

Stress distribution in the transitional peri-implant bone in a single implant-supported prosthesis with platform-switching under different angulated loads

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Abstract A 3D finite element analysis was conducted to evaluate and compare the stress distribution in the peri-implant bone (transitional cortical and trabecular bone) of one single implant-supported crown with platform switching and another without platform switching, under a vertical and an oblique load. Two models were created, simulating an osseointegrated implant (4 × 13 mm, platform 4.1 mm) embedded in the jaw bone. One model simulated a 4.1-mm diameter abutment connection (conventional model) and the other a 3.8-mm diameter abutment connection (platform-switching model). A crown with a Co–Cr alloy framework and feldspathic porcelain veneering was applied over the titanium abutment. Static, vertical and oblique loads (0°, 15°, 30°, 45°) with a maximum value of 150 N were applied to the crown. For any inclination of the applied load, the stress values in the transitional cortical bone were lower in the platform-switching model than in the conventional model. However, the stress in the transitional trabecular bone was higher in

the platform-switching model than in the conventional model. Stress values increased when the load was more oblique at the transitional cortical bone in both models and was slightly reduced at the transitional trabecular bone of the conventional model. The platform-switching technique reduces the stress at the transitional cortical bone. In both models, this stress gradually increases as the load becomes more inclined. The transitional trabecular bone shows lower stress values than the transitional cortical bone. The location of stress is similar in both models.

Keywords Platform-switching · Transitional periimplant bone · Stress · Finite element analysis · Angulated load

Introduction

Oral rehabilitation with implant-supported prostheses to replace one or more teeth is a widely used technique and a predictable and safe method. However, implants and implant restorations could fail if there is progressive peri-implant bone resorption of mechanical etiology (occlusal overload), infectious etiology (peri-implantitis), or a combination of the two. In this regard, a lot of research has been carried out to determine which factors influence the conservation or resorption of the bone around implants. The results of the studies carried out, first by Gardner [1] and then by Lazzara and Porter [2], focused on the platform-switching concept as a way to prevent bone loss. This technique consists in using abutments narrower than the implant platform diameter and many biomechanical and clinical studies were published to prove the efficacy of this procedure. Most of these studies showed a reduction of crestal bone remodelling, lower peri-implant bone loss or reduced stress on the bone around the implant neck in the

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platform-switching models than in those without platform-switching [3–5]. Nevertheless, some authors have questioned the benefit of platform-switching, finding neither significant improvements in biomechanical aspects [6], nor minimal stress reduction in crestal cortical bone loss compared to implants without platform-switching [7, 8]. The dental literature also reported that the application of oblique forces, both in platform-switching and non-platform-switching models, generates higher levels and more concentrated stress [4, 7, 9, 10], increasing progressively as the load becomes more inclined [11, 12]. Regarding this, the platform-switching model reduces peri-implant bone stress in the case of an oblique load compared to a conventional model [4, 5]; however, some studies found a similar distribution of stress on cortical and trabecular bone under axial and oblique loads in both models [9]. Likewise, with the platform-switching technique, stress reduction in the periimplant bone is more evident in cortical bone than in trabecular [3, 13] compared to non-platform-switching. In contrast, another study found greater stress in the cancellous bone under oblique load in models with platform-switching than in conventional ones [5].

In addition, since the preservation of the crestal bone after loading is a very important factor for prosthetic rehabilitation success and the platform-switching concept modifies the traditional design of the abutment-implant connection, due to the importance of the transitional bone in regeneration and bone repair processes, it is necessary to test whether this technique can improve the levels and distribution of stress transferred from implant to transitional peri-implant bone and whether the stress distribution in the transitional cortical and trabecular peri-implant bone might be affected when axial and oblique loading occurs. Hence, the review of the biomechanical advantages of platform-switching is as yet incomplete and has to be clarified. Therefore, the null hypothesis states that the platform-switching technique in a single implant-supported crown decreases and improves the stress distribution in the peri-implant transitional cortical and cancellous bone when compared to a non-platform-switching model. The aim of the present study is to evaluate and to compare the stress distribution on the transitional peri-implant bone of a single implant-supported prosthesis with platform-switching under axial and different non-axial occlusal loads compared to a non-platform-switching model.

Materials and methods

Finite element model design

A 3D finite element model was created to evaluate the stress distribution on the peri-implant bone of an implant-

supported single crown. An edentulous mandibular posterior bone segment, type 2 according to the Lekholm and Zarb [14] classification, was modelled. The bone around the implant has a height of 23 mm and a width of 12 mm, simulating cortical bone and trabecular bone. In addition, due to the bone in contact with the surface of the implant undergoing processes of bone modelling and remodelling during osseointegration, in both trabecular and cortical bone we differentiated and modelled two areas in direct contact with the surface of the implant and labelled them transitional cortical bone and transitional trabecular bone. Both were 1 mm in thickness.

The geometry of the internal connection Certain Prevail Implant (Biomet 3i, Implants Innovations Inc, Palm Beach gardens, FL, USA)—body height 13 mm, diameter 4.0 mm and platform diameter 4.1 mm—was used as a reference to model a threaded implant. A finite element model simulated a 4.1-mm diameter, 5 mm-high abutment connection and gold retention screw (Gold-Tite; Biomet 3i, Implants Innovations Inc, Palm Beach gardens, FL, USA); this is the non-platform-switching model. The other finite element model simulated a 3.8-mm diameter, 5 mm-high abutment connection (Gingi Hue; Biomet 3i, Implants Innovations Inc, Palm Beach gardens, FL, USA) and gold retention screw; this is the platform-switching model. A Co–Cr alloy and porcelain-fused crown, 8 mm in height, with a buccolingual and mesiodistal diameter of 10.6 mm and an occlusal thickness of 3 mm (1 mm alloy; the veneering material varied from 1 to 2 mm from cervical to occlusal area) was applied to the titanium abutment. Although all components of a single implant-supported cemented prosthesis had been modeled, only the analysis based on the peri-implant bone stress is presented. The stress in the abutment and retention screw was reported in a previous work [15].

Material properties and interface conditions

All the materials used in these models are considered linearly elastic, homogeneous and isotropic, and the values of Young's modulus and Poisson's ratio were taken from the literature [16–21], Table 1.

It should be noted that a system made up of one or more elements is homogenous only when its properties are identical in all its parts. Furthermore, if the directional properties (such as thermal dilatation, mechanical resistance or the speed of light) are the same in all directions, it is considered to be isotropic. On the other hand, static linear models have been used in studies with finite elements and are considered reliable if the structure shows a linear relationship between tension and deformity until a level of stress known as the proportional limit is reached; this is also true if all of the elemental volume is united to

Table 1 Mechanical properties of materials and structures

Material	Structure	Young's modulus (<i>E</i>) (GPa)	Poisson's ratio (<i>v</i>)	References
Cortical bone		15.0	0.30	Stegariou et al. [16]
Trabecular bone		1.0	0.25	Natali et al. [17]
Transition cortical bone		10.0	0.25	Natali et al. [17]
Transition trabecular bone		4.0	0.25	Natali et al. [17]
Titanium	Implant	110.0	0.35	Lewinstein et al. [18]
Titanium alloy	Abutment	107.2	0.33	Suansuwan and Swain [19]
Gold alloy type III	Retention screw	100.0	0.30	Geng et al. [20]
Co–Cr alloy	Framework crown	218	0.33	Anusavice and Phillips [21]
Feldespatic Porcelain	Veneering framework crown	68.9	0.28	Geng et al. [20]

form just one. Bone is not an isotrope and does not have linear elasticity. However, it may actually be considered as being isotropic and having elasticity because it is necessary to perform certain simplifications to make the process of shaping and obtaining results possible at a reasonable computational cost.

Furthermore, the bone-implant interface was considered perfect, with 100 % osseointegration. The layer of cement between the crown and the abutment was not considered and the crown-abutment and the abutment-implant were assumed to be completely bonded with no loosening.

Loading and boundary conditions

For both models, a load of 150 N was applied to the central occlusal fossa surface of the crown and systematically varied loading directions were simulated, with a buccolingual load at 0°, 15°, 30° and 45° relative to the long axis of the implant. These angles were chosen because they make it possible to simulate the biochemical performance of truly tilted implants due to the fact that they are the ones most frequently encountered in clinics.

Von Mises stress and strain data were produced numerically, and stress distribution in the finite element models was colour-coded to compare the biomechanical differences between the conventional and platform-switching models. The finite element models representing mandibular bone segments, conventional-implant and platform-switching restorations were created and meshed using the commercial three-dimensional finite element software Ansys 11.0 (Ansys, Swanson Analysis System, Canonsburg, PA). The finite element model which simulated the conventional model was composed of 59,206 elements and 73,237 nodes, while the other finite element model, assuming a platform-switching configuration, was composed of 61,673 elements and 77,091 nodes.

Results

The present study focuses on the distribution and values of the highest stress/deformation; hence, the von Mises stress was chosen to display the results of the computations. Table 2 shows that the transitional cortical bone of the non platform-switching model displayed more stress than did the platform-switching model for any inclination of load, approximately 1.2 times in all cases. In both models the smallest stress is found when an axial load is applied; it increases progressively in a similar proportion to the increase in the inclination of the occlusal force. With an inclination of 15°, stress is twice that encountered with an axial load. At 30° it is three times more and at 45° four times more.

However, the behaviour of the stress in the transitional trabecular bone is different from that of the transitional cortical bone. The transitional trabecular bone presents the lowest value and the greatest reduction in stress transfers for any load inclination in the conventional model as compared to the platform-switching model. On the other hand, in both models, the greatest or least inclination of the load does not significantly modify stress values in the transitional trabecular bone, with a maximum difference of 0.392 MPa. However, in the conventional model, as the inclination of the load increases, stress slightly decreases; the opposite is true of in the platform-switching model.

The location and distribution of stress in the transitional cortical bone is similar in both models with axial or inclined loading. With axial loading, stress is concentrated and evenly distributed in the periphery of the crestal area of the bone next to the platform of the implant; this stress is dissipated as it moves away from the platform both vertically and horizontally. With inclined loads, stress is distributed throughout the area of crestal bone located on the opposite side to the application of the force, concentrating in the area closest to the implant platform and dissipating as it moves away, Figs. 1 and 2.

Table 2 Von Mises stresses in MPa and deformation (in brackets) in mm for periimplant bone in platform-switching and conventional models with 150 N load in all angulations

	Platform switching model				Conventional model			
	0°	15°	30°	45°	0°	15°	30°	45°
Cortical bone	39.594 (0.0063)	155.612 (0.0172)	270.063 (0.0296)	371.484 (0.0406)	36.028 (0.0059)	246.273 (0.0162)	447.792 (0.0279)	619.883 (0.0381)
Transition cortical bone	9.731 (0.0052)	19.877 (0.0082)	30.099 (0.0116)	38.405 (0.0145)	11.581 (0.0052)	23.395 (0.0083)	34.998 (0.0118)	44.384 (0.0147)
Transition trabecular bone	6.695 (0.0051)	6.897 (0.0072)	7.087 (0.0097)	6.844 (0.0117)	5.839 (0.0051)	5.513 (0.0073)	5.671 (0.0097)	5.507 (0.0118)
Trabecular bone	1.100 (0.0053)	1.085 (0.0096)	1.236 (0.0152)	1.444 (0.0202)	1.105 (0.0052)	1.088 (0.0095)	1.246 (0.0152)	1.467 (0.0201)

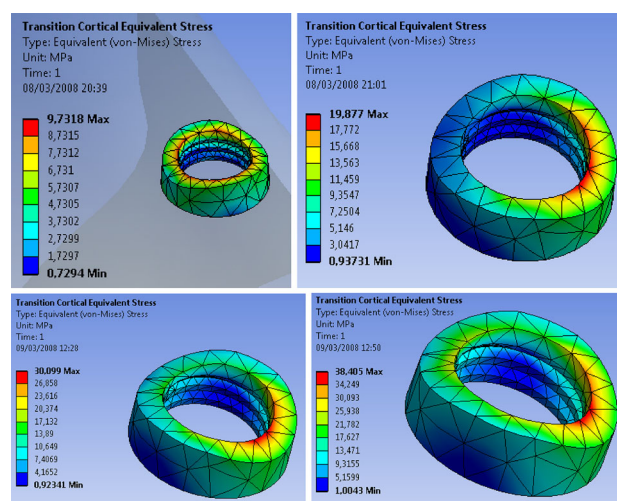


Fig. 1 Von Mises stress distribution in transition cortical bone under vertical and oblique load (0°, 15°, 30°, 45°; from top to bottom and left to right) in the platform-switching model

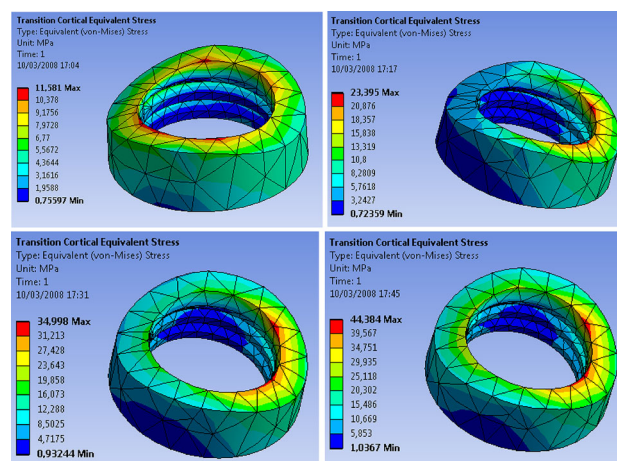


Fig. 2 Von Mises stress distribution in transition cortical bone under vertical and oblique load (0°, 15°, 30°, 45°; from above to below and from left to right) in the no platform-switching model

The location and distribution of stress in the transitional trabecular bone is different from the transitional cortical bone. In this case, with the platform-switching model subjected to an axial and to 30° and 45° inclined loads, the stress is located and concentrated in a coronal peri-implant area away from the surface of the implant and dissipates towards the apical region, where stress is also recorded. When a load inclined at 15° is applied, stress is located more in the apical region. In the conventional model, the location and distribution of stress at the transitional trabecular bone is similar to the platform-switching model, with differences of a greater area of distribution around the implant in the coronal-apical direction, for any degree of inclination, Figs. 3 and 4.

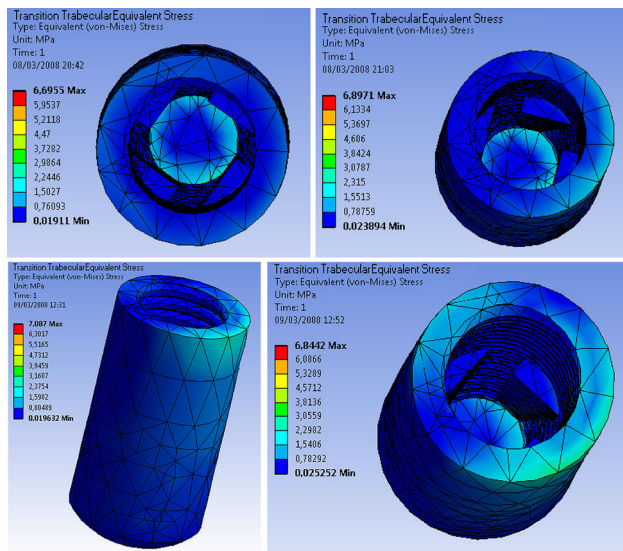


Fig. 3 Von Mises stress distribution in transition trabecular bone under vertical and oblique load (0°, 15°, 30°, 45°; from *above* to *below* and from *left* to *right*) in the platform-switching model

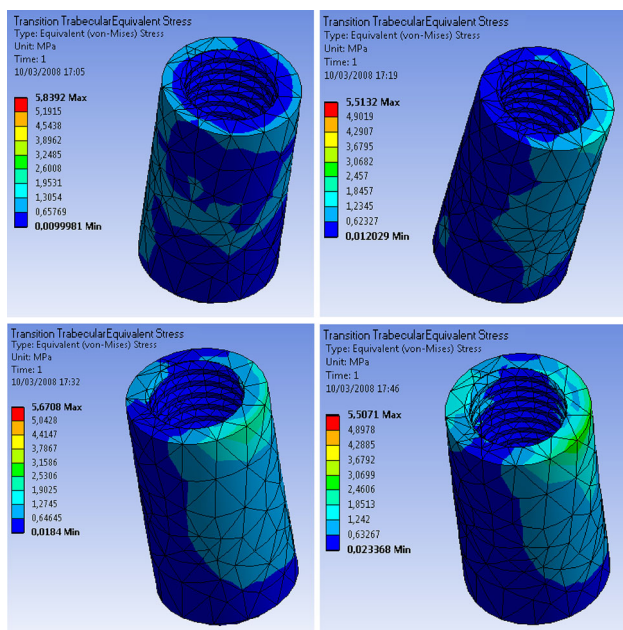


Fig. 4 Von Mises stress distribution in transition trabecular bone under vertical and oblique load (0°, 15°, 30°, 45°; from *above* to *below* and from *left* to *right*) in the no platform-switching model

Discussion

Limitations and justification of the finite element analysis model

The use of a 3D finite element analysis involves making several simplifications related to material properties,

geometry and load conditions with the result that the data obtained fail to correspond to results obtained in clinical practice. Material properties greatly influence the distribution of stress and deformation in a structure, and in this study the assumption is made that the materials are homogenous and linearly isotropic. Also, the transitional cortical bone and transitional trabecular bone in contact with the surface of the implant were differentiated from the rest of the trabecular and cortical bone. This bone-implant interface is the region of greatest clinical importance, where modelling and remodelling processes occur which lead to the maintaining or loss of surrounding bone. Perhaps the answer to assess these processes cannot be obtained by finite element analysis, because the choice of different elastic properties of peri-implant bone affects the response of the value and distribution of the stress/strain. Nevertheless, different elastic values between the surface of the implant and the surrounding trabecular and cortical bone can be considered acceptable as characteristics of bone tissue in the healing process [17, 22, 23]. In this line, although the majority of biomechanical studies with platform-switching [3–6, 13], cortical and trabecular surrounding bone were modelled with a specific Young’s modulus and Poisson’s ratio; this study chooses Young’s moduli similar to those selected by other authors [17, 23] that differentiated the cortical and transitional trabecular region from the rest of the cortical and trabecular peri-implant bone. In any case, the transitional cortical and trabecular bone of this study is the equivalent of the cortical and trabecular bone in the rest of the studies, the only difference being in thickness, volume and elastic properties, which are also a limitation for the comparison of results.

The load of 150 N is similar to the average values recorded in patients with dental implants [24, 25] and is considered normal occlusal force as it is similar to the chewing forces [25]. Nevertheless, mastication would produce complex force patterns impossible to reproduce, and even though the results of the finite element analysis carried out by applying isolated forces reflect reality very closely, clinicians must consider this limitation when discussing a clinical application of this analysis. The different inclinations of 0°, 15°, 30° and 45° relative to the long axis of the implant of the applied loads were chosen to represent the greatest possible number of realistic clinical situations. However, the dental literature, with or without platform-switching technique, reports wide variations in the direction and magnitude of the occlusal loads; this is also a limitation for the comparison of results and would require standardisation. Furthermore, the force vectors simulating the actions of the muscles of mastication, the temporomandibular joints and the cement layer were not modelled,

a fact that should be considered as an inherent limitation of this study.

Stress distribution analysis in peri-implant bone: clinical and biological implications

Data from this study show that the transitional cortical bone is subjected to greater stress than the transitional trabecular bone, regardless of load and the narrowing of the platform. Also, the influence of the platform-switching technique in stress reduction is more evident in transitional cortical bone than in trabecular bone. This is in keeping with the results of other biomechanical studies [3–5, 10, 13, 26]. Moreover, the results from clinical trials of different designs and durations [27–30] and histological assays [31, 32] confirm the good performance of platform-switching in maintaining peri-implant bone and lesser bone loss after loading, and even retrieved human platform-switching implants showed minimal peri-implant bone loss [33, 34]. Nevertheless, some clinical trials [35], and histomorphometric studies in dogs [36, 37], report no statistically significant differences in bone level changes or in peri-implant bone loss between platform-switching and conventional connection. This study also found that the stress in transitional cortical bone and in the rest of the cortical bone in the model with and without platform-switching gradually increases as the load inclination does so in relation to the long axis implant. This tendency is in accordance with that found in dental literature for the platform-switching technique [4, 5, 7, 10]. Oblique forces of 15° [7], 30° [4] or 45° [10] boost and increase the stress in the surrounding cortical bone regardless of whether the abutments are tilted or straight [10], and platform-switching reduces it compared to a conventional model. The obtained data show that the stress was lower in the platform-switching model than in the conventional one under oblique loads and slightly higher under axial load. One explanation for this result under axial load, which disagrees with that cited in other studies of platform-switching [4, 7], may be that the complex implant-abutment-crown in the model without platform-switching makes for a better distribution of the load by increasing the contact surface, the result of a lower transfer of stress to the surrounding bone. In this regard, the best biomechanical environment is for the platform-switching system to be used in unitary or partial fixed prostheses that receive loads with varying degrees of inclination.

However, the results show that stress distribution in the transitional trabecular bone is different to that of the transitional cortical bone when oblique loads are applied. While with platform-switching models stress values increase when the inclination is increased, in the conventional model stress values are slightly lower and decrease when the inclination of the load is increased so that the lowest stress is recorded with the maximum inclination

(45°). The rationale for this finding may be due to the fact that a greater implant-abutment contact surface in the conventional model leads to better distribution and greater dissipation of the stress towards the transitional trabecular bone. This is in accordance with load dispersion and transfer of support functions attributed to trabecular bone pattern creation [38]. However, more research is needed to confirm this.

Also, in both models, the stress distribution pattern in the peri-implant cortical and trabecular bone as well as the behavior when subjected to angulated loads is similar to what was related for the transitional cortical and cancellous peri-implant bone, but with much higher stress values, except those registered in trabecular bone, which are minor compared to transitional trabecular bone. These results agree with those reported in dental literature, which relates higher stress values with oblique loads [4, 7, 9–12] and also that platform-switching reduces peri-implant bone stress in the case of an oblique load compared to a conventional model [4, 5]. These results are in line with other biomechanical studies that have reported that the cortical bone shows higher stress levels than trabecular bone for any design of implant/abutment connection [3, 4, 10, 13]. This is more significant in cortical bone than in the trabecular bone compared to the conventional model when the platform-switching technique is applied [3, 13]. Regardless of other factors, these data might be linked to the 0.3-mm discrepancy between the diameter of the abutment and the platform of the implant, as biomechanical and clinical studies [26, 30, 39, 40] showed the favourable effect of the implant-abutment mismatch to stress on crestal bone. However, only with axial load, the stress values in the cortical bone are not enough to trigger a process of peri-implant bone loss, according to Frost's mechanostat theory [41]. This theory states that those values over 3000–3500 microstrains make that bone resorption predominates over the process of bone absorption/formation. Please note that the equivalence of 1 MPa is of 50 microstrains for healthy cortical bone. With any non-axial load the likelihood of the peri-implant marginal bone loss increases because the stress values in the cortical bone are higher than 3500 microstrains. Although no exact correlation exists between biomechanical simulation and the clinical reality, the dentist should forestall and avoid these loads as well as all those patient force factors that may increase the cortical bone stress (bruxism, inadequate oral habits, preferred chewing side, antagonistic arcade nature, etc.). Likewise, the recording of very low stress values in trabecular bone barely modified with angulated load is in agreement with the aforementioned cancellous bone functions [39] and would lead to less microdamage in the bone.

On the other hand, the localization of stress in the transitional cortical and trabecular bone of both models is similar, albeit with some differences between the two bone

types. These results agree with the findings concerning the localization of stress in the cortical bone in other studies of single implant-supported prostheses [4–6]. These findings indicate stress in the cortical bone surrounding the platform of the implant and adjacent to the first thread of the implant near the junction of cortical and trabecular bone and the apical area in both models [5] and with a similar stress distribution pattern under axial load and 30° [4], but with the difference that the compressive stress concentration was located on the applied load side of the models and the tensile stress concentration was on the side opposite the load application, contrary to this and others' studies [5, 6]. The differences highlighted in this study with reference to the localization of stress in the axial load compared to the inclined load in both models may be a result of the altered direction of stress flow. The localization of stress in the transitional trabecular bone by the area of the implant is similar to that found by other authors, who point out that the stress in the trabecular bone was shifted along the entire surface of the thread in the platform-switching model [5]. Further study may be necessary to evaluate the influence of stress in trabecular bone.

Conclusions

In accordance with the data obtained and within the limitations of a finite element analysis study, the following conclusions can be drawn:

1. With both axial and angulated load, the maximum transitional cortical bone stress was lower in the platform-switching model than in the conventional model. In both models, these stress values gradually increased as the load becomes more inclined.
2. For any load inclination, the transitional trabecular bone stress values were somewhat lower in the conventional model compared to the platform-switching model.
3. Regardless of the inclination of the load and of the use or not of platform-switching, the transitional trabecular bone shows lower stress values than the transitional cortical bone.
4. The platform-switching does not affect the concentration and distribution of stress on the transitional cortical and transitional trabecular bone, which are similar in both models.
5. The obtained results do not allow the stated null hypothesis to be accepted in its entirety.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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