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RESEARCH AND EDUCATION

Effect of platform switching on peri-implant bone: A 3D finite element analysis

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ABSTRACT

Statement of problem. A consensus regarding the effects of platform switching on peri-implant marginal bone levels is lacking. Finite element studies have reported contradictory results.

Purpose. The purpose of this finite element analysis study was to evaluate stress distribution in platform-switched (PS) and platform-matched (PM) implants and their surrounding bone.

Material and methods. An implant (4.5×11 mm) was modeled and screwed into a human mandibular bone block using a computer-aided design (CAD) software program. Two separate models were generated: (1) PM, 4.5-mm implant with 4.5-mm-wide abutment and (2) PS, 4.5-mm implant with 3.5-mm-wide abutment. Implant components were modeled with linear isotropic properties and bones with anisotropic properties. Vertical (200 to 800 N) and oblique (50 to 150 N) forces were applied to each model to simulate occlusal loads. Linear elastic analysis was performed using ANSYS Workbench 16. von Mises equivalent stresses in the implant assemblies and peri-implant bone were calculated and compared with independent samples *t* test (α=.05).

Results. von Mises equivalent stress values under simulated axial and nonaxial occlusal loads were lower for PM than for PS implant assemblies. However, the differences were not statistically significant. Stress within the peri-implant bone was significantly higher for the PM group than for the PS group (P<.001).

Conclusions. Platform switching decreased stress within peri-implant bone and may help limit marginal bone resorption. (J Prosthet Dent 2019;121:935-40)

Prosthodontic rehabilitation with dental implants has evolved into a predictable and highly successful treatment option.[1] The stability, and hence the survival, of dental implants depends on their ability to osseointegrate. However, the success of a dental implant cannot be assessed solely on the basis of osseointegration,[2] and preservation of hard tissues around the implant is a significant factor.[3] Peri-implant bone undergoes remodeling after implant placement and functional loading, resulting in marginal bone loss (MBL) around the implant,[4] and MBL of up to 1.5 mm during the first postoperative year has been reported.[5]

Different factors can result in peri-implant MBL, yet the phenomenon itself remains inevitable, ultimately leading to implant failure.[6] Attempts have been made to limit the extent of MBL around implants by modifying implant design and surface coatings.[7] In 2006, Lazzara and Porter[8] reported on another method of preserving peri-implant crestal bone levels named platform switching which is defined as "an act of changing an implant abutment to one with a smaller diameter, so as to place the implant-abutment interface medial to the edge of the implant platform."[9] This results in a horizontal step between the implant platform and abutment, shifting the implant-abutment junction inward toward the central axis of the implant.[10] This may reduce stress-concentration in peri-implant bone, resulting in a more favorable hard and soft-tissue response.[11,12]

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Clinical Implications

Clinicians should consider providing their patients with platform-switched dental implants to reduce the stresses transmitted to peri-implant bone. This may prevent marginal bone resorption and improve dental implant treatment outcome.

Although platform switching has been practiced for over a decade, the concept is still not completely understood, and although the concept has been the subject of numerous clinical trials, its proposed effects remain controversial.[13] Vigolo and Givani[14] compared crestal bone levels between platform-switched (PS) and platform-matched (PM) implants in a 5-year prospective clinical trial. They concluded that PS implants showed significantly less crestal bone loss. Similar results were reported by Canullo et al[15] from a randomized controlled trial that included a follow-up of the placed implants for 21 months. They reported that crestal bone levels are better maintained around PS implants. However, Enkling et al[16,17] reported no significant effect of PS on marginal bone levels at 1-year and 3-year follow-ups. A systematic review of randomized controlled trials[18] assessing the effect of platform switching on peri-implant marginal bone levels concluded that although platform switching has a positive effect in preserving peri-implant marginal bone, numerous confounders such as implant position relative to the crest of bone, implant surface characteristics, degree of implant-abutment diameter mismatch, and standardization of the data collection tools such as periapical radiographs greatly affected study quality, making interpretation of results difficult. In another systematic review and meta-analysis on platform switching,[19] a trend favoring the PS dental implants was observed. The researchers, however, reported that the published studies had an unclear or high risk of bias, requiring cautious interpretation of results, and that a need existed to evaluate the effect of platform switching by conducting well-designed research studies.

The positive effects of platform switching on peri-implant marginal bone have been attributed to reduced stress distribution in the bone.[20] This has been evaluated in a number of finite element analysis (FEA) studies. Although some studies revealed a positive impact of platform switching on stress distribution in implants and the peri-implant bone,[10,21-23] other studies reported insignificant results.[24,25] A few FEA studies have demonstrated that peri-implant bone strain is influenced more by the diameter of the selected implant rather than by platform switching.[26,27] These controversies may be ascribed to deficiencies in the FEA studies, especially to the use of oversimplified models that yield inaccurate results.[21]

A review of existing literature revealed a need to conduct well-structured research to evaluate the biomechanical effects of platform switching on peri-implant marginal bone levels.[13,18,19] Therefore, the purpose of this study was to evaluate the effect of platform switching on stress distribution in dental implants and peri-implant bone using 3D nonlinear FEA. The null hypothesis was that no difference would be found between PS and PM dental implants in terms of stress distribution in dental implant assemblies or peri-implant bone.

MATERIAL AND METHODS

Prior approval from the institute's review board was obtained to use patient-derived data. A 3D model of a human jaw bone based on a cone beam computed tomography image of a patient was designed using a computer-aided design (CAD) software program (Creo Parametric 3.0; PTC Inc). A cross section of bone, 24.2-mm high and 9-mm wide, representing the section of the mandible in the posterior (second premolar to first molar) region was designed. It consisted of a trabecular center, representing cancellous bone, surrounded by thick compact bone. An implant (4.5×11 mm) was modeled and screwed into the bone block.

Based on the diameter of the abutment, 2 separate models were generated (Fig. 1), PM, 4.5-mm implant with 4.5-mm abutment and PS, 4.5-mm implant with 3.5-mm abutment. Dental implants and prosthetic abutments were modeled using titanium alloy with linear isotropic properties. Bone, in contrast, has anisotropic properties.[28,29] To account for this behavior, cortical bone was modeled as an orthotropic material, whereas cancellous bone was modeled as transversely isotropic. Properties of implant, implant abutment, cancellous, and cortical bone have been derived from published literature (Table 1).[29,30]

An intermediate-sized mesh with tetra elements was selected for discretization of the models into finite elements. A total number of 44 208 elements and 76 150 nodes were generated. The dental implant was assumed to be completely integrated with the bone. The implant-bone assembly was constrained in the X, Y, and Z planes. Nonlinear contact zones were defined at 2 critical interfaces: the implant-abutment interface and the implant-bone interface. Cortical bone was connected to cancellous bone with a bonded contact. An insertion torque of 35 Ncm was applied to the implant, and the abutment was preloaded to 25 Ncm torque.

Occlusal loads were simulated by subjecting the implant-bone assembly to vertical and oblique forces. Vertical force (200 to 800 N) and oblique force (50 to 150 N) at an angle of 45 degrees to the long axis of the assembly were successively applied to each model. Linear elastic analysis was performed using a software program

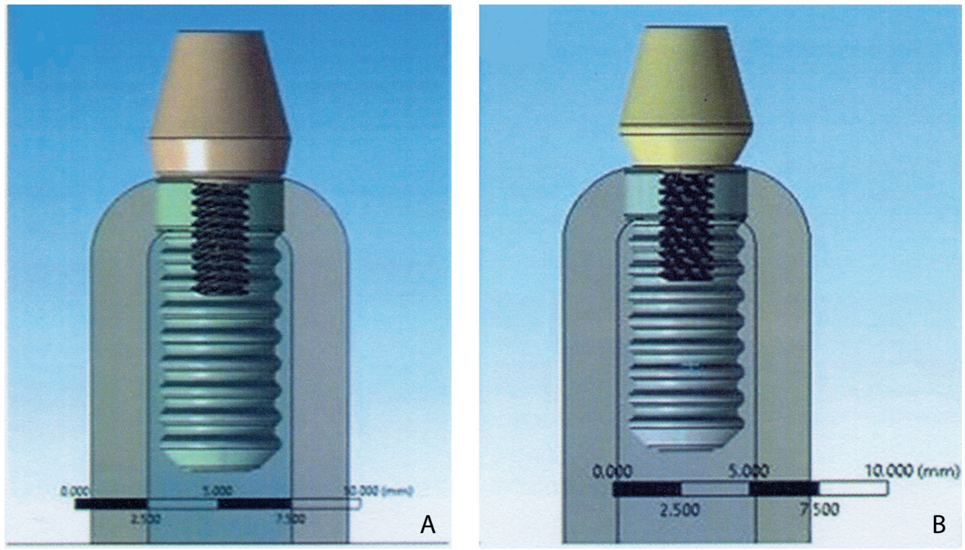

Figure 1. Study models. A, Platform-matched implant. B, Platform-switched implant.

Table 1. Physical properties of materials used

Material	Density, kg/m^3	Yield Strength (MPa)	Young Modulus (GPa)	Poisson Ratio	Shear Modulus (GPa)
Cortical bone	1500	150	E_x 12.6	ν_{xy} 0.3	G_{xy} 4.850
				ν_{yz} 0.253	
			E_y 12.6	ν_{xz} 0.253	G_{yz} 5.700
				ν_{yx} 0.3	
			E_z 19.4	ν_{zy} 0.39	G_{xz} 5.700
				ν_{zx} 0.39	
Cancellous bone	50	130	E_x 1.15	ν_{xy} 0.055	G_{xy} 0.068
				ν_{yz} 0.01	
			E_y 0.210	ν_{xz} 0.322	G_{yz} 0.068
				ν_{yx} 0.01	
			E_z 1.15	ν_{zy} 0.055	G_{xz} 0.434
				ν_{zx} 0.322	
Titanium alloy	4500	870	110	0.35	

(ANSYS Workbench 16.0; ANSYS Inc). von Mises equivalent stresses in the implant assemblies and peri-implant bone were calculated and compared with the independent samples t test (α=.05).

RESULTS

Stress generated in dental implant assemblies as a result of axial and nonaxial loads is given in Table 2. Higher stress values were seen for the PS model. However, mean stress values in dental implant assemblies did not differ significantly (P>.05). When stress within peri-implant bone was evaluated, significantly higher stress was seen in peri-implant bone surrounding the PM dental implant (Fig. 2). The mean stress in peri-implant bone surrounding both the models is shown in Table 3.

Under nonaxial loads, maximum stress in the PS model is directed along the center of the implant assembly, whereas the point of maximum stress in the PM model shifts toward the edge of the assembly, closer to the bone-implant interface. The distribution and spread of data presented in Tables 3 and 4 using a boxplot is shown in Figure 3. For the same applied loads, the strain and corresponding deformation is of a greater magnitude for the PM model, indicating probable bone resorption (Table 4).

DISCUSSION

Findings from this 3D FEA study led to the rejection of the null hypothesis. When stress in the implant assemblies was compared, higher von Mises equivalent stress values were seen for the PS model. However, mean stress values in implant assemblies did not differ significantly under axial (P=.918) and nonaxial loads (P=.211). Moreover, these values did not exceed the yield strength of titanium alloy (870 MPa). Because stress values are well within the range, even relatively higher stresses in the PS model will not cause any permanent deformation in the implant assembly. However, increased stress in the abutment may lead to abutment screw loosening unless an adequate preload torque is applied to the abutment. When stress in the peri-implant bone was evaluated, the opposite results were seen. Mean stress in the peri-implant bone was significantly higher in the PM model under both axial (P=.002) and nonaxial loads (P<.001). For the PM model, stress values approached and even exceeded the compressive and tensile yield strength of cortical bone (130 to 150 MPa). This indicates that bone will yield under such forces, resulting in resorption. Conversely, stress generated in the peri-implant bone in

Table 2. Statistical comparison of mean stress in implant assemblies of 2 study models under axial and nonaxial loading

	Mean Stress (MPa)				
	Platform-Matched Model		Platform-Switched Model		
Direction of Load	Original Data (Mean ±SD)	Transformed Data (Log10)	Original Data (Mean ±SD)	Transformed Data (Log10)	*P* (Independent Sample *t* Test) (α=.05)
Axial	178.75 ±74.70	2.13 ±0.39	188.57 ±80.09	2.14 ±0.40	.918
Nonaxial	176.15 ±18.42	2.24 ±0.07	196.27 ±25.47	2.28 ±0.08	.211

SD, standard deviation.

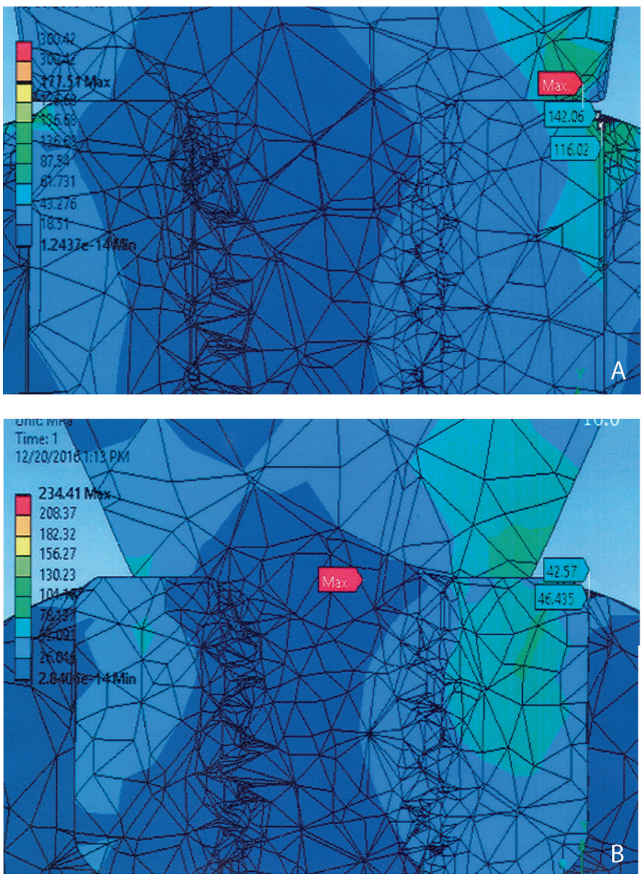

Figure 2. Stress distribution within peri-implant bone under nonaxial loads (400 N). A, Platform-matched model. B, Platform-switched model.

the PM model is well below the yield strength of cortical bone. Such a stress results in the physiological stimulation of the bone necessary to maintain the bony structure and strength.

Findings of this analysis are consistent with those of Tabata et al,[31] who carried out a 2D FEA study and reported that using regular PM implants led to increased stress both in the implant (1610 MPa) and in the bone (159 MPa). However, PS implants showed about 80% lower stress in the implant (649 MPa) and peri-implant bone (34 MPa). In another study using 3D FEA, Tabata et al[22] concluded that platform switching reduced tensile stresses up to 46.6% and compressive stresses up to 19.4% in the peri-implant bone under axial loading.

The results of the present study are also consistent with those of Liu et al,[10] Sahabi et al,[21] and Chang et al.[23] An FEA study by Pellizzer et al[25] also reported results favoring platform switching. They also reported that stresses were not only high in the PM model but were even higher if an implant was restored with a wider abutment.

Contradictory results were, however, reported by Schrotenboer et al.[11] They carried out a 2D FEA to analyze stress in peri-implant crestal bone under vertical and oblique forces. PM implants showed a von Mises stress of 28 MPa and 6.977 MPa under oblique and vertical loading, respectively, whereas PS implants showed 27.43 MPa and 6.502 MPa under the same loads. They concluded that platform switching has no significant effect in reducing peri-implant bone stress. These results may be because a static load of only 100 N was applied, which is well below the forces encountered in posterior tooth segments in the oral cavity.[32] Offset loads were applied at an angle of 15 degrees, which does not vary significantly from the vertically directed forces. Also, their study relied on a 2D simulation which oversimplifies the model, lacks details, and does not realistically simulate in vivo conditions. In addition, isotropic properties were assumed for both cortical and cancellous bones when, in effect, the bones are orthotropic and transversely isotropic, respectively.[23,28] This difference in properties alone can lead to a major difference in results.

Pessoa et al[33] compared effects of platform switching in fresh extraction sockets and healed sites. They suggested that although platform switching decreases bone strain levels in osseointegrated implants, it has no significant effect on strain levels in bone around immediately placed implants. Immediate implant placement was associated with similar bone strain levels for both PS and PM implants. This is because in immediate implant placement, bone levels are not stable, and postextraction remodeling is yet to occur and can be unpredictable. Hence, an immediate protective effect of platform switching may not be evident. In contrast, in delayed placement protocols where the alveolar bone has remodeled and become relatively stable, the protective effects of platform switching on bone can be readily seen.

The results of the present study suggest that PM assemblies are more likely to result in peri-implant MBL as a result of occlusal contact during mastication and

Table 3. Statistical comparison of mean stress in peri-implant bone around study models due to axial and nonaxial loading

	Mean Stress (MPa)				
	Platform Matched		Platform Switched		
Type of Load	Original Data (Mean ±SD)	Transformed Data (Log10)	Original Data (Mean ±SD)	Transformed Data (Log10)	*P* (Independent Sample *t* Test) (α=.05)
Axial	93.30 ±39.85	1.83 ±0.42	20.08 ±8.33	1.19 ±0.35	.002
Nonaxial	137.15 ±11.01	2.13 ±0.05	45.36 ±3.76	1.65 ±0.05	<.001

SD, standard deviation.

Table 4. Effect of load variation on strain and deformation in study models

	Strain		Deformation (10^{e-5} m)	
Load (N)	PM	PS	PM	PS
Axial				
200	0.0066	0.0012	26.63	10.46
400	0.013	0.0025	53.25	20.92
800	0.016	0.0031	66.57	26.15
Oblique				
50	0.0099	0.0041	40.66	3.61
100	0.011	0.0043	40.71	3.86
150	0.012	0.0045	40.84	4.23

PM, platform-matched; PS, platform-switched.

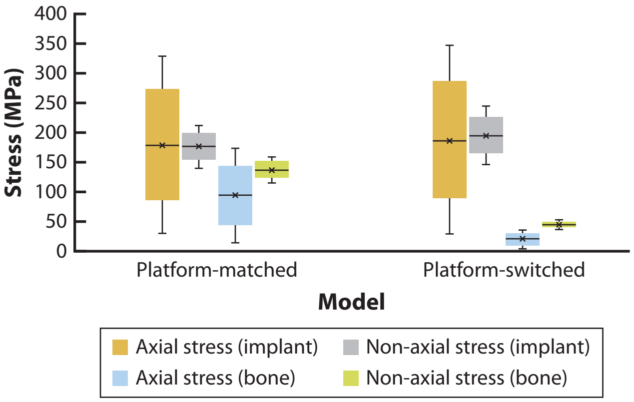

Figure 3. Spread of axial and nonaxial stress values in implants and peri-implant bone in platform-matched and platform-switched models (error bars represent the minimum and the maximum values of stress).

swallowing. Bone levels usually tend to stabilize upon reaching the first thread of the implant where the presence of threads minimizes shear stresses and increases compressive stresses.[34] Bone resorption can be further limited by designing the prosthesis to minimize loads on the implant. Therefore, platform switching has an advantage over platform matching in marginal bone preservation, but platform matching is not as detrimental as it might appear.

An effort has been made in the present study to keep it straightforward yet comprehensive. This study used a 3D rather than a 2D model for analysis, which helps simulate the oral conditions and responses more realistically. All data pertaining to material properties and model dimensions were derived from published literature; none of the values were hypothetical, which should closely replicate in vivo conditions. Analysis was performed over a range of applied loads because occlusal forces vary among individuals. Previous studies[11,23,31] usually applied a single static load below the average human occlusal force, yielding questionable results.

This study has limitations inherently associated with FEA. It did not account for anatomic or physiological variation. Occlusal loads were simulated as static not dynamic loads. The material properties attributed to cancellous and cortical bones were taken from the literature, but a lack of consensus exists regarding these properties. Mechanical properties of bone vary from person to person depending on their build, health, diet, and genetic makeup.[35] FEA gives a mathematical approximation of the problem but does not take into account ongoing biological processes. The results of the study may differ if the geometry design, material properties, or magnitude and direction of applied loads are altered.

CONCLUSIONS

Based on the findings of this 3D FEA study, the following conclusions were drawn:

1. von Mises equivalent stress and the corresponding strain in peri-implant bone were significantly lower for the PS model.
2. No significant difference was observed between PS and PM dental implants in terms of stress distribution in implant assemblies.
3. Under both axial and nonaxial loads, stress in implant assemblies did not exceed the yield strength of titanium.

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