0.3	(Cruz et al., 2009)
Trabecular bone	1.37	0.3	(Cruz et al., 2009)
Titanium	110	0.33	(Cruz et al., 2009)
Ceramic	68.9	0.28	(Coelho et al., 2009)
Co-Cr alloy	90.0	0.28	(Sertgoz, 1997)

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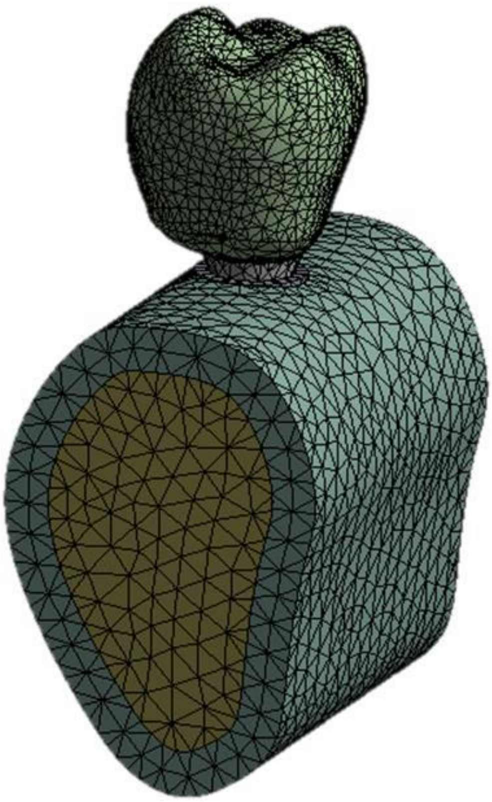

Fig.2: Final mesh obtained after convergence analysis with 0.6 mm elements.

Interface conditions

The bone-implant interface was assumed to be perfect bonded, simulating 100% osseointegration, and the crown, abutment, and the implant were assumed to be completely bonded.

Loading and Boundary Conditions

The boundary conditions were defined by fixing the mesial and distal external surfaces of the bone segment in all directions. The models were loaded in two steps: an initial loading using a 32N/cm to preload torque on the prosthetic screws, and the second stepwas simulated an occlusion loading by applying a 220N oblique load distributed over eight 1.5-mm² points (Figure 3). The forces were applied in the direction of normal occlusion, 45º to the cusp of the tooth.

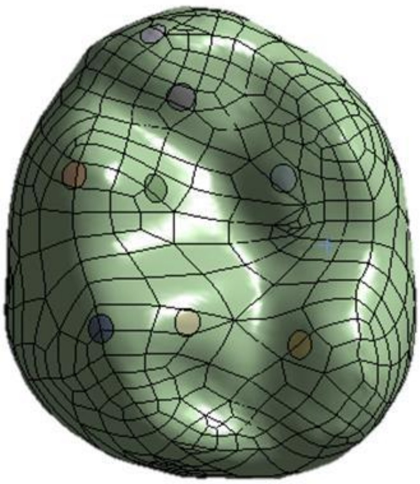

Fig.3: Eight loading points distributed on the occlusal surface of the tooth for the oblique loading (45 degrees) of 220 N.

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The maximum tensile (σmax) and the maximum principal elastic strain (Ɛmax) for the cortical and cancellous bone and the von Mises equivalent stress (σvM) for the implant, abutment and the abutment screw were obtained.

III. RESULTS

The results were obtained in both quantitative qualitative analysis. The quantitative data is shown in Table 2 and qualitative images are shown in Figures 4 and 5.

Table 2: Stress and strain values for all eight models of the study.

Groups		Cortical bone		Trabecular bone		Implant	Abutment	Screw
		σmax (MPa)	Ɛmax (μm/μm)	σmax (MPa)	Ɛmax(μm/μm)	σvM (MPa)	σvM (MPa)	σvM (MPa)
IH	3.8	47.9	3.72	6.25	4.99	246.7	523	155
	4.2	49.6	3.77	6.15	4.90	192	243	244
	4.6	48.6	3.72	6.09	4.85	191	205	241
	5.0	48.0	3.68	6.05	4.81	190	161	240
EH	3.8	53.1	4.01	6.91	5.22	569	739	645
	4.2	52.6	4.01	6.39	5.09	209	355	373
	4.6	51.1	3.92	6.30	5.00	194	201	231
	5.0	50.3	3.88	6.26	4.96	194	192	209

IH: internal hexagon; EH: external hexagon; σmax: Maximum Principal Stress; Ɛmax: Maximum principal elastic strain ;σvM: equivalent von Mises stress.

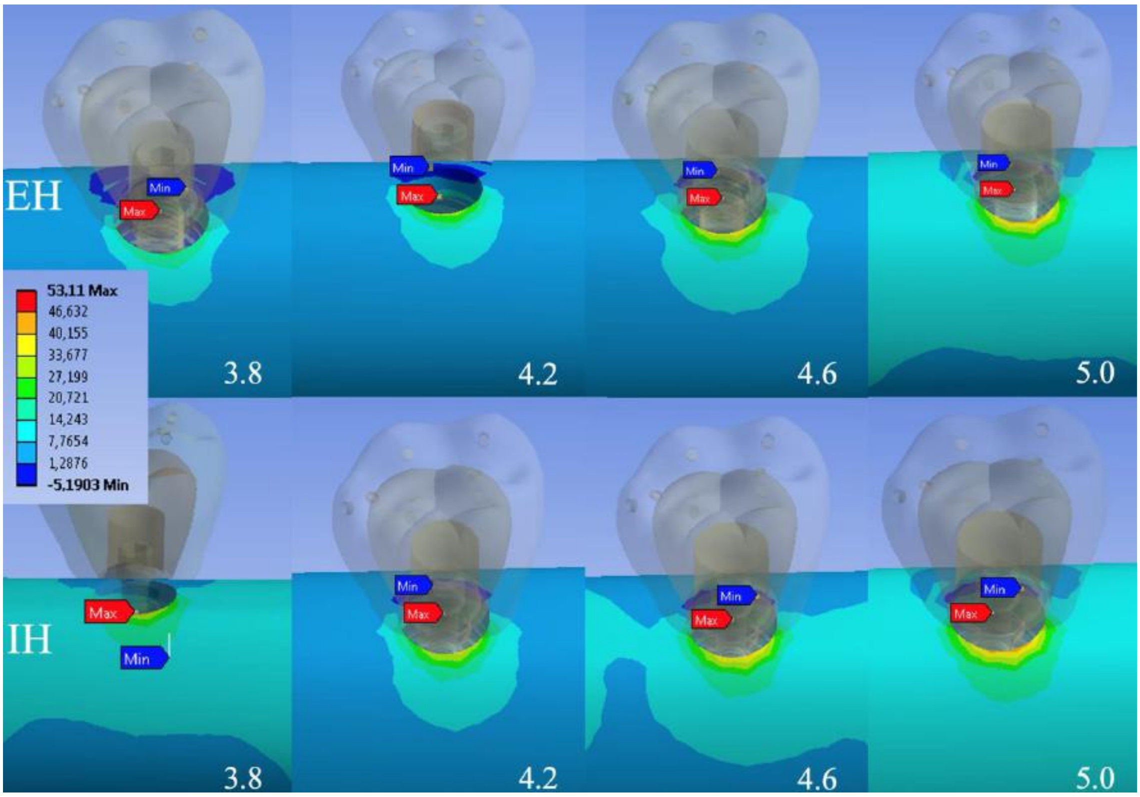

Fig.4: Qualitative visualization of σmax (MPa) distribution on surrounding cortical bone among all experimental models. The maximum tensile stress were observed on the buccal area due to the oblique loading simulating chewing.

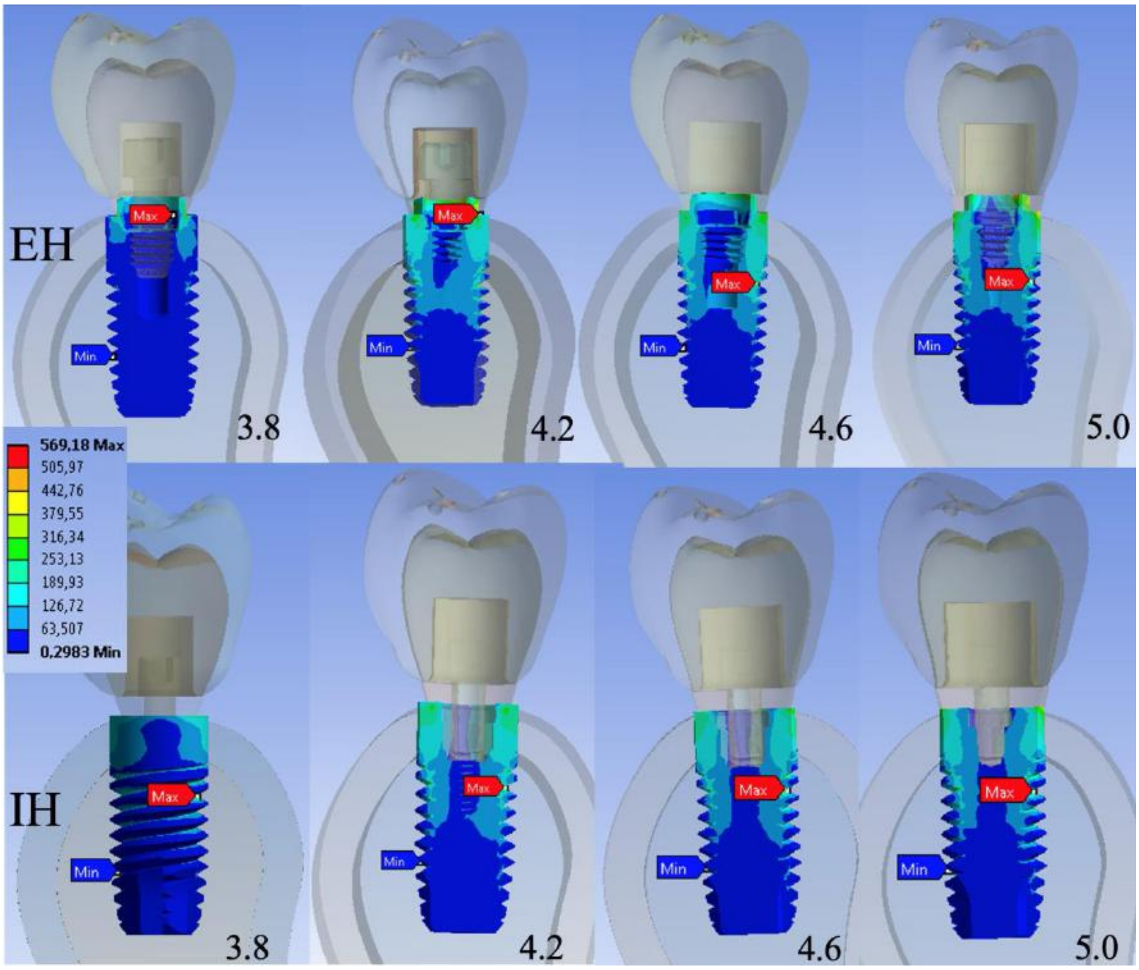

Fig.5: Qualitative visualization of σvM (MPa) distribution on implant among all experimental models. The maximum von Mises stress were observed on the platform area for small abutment diameters on external hexagon and on the third thread of the implant for all other models.

The lowest tensile stress values for the cortical bone(47.87 MPa) was found in the 3.8 HImodel, while the highest value was found in the 3.8 EH model (53.11 MPa), that represents an increase of 11%. The Ɛmax for cortical bone varied from 3,68 x 10^{-3} mm/mm (5.0 IH) to 4,01 x 10^{-3} mm/mm (3.8 EH), which represents an increase of 9%. For trabecular bone the σmax varied from 6,05 MPa (5.0 IH) to 6,91 MPa (3.8 EH), which represents an increase around 14%. The Ɛmax for trabecular bone varied from 4,81 x 10^{-3} mm/mm (5.0 IH) to 5,22 x 10^{-3} mm/mm (3.8 EH), which represents an increase of 8,5%. The σmax stress for cortical bone was concentrated in the buccal area, as shown in Figure 4. It was observed the improvement of stress distribution on the surrounding bone area when decreasing the abutment diameter, increasing the platform switching effect, regardless of implant connection type.

For implants and abutments, it was observed an increase of the σvM stress when decreasing the abutment diameter regardless of implant connection type (Table 2). The lowest σvM value for implant was found in the 5.0 IH (190 MPa) and the highest in the 3.8 EH (569 MPa). That is a 200% increase. Likewise the same happened for the abutment, from 161 MPa in IH 5.0 to 740 in 3.8 EH, with a 360% of increase. As shown in Figure 5, the σvM stress concentrated in the lingual area of the connection platform for the increased platform switching models of external hexagon implants (3.8 and 4.2). In the reduced platform switching (4.8) and regular platform (5.0) EH implants, the maximum stress was concentrated in the first tread of the implant, away from the implant/abutment interface. For the internal hexagon implants, regardless of abutment diameter, the stress also concentrated close to the third thread of the implant (Figure 5).

Considering the screw, the lower σvM stress was found in the 3.8 IH (155 MPa) and the highest in the 3.8 EH (645 MPa). The internal connection provided less stress in the screw than the external connection.

IV. DISCUSSION

The present study evaluated the effect of implant connection (internal and external hexagon) and platform switching concept (abutment diameter of 3.8, 4.2, 4.6 and 5.0) on the stress and strain magnitude and distribution on implant-supported lower molar crown. Both the study factors influenced the results of the analysis. Internal connection provided lower values for all criteria of the study. The surrounding bone tissue was less affected when internal connection was used associated with increase platform switching (3.8 IH). On the other hand, when using external connection, the implant, abutment and screw was highly affected by platform switching, with high increase in stress

The better understanding of stress and strain magnitudes and distributions around implants can enlighten the clinical findings for implant-supported restorations, as marginal bone loss around implants after surgical placement and loading inan important parameter in assessing the success of the implant fixture. The radiographic bone loss ranges of 1.5 mm during the first year, followed by 0.2 mm in subsequent years.(Tarnow et al., 2000)Bone resorption close to the first thread of Osseo integrated implants is frequently observed during initial loading. The mechanism of bone resorption has been attempted to be explained by formation of the biologic width as with the periodontal tissue around natural teeth(Berglundh et al., 1996) or by the mechanical stress to the bone– implant interface (Duyck et al., 2001).

Prevention of horizontal and vertical marginal peri-implant bone resorption during the post-loading period is necessary to maintain gingival levels.(Canullo et al., 2012) Features of the implant-abutment connection were considered to influence the biological outcomes(Hermann et al., 2001) and the mechanical behavior of implants(Hansson, 2000; Norton, 1997).The microbiological approaches involve shifting the implant–abutment interface medially, moving the inflammatory infiltrate away from the bone and the deleterious impact of the implant–abutment micro gap on the peri-implant bone(Lazzara et al., 2006). The biologic consequences is the increased exposed horizontal area of the implant surface, connective component of biologic width to have more space to get attached, preventing epithelial down-growth (Annibali et al., 2012; de Almeida et al., 2011; Farronato et al., 2012; Messias et al., 2019); and biomechanical consequences by shifting the stress concentration area away from the cervical bone–implant interface, may result in less post-loading bone resorption(Annibali et al., 2012; Gupta et al., 2019; Maeda et al., 2007; Messias et al., 2019; Rodríguez-ciurana et al., 2009).

Considering the findings of this study, shifting to a smaller abutment diameter seems to be promising in the prevention of higher stress in the cortical bone for internal connections. Internal connections have been introduced to lower these mechanical complications and reduce stress transferred to the crestal bone (Maminskas et al., 2016; Norton, 1997).

High strains and marginal bone loss have been found around the neck of implants with an external hexagon design (Hoshaw et al., 1994; J.-W. Lee et al., 2011)maybe due to the abutment screw being responsible on its own for maintaining the fixture-abutment joint in this type of connection. The internal hexagon and the Morse taper connections have greater mechanical friction, stability, and form lock than the external hexagon joint(Caricasulo et al., 2018; Maminskas et al., 2016; Nishioka et al., 2011).All criteria evaluated in the present study presented lower values for the internal hexagon in comparison to the external hexagon.

Two studies found an increase of σvM stress for implants and abutments in the platform switching model in comparison to regular platform model(Aslam et al., 2019; Çimen et Yengin, 2012). The same pattern was observed in the present study. For obtaining the PS concept, there is a decrease of thickness in the abutment, therefore an increase of stresses is expected. Nevertheless, the current reinforced alloys used for implants and abutments enhances the survival rates, and fractures of such parts are not increased in comparison to regular implants, without PS concept (Ackermann et al., 2020; C.-T. Lee et al., 2016).

Regarding the surrounding bone tissue, the findings of the present study corroborate with a recent finite element analysis, whereas the platform switching also decreased the stress on the periimplantar area.(Aslam et al., 2019). That is expected, as the migration of the implant-abutment interface toward the center of the implant, decrease the stress concentration on the outer edge of the implant platform.

The findings of the present study should be carefully considered, as this finite element analysis has the limitation of a linear analysis.(Murakami et Wakabayashi, 2014) Despite the finite element method be considered trustworthy in biomechanical research (Cervino et al., 2020) the simplification on a linear analysis with bonded contact may jeopardize the stress and strain dissipation between parts of the assembly. Nevertheless, the bonded contact between implant and bone is considered to simulate a fully Osseo integrated implant. Therefore, future studies with non-linear analysis should be performed to better understand the biomechanics involved in the simulated systems.

V. CONCLUSION

Considering the limitation of this non-linear in silico study, the following conclusions can be drawn:

1. Internal hexagon connection provided lower stress and strain magnitudes
2. The decrease of abutment diameter resulted in lower stress for cortical bone with internal or external hexagon
3. There is an important increase of stress on implant, abutment and screw when reducing the abutment diameter for both connections.

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