The Effect of Placement Depth of Platform-Switched Implants on Periimplant Cortical Bone Stress: A 3-Dimensional Finite Element Analysis

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Purpose: *The purpose of this study was to evaluate periimplant bone stress distribution for platform-switched implants placed at different depths relative to the bone crest, maintaining the occlusal plane at the same level.*

Materials and Methods: *Sections of posterior mandibular bone blocks comprising cortical and cancellous bones were simulated in a computer-aided design software. A platform-switched implant was simulated and placed at 1.0 mm supracrestal to 1.8 mm subcrestal positions at 0.1 mm intervals. All bone and implant materials were presumed to be homogenous and isotropic. Conical gold crowns were designed for each model, maintaining the occlusal plane at the same level. Models were analyzed under axial and nonaxial loads.*

Results: *Cortical bone stress increased only slightly from equicrestal to 0.8 mm subcrestal positions, whereas supracrestal and deeper subcrestal positions resulted in higher stress values. Subcrestal positions showed maximum stress concentration away from crestal bone.*

Conclusion: *It can be concluded that shallow subcrestal placement of 2-stage platform-switched implants only slightly increases the stress within the cortical bone. (Implant Dent 2013;22:165–169)*

Key Words: subcrestal, equicrestal, platform switching, biomechanics

The transfer of stress from implant to the bone is a critical aspect in success or failure of an implant.[1] Crestal bone remodeling around implants after loading has been related to this stress.[2–4] Other periimplant conditions such as plaque retention,[5] biologic width formation,[6] and lack of attached gingiva[7] have been also proposed as possible factors promoting bone remodeling. Researchers have also stressed factors such as the distance from adjacent implants or teeth,[8] microgap,[9] or micromotion.[10]

It has been shown that bone remodeling is correlated with the amount of strain in the bone, which in turn is related to stress values.[11] Frost[12] stated that bone cells may trigger cytokines to begin a resorption response under a strain of 20% to 40% of which is enough for bone fracture.[13] Different methods of stress assessment have been used by researchers including application of strain gauges, photoelastic analysis, or finite element analysis (FEA).[14] These methods have shown that stress is most concentrated in crestal periimplant bone.[15] It has been proposed that increasing implant surface area by means of increasing implant diameter or changing the thread design may reduce the stress in this area.[16]

Altering the horizontal relationship between the outer edge of the implant and the smaller diameter of the abutment at the implant-abutment interface (the platform switching concept) was observed to reduce or eliminate the expected crestal bone remodeling after loading.[17] FEAs on platform-switched implants have shown stress reduction in crestal bone, which may explain the reduced resorptive response in this area.[18–22]

Another factor of interest is relative position of implant shoulder to the bone crest. Although it is not recommended to place polished surface of 1-stage implants below bone crest,[23] studies on 2-stage platform-switched implants showed that subcrestal placement may cause bone formation over the implant shoulder[24] and the periimplant bone slope around these implants in a histologic

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animal study was steeper than implants with matching abutment diameters,[25] leaving more bone height to support the papilla.[8] These studies, however, have only studied 1- to 3-month postsurgical healing periods. A study on 69 implants with nonmatching implant-abutment diameters placed 1 to 2 mm subcrestally for 9 to 20 months revealed a mean bone loss of 0.11 mm, and in 69% of implants, mineralized tissue was radiographically evident over the implant shoulder at the end of the follow-up period.[26] No controlled study was found in the literature comparing equicrestal and subcrestal implant placement.

There are few finite element (FE) studies on the effect of subcrestal placement of implants with nonmatching abutment diameters on bone stress values. Whereas Huang et al[27] have reported that equicrestal placement of implants will produce less stress in the cortical bone, Chu et al[28] found that stresses are lowest when implants are placed 0.6 to 1.2 mm subcrestally. The aim of this study was to evaluate the effect of placement depth of implants with nonmatching abutment diameters on stress distribution in the cortical bone using 3-dimensional (3D) FEA.

MATERIALS AND METHODS

A cross section of a bone block with 9 mm crestal ridge width and 32 mm vertical height was designed in the computer-aided design (CAD) software (SolidWorks 2012; Dassault Systémes, Vélizy-Villacoublay, France) based on a mandibular cone beam CT scan of a patient. The cross section was extruded 35 mm mesiodistally to form both the cancellous and the 2-mm-thick cortical layers (Fig. 1). A 4.5-mm-wide implant (Ankylos C/X B14 implant, 3101 0440; Dentsply Friadent, Mannheim, Germany) and an abutment with Morse taper connection (Regular C/abutment, G/H = 3.0 mm, 3102 4170; Dentsply Friadent) were scanned using a 3D scanner (Atos Compact Scanner; GOM mbH, Braunschweig, Germany) and modeled in the CAD software. The implant model was placed in the bone block with the implant shoulder level with the crestal ridge to form the equicrestal model. Subcrestal models were created by placing the implant model below the crestal level at 0.1 mm increments up to 1.8 mm. Supracrestal models were created by placing the implant model above crestal level at 0.1 mm increments up to 1.0 mm, to form totally 29 FE models. Implant-bone interface was assumed to have 100% osseointegration. The abutment height was reduced to 5 mm and attached to the implant using contact mode with a friction coefficient of 0.4.[29] The abutment screw was not simulated.

A conical gold alloy crown with a maximum diameter of 8 mm was designed with 1.5-mm occlusal thickness for the equicrestal model. A conical crown was designed instead of an anatomical crown because the aim was to maintain the occlusal plane and the point of force application in the same place in all models. The occlusal thickness was increased 0.1 mm for each subsequent subcrestal model and decreased 0.1 mm for each subsequent

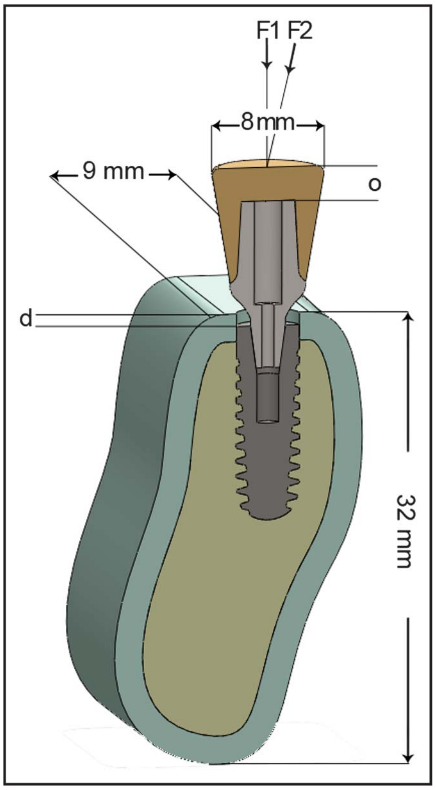

Fig. 1. Cross section of the 3D CAD model. *d*: indicates placement depth relative to the crestal ridge (positive for subcrestal positions, negative for supracrestal positions); *o*: occlusal thickness of the crown (=*d* + 1.5); *F1*: axial load (load type 1); *F2*: 15-degree angled load (load type 2). Buccal side is on the left.

Table 1. Material Properties Used in FEA

Material	Young Modulus (MPa)	Poisson Ratio
Cortical bone	13,700	0.30
Cancellous bone	1370	0.30
Titanium (implant)	117,000	0.30
Ti-6Al-4V (abutment)	110,000	0.33
Gold	100,000	0.30

Table 2. Maximum von Mises Stress Values in Cortical Bone for Different Placement Depths and Loading Types (Megapascals)

	Placement Depth*									
Loading type	–1.0	–0.9	–0.8	–0.7	–0.6	–0.5	–0.4	–0.3	–0.2	–0.1
Axial	15.9	14.9	15.7	15.3	14.8	14.3	13.8	12.5	11.8	11.7
Nonaxial	54.6	50.5	53.1	51.3	49.0	47.2	44.6	39.9	37.0	35.7
Loading type	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Axial	11.1	9.8	11.7	11.3	12.3	12.2	11.9	12.5	12.2	12.0
Nonaxial	30.8	25.3	31.0	29.5	32.8	33.8	33.7	34.5	33.6	35.3
Loading type	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	
Axial	10.9	11.9	11.8	12.6	14.0	16.6	15.2	19.3	21.5	
Nonaxial	37.0	40.3	42.4	49.8	52.0	61.6	58.8	74.8	100.0	

*Negative values indicate supracrestal position.

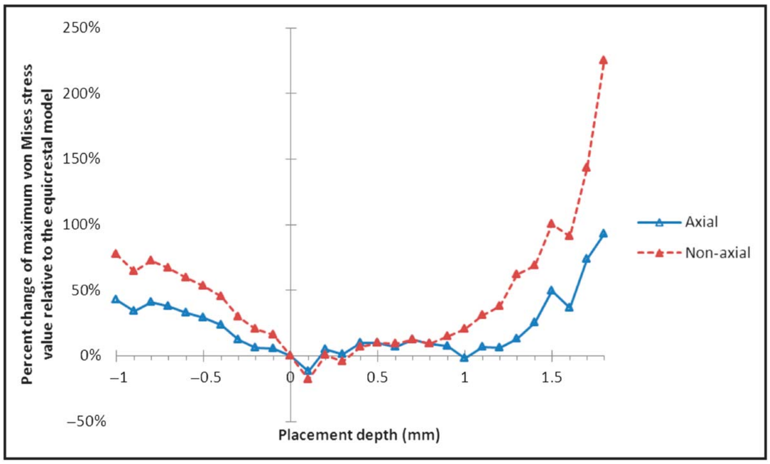

Fig. 2. Percent changes of maximum von Mises stress values in cortical bone under axial and nonaxial loading relative to the equicrestal model for different placement depths. Negative depth values indicate supracrestal position.

supracrestal model to maintain the occlusal plane at the same level. The crowns were assumed bonded to the abutments, and no cement layer was simulated. Veneering porcelain was not simulated in this study because previous studies showed no difference in the bone and implant stresses between these materials.[30]

The models were assembled using Boolean operations and transferred to FE software (Abaqus 6.10; Dassault Systémes). Mesial and distal surfaces of the bone block were constrained in all directions. A mesh size of 0.6 mm was selected for the models according to convergence tests. The meshes comprised linear tetrahedral (type C3D4) elements. Models consisted of 640209 to 668595 nodes and 519896 to 541525 elements.

The force conditions consisted of a 200 N vertical force (load type 1) and a 200 N angled force with 15 degrees lingual to buccal direction (load type 2) applied to the center of the crown occlusal surface.[22,31] All the materials were considered homogenous and isotropic. Each model was analyzed using material properties listed in Table 1 according to the literature,[32] and maximum von Mises stress values were reported.

RESULTS

Maximum von Mises stress values in the cortical bone for all placement depths under both load types were higher than the equicrestal model except for 0.1 and 1 mm subcrestal placement under axial loading and 0.1 and 0.3 mm subcrestal placement under nonaxial loading (Table 2). Figure 2 shows percent changes of stress values for different placement depths relative to the equicrestal model. Supracrestal positions increased the stress values more than corresponding subcrestal positions under both load types. Placing the implant 0.5 mm supracrestally increased the cortical bone stress 29% and 53% relative to the equicrestal position for axial and nonaxial load, respectively, whereas 0.5 mm subcrestal position resulted in a 10% increase under both load types. Subcrestal placement up to 1.2 mm under axial loading and 0.8 mm under nonaxial loading increased the stress in cortical bone only to a limited extent (on average 6.8% and 6.3%, respectively). Stress values were higher under nonaxial loading, regardless of the depth of placement.

Stress distribution patterns revealed stress concentration in buccal apical areas of the cortical bone adjacent to implant in subcrestal models under axial and nonaxial loading. Supracrestal and equicrestal positions showed stress concentration in buccal marginal bone under both axial and nonaxial loading (Fig. 3).

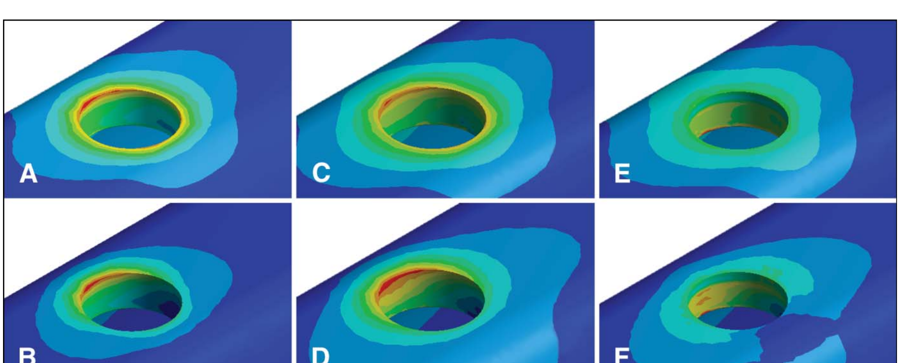

Fig. 3. Cortical bone stress distribution patterns in selected models. **A**, 0.5 mm supracrestal, axial load; **B**, 0.5 mm supracrestal, nonaxial load; **C**, equicrestal, axial load; **D**, equicrestal, nonaxial load; **E**, 0.5 mm subcrestal, axial load; **F**, 0.5 mm subcrestal, nonaxial load. Patterns are not equally scaled. Buccal side is on the left.

DISCUSSION

FEA has been used widely in studies on the biomechanical performance of implant designs as well as the effect of clinical factors on implant success or failure.[9,15,31,33–35] FEA is only an approximation of the real situation, and the results should be evaluated in light of experimental and clinical data. However, it is a good method to estimate strain/stress values within the bone, although the strain gauges are only sensitive to surface strains. The information about stress distribution and magnitude within the bone can contribute to the optimization of the implant design and insertion techniques.[33]

The results of the current study revealed that periimplant cortical bone stress increased by placing the implant either below or above the bone crest. This is in accordance with Huang et al[27] who also showed that this increase is more prominent in supracrestal positions. In contrast, Chu et al[28] stated that cortical bone stress values decreased by increasing the placement depth. They did not simulate any superstructure, and the force was applied to the abutment. A major difference between this study and those mentioned above is the position of the occlusal plane. If a decision is made to place an implant subcrestally, then the occlusal plane will not be changed, and hence, the lever arm from the point of force application to the bone-implant contact will increase, which is not favorable regarding bone stress. Our results showed that although the occlusal plane was maintained in the same position in different models, the stress increased slightly from 0.2 to 0.8 mm subcrestal positions. This suggests that if any biologic benefits are to be obtained from subcrestal placement, as claimed by some studies,[8,25,26] placing the implant less than 1 mm subcrestally in a 2-mm-thick cortical bone will not increase the stress dramatically. This is also promoted by the fact that maximum stress concentration in subcrestal positions occurred in apical areas of cortical bone, which may imply a mechanism for marginal bone preservation. It should be noted, however, that any comparison between the current study and similar studies[27,28] should be made cautiously due to different models and loading conditions.

In agreement with many other studies,[31,35–37] the results also showed that loading angle was a critical factor for stress distribution. The maximum stress values were higher in models under nonaxial load than models under axial load, which can be described by a larger bending moment that increased stress compared to that generated by axial load.

The current study did not simulate different cortical bone thickness. Cortical bone thickness has been shown to affect the stress distribution and values in alveolar cortical bone,[38] and the effect of placement depth in different cortical bone thickness should be evaluated to outline better clinical situations and procedures.

Conclusions

Within the limitations of this 3D FEA, the following can be concluded:

1. Maximum von Mises stress values within cortical bone adjacent to platform-switched implants increase in both supracrestal and subcrestal positions relative to the equicrestal position.
2. The expected increase in subcrestal placement depths up to 0.8 mm is less than 10% relative to the equicrestal position.
3. Supracrestal placement of the platform-switched implant results in more increased stress values compared to corresponding subcrestal positions.
4. Cortical bone is more stressed under lateral loads than axial loads.

Disclosure

The authors have no direct or indirect financial interest in any products/brands used or named in this study.

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