Biomechanical Evaluation of Stress Distribution in Subcrestal Placed Platform-switched Short Dental Implants in D4 Bone: In Vitro Finite-element Model Study

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Abstract

The present study was carried out to assess stress distribution in the maxillary posterior bone region (D4 bone) with the help of a short platform switched subcrestal dental implants using the FEM model. Missing teeth surfaces related to the maxillary posterior region were stimulated. The bone model had a cancellous core of (0.5mm) which represents D4 bone. A 7.5x4.6mm screw type implant system with 3.5 platform switch abutment was selected. ANSYS WORKBENCH was used to model all the finite element structures. Force of 100 N was tested and adapted at an angle of 0º, 15º, 30º on the tooth model. Overall results from the current study showed that a high amount of stress was seen in cortical than in relation to cancellous bone. Stress values reduced from equicrestal to subcrestal (2mm) placement of dental implants irrespective of angulation of load from 0o to 30o in both types of bone. However higher stress values were seen when force was applied in an oblique direction (30o) in comparison to a vertical load (0o). Least amount of stress was noticed when platform switched implants were placed 0.5mm subcrestatlly irrespective of angulations of a load. Platform switched short subcrestal implants reduced the stress in the D4 cortical bone than in contrary equicrestal implant placement. This results in the preservation of marginal bone leading to implant success.

Keywords: FEM, subcrestal, equicrestal, platform switched implants, short implants

Introduction

Replacement of missing teeth with osseous integrated dental implants has become a regular practice in the current clinical setup. With an improvement in science and technology, a high success rate of approximately 90% has been reported.[1-3] In spite of the high success rate, crestal bone loss has been a concern for many clinicians.[4,5] In the past, 1.5 mm bone loss in the crestal region in the early years and 0.2 mm in the next consequent years were considered normal.[6,7] However in regions with poor bone quality, losing that vital bone with reduced bone height is of major concern. Thus, variation in surgical technique (subcrestal placement) and implant designs (platform switching, short wider diameter) have been planned for the preservation of crestal bone.[8,9]

Authors have reported three different kinds of stress observed at any bone-implant boundary. They comprise compressive, tensile, and shear stress. Literature reveals improved bone density with compressive stress; on the contrary, tensile and shear stress diminish bone density with shear stress being less helpful. It is the macroscopic implant design that has significance to influence stress distribution on the adjacent bone.[10,11]

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Short and wider diameter dental implants have been used in the past with various amounts of success rate. Clinically short and wider diameter implants have been used in posterior maxillary and mandible region with reduced bone height. Short implants were indicated to avoid additional bone augmentation procedures with reduced bone height. Short implants are used in posterior maxilla owing to changes in surface topography, new surgical techniques thereby improving contact ratio between bone and implant, which in turn reducing stress at the crestal region.[12-14] Previous concept stresses on the need for implant length as it leads to increase in primary stability by increasing in bone to implant contact (BIC).[15-17] but the latest concept is increase in functional surface area (FSA) that could be obtained by short and wider dental implants that result in better distribution of compressive and tensile stress owing to its FSA.[18,19]

Platform-switching concept was introduced way back in 1991 to effectively reduce circumferential bone loss with an added advantage of better acceptance by both adjacent hard and soft tissues.[20-22] As a result, this technique could be used in the esthetic zone. Currently, we do not have enough data with regard to platform switch and subcrestal dental implant placement, which lead us to carry out this experiment.

Three-dimensional (3D) finite-element model (FEM) is a mathematical model used to evaluate stress distribution in dental implants as well as the shrouding bone. FEM has become a vital instrument in evaluating bone to implant boundary with mechanical load application. It is a computerized 3D model that has added advantages as compared to other models in implant dentistry.[23] Hence, owing to limited information concerning the effect of platform-switched short implants and subcrestal placement, this study was carried out to estimate the influence of platform-switched subcrestal short dental implants on stress distribution in the D4 bone using FEM model. To test null hypotheses, we assume that (1) no difference exists in stress distribution between platform-switched short implants when placed equicrestally and subcrestally and (2) stress distribution is not governed by the angulation of load.

**Materials and Methods**

Missing teeth surfaces related to maxillary posterior region were stimulated. The bone model had a cancellous core of 0.5mm, which represents D4 bone. Diameters of implant length, implant body, and implant platform are 7.5, 4.6, and 3.5 mm, respectively. ANSYS Workbench version 17.5 was used to model all the finite-element structures. Regarding material properties, all materials used in this study were isotropic, homogeneous, and linearly elastic. Literature search was done concerning elastic properties[24,25] [Table 1]. Loads of 100 N were tested at an angle of 0º, 15º, and 30º. Center of the abutment was area where force was applied. The parameters analyzed were von Mises stress.

**RESULTS**

Following results were obtained through FEM. Force of 100 N was applied in axial and oblique direction at the center of the occlusal surfaces. The mean and standard deviation values of maximum principal stress on buccal and lingual surfaces of cortical and cancellous bone are shown in Figures 1 and 2. Table 2 represents the maximum von Mises stress in cortical and cancellous bone. The overall stress distribution is greater in cortical bone than in the cancellous bone [Figure 3]. Stress values reduced from equicrestal to subcrestal (2 mm) placement of dental implants irrespective of angulation of load from 0º to 30º in both types of bone [Figure 4]. However, higher stress values were seen when force was applied in an oblique direction (30º) in comparison to a vertical load (0º).

**Table 1: D4 bone mechanical properties as well as materials used in finite-element model analysis**

| S.No | Material        | Young’s Modules (MPa) | Poisson’s Ratio |
|------|-----------------|-----------------------|----------------|
| 1    | Cortical bone   | 13.700 (GPa)          | 0.30           |
| 2    | Cancellous bone | 1.10 (GPa)            | 0.30           |
| 3    | Pure Titanium   | 110000 (MPa)          | 0.33           |
| 4    | Titanium alloy  | 114000 (MPa)          | 0.30           |

**Figure 1:** The von Mises stress (MPa) in cortical bone under force of 100N in vertical (0c) and oblique (15c and 30c) direction in implants placed at equicrestal or subcrestally
Least amount of stress was noticed when platform-switched implants were placed 0.5 mm subcrestally irrespective of angulations of a load [Figure 3].

**DISCUSSION**

Stress distribution around endosseous dental implants and the supporting bone were closely pertinent to the angulations of load and placement of platform-switched short dental implants either equicrestal or subcrestal. To precisely animate and design the stress state of bone and dental implants, three different angulations of load and five types of implant positions in bone have been considered. To the best of our knowledge, this is the first report to analyze subcrestal or equicrestal platform-switched short dental implant and FEM. This study also centered on the collective outcome of platform-switched short and subcrestal dental implants on stress distribution in the cortical and cancellous bone under the force of 100 N at three different angulations. We believe this approach safeguards the crestal bone that intern prevents implant expose and peri-implantitis.

Our results show that stress distribution in cortical and cancellous bone under similar loading conditions was greater when the angulations of forces shifted from 0° to 30° (from vertical to oblique force). This is due to the increased load transfer to the bone in an oblique manner. The von Mises stress values in cancellous bone under 100 N are given in Table 2. The maximum stress concentrations in cortical and cancellous bone when load of 100 N applied in vertical and oblique direction when implants placed at 0.5 mm subcrestally are shown in Figure 3.

| Angulations of force | Cortical Bone | Cancellous Bone |
|----------------------|---------------|-----------------|
|                      | Equicrestal   | 0.5mm | 1mm | 1.5mm | 2mm | Equicrestal   | 0.5mm | 1mm | 1.5mm | 2mm |
| 0c                   | 11.98         | 10.5  | 11.53| 11.47 | 11.24| 2.81         | 2.6   | 2.8  | 2.46 | 1.74 |
| 15c                  | 22.67         | 15.82 | 21.03| 20.99 | 19.34| 3.19         | 2.68  | 2.61 | 2.48 | 1.91 |
| 30c                  | 31.82         | 22.57 | 29.54| 29.5  | 27.27| 3.78         | 3.05  | 2.9  | 2.82 | 2.49 |

*Figure 2:* The von Mises Stress (MPa) in cancellous bone under force of 100 N in vertical (0c) and oblique (15c and 30c) direction in implants placed at equicrestal or subcrestally

*Figure 3:* Maximum stress concentrations in cortical and cancellous bone when load of 100 N applied in vertical and oblique direction when implants placed at 0.5 mm subcrestally
mainly because vertical forces distribute the stress more uniformly along the implant length and to the adjacent bone. On the contrary, oblique load creates shear forces and lateral movements on the implant, thus leading to more stress on the surrounding bone.[29,30]

In comparison with equicrestal to subcrestal [Figure 3], platform-switched short dental implants, the cortical bone showed less stress concentration at 0.5 mm subcrestally irrespective of angulations of force applied.[26] Also, cortical bone showed overall stress reduction when short dental implants were placed subcrestally [Figure 4]. This is largely due to the opinion that cortical bone is responsible for the distribution and transmission of occlusal forces to the adjacent bone.[31] A secondary reason is based on the mechanism of stress principle that is whenever two different materials are placed together and when a load is applied on one (implant), we can observe stress concentration where the two materials first come in contact.[32] In this case, it would the cortical bone. Other reason could be, short wider diameter implants have better stress distribution as it improves implant strength and fracture resistance at the bone crest.[18,33-35] However, in the cancellous bone least stress reduction was observed at 2 mm when short implants placed subcrestally regardless of angulations of force applied.[36] Mainly attributed to cancellous bone lesser elastic modulus, bone implant contact (BIC) and implant are placed 2 mm below the crest. Furthermore, the apex of the implant exhibits maximum stress in the cancellous bone in comparison with cortical bone.[37] The results of this study coincide with other studies that short dental implants affect the peak stress concentration in the cancellous bone as stress values are influenced by implant length.[38,39] Short and subcrestal dental implants have similar survival rate to regular implant, but the marginal bone loss was lower in short dental implants.[40] Although platform switch and insertion depths are two independent variables for the marginal bone loss, its synergistic effect can be effective in minimizing crestal bone loss by reducing inflammatory infiltrate and increasing implant–abutment interface from the marginal bone. All of which could be helpful in clinical scenario.[41,42]

**Conclusion**

Within the limitations of this study, designs mimicking bone and implants have considered measuring peri-implant bone stress. However, till date there is no evidence on the level of stress at which bone remodeling ends and resorption begins. Platform-switched short subcrestal implants reduced stress in the cortical bone as compared with equicrestal implant placement. This results in preservation of marginal bone leading to implant success. Further studies need to assess the critical stress value that leads to bone resorption.

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**Figure 4:** Maximum stress concentrations in cortical and cancellous bone when load of 100 N applied in vertical and oblique direction when implants placed at 2 mm subcrestally.
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Conflicts of interest
There are no conflicts of interest.

REFERENCES
1. Howe MS, Keys W, Richards D. Long-term (10-year) dental implant survival: a systematic review and sensitivity meta-analysis. J Dent 2019;84:9-21.
2. Oh SL, Shiau HJ, Reynolds MA. Survival of dental implants at sites after implant failure: a systematic review. J Prosthodont 2020;12:54-60.
3. Moraschini V, Poubel LA, Ferreira VF, Barboza Edos S. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: a systematic review. Int J Oral Maxillofac Surg 2015;44:377-88.
4. Nayak R, Devanna R, Dharamsi AM, Shetty J, Mokashi R, Malhotra S. crestal bone loss around dental implants: platform switching vs platform matching-A retrospective study. J Contemp Dent Pract 2018;19:574-8.
5. Prasad DK, Shetty M, Bansal N, Hegde C. Crestal bone preservation: a review of different approaches for successful implant therapy. Indian J Dent Res 2011;22:317-23.
6. Nagarajan B, Murthy V, Livingstone D, Surendra MP, Jayaraman S. Evaluation of crestal bone loss around implants placed at equicrestal and subcrestal levels before loading: a prospective clinical study. J Clin Diagn Res 2015;9:ZC47-50.
7. Dannan A. Crestal bone loss around dental implants; a short communication. Internet J Dent Sci 2012;10:1-4.
8. Rastelli C, Falsi G, Gatto R, Galli M, Saccone E, Severino M, et al. Implant stability in different techniques of surgical sites preparation: an in vitro study. Oral Implantol (Rome) 2014;7:33-9.
9. Ramasamy M, Giri, Raja R, Subramanian, Karthik, Narendrakumar R. Implant surgical guides: from the past to the present. J Pharm Bioallied Sci 2013;5:S98-S102.
10. Udomsawat C, Rungsiyakull P, Rungsiriyakull C, Khongkhumthan P. Comparative study of stress characteristics in surrounding bone during insertion of dental implants of different thread designs: a three-dimensional dynamic finite element study. Clin Exp Dent Res 2019;5:26-37.
11. Oflahed R, Perez-Viloria M, Villa-Camacho JC, Vaziri A, Nazarian A. Biomechanics and mechanobiology of trabecular bone: a review. J Biomech Eng 2015;137:0108021-215.
12. Karthikeyan I, Desai SR, Singh R. Short implants: a systematic review. J Indian Soc Periodontol 2012;16:302-12.
13. Annibali S, Cristalli MP, Dell’Aquila D, Bignozzi I, La Monaca G, Pilloni A. Short dental implants: a systematic review. J Dent Res 2012;91:25-32.
14. Neldam CA, Pinholt EM. State of the art of short dental implants: a systematic review of the literature.Clin Implant Dent Relat Res 2012;14:622-32.
15. Kang SW, Lee WJ, Choi SC, Lee SS, Heo MS, Huh KH, et al. Volumetric quantification of bone-implant contact using micro-computed tomography analysis based on region-based segmentation. Imaging Sci Dent 2015;45:7-13.
16. Lian Z, Guan H, Ivanovski S, Loo YC, Johnson NW, Zhang H. Effect of bone to implant contact percentage on bone remodelling surrounding a dental implant. Int J Oral Maxillofac Surg 2010;39:690-8.
17. Himanshu P, Chandrasekharan NK, Shivangi S. Bone implant contact and its relationship with strain in the surrounding bone. J Interdiscip Dent 2018;8:102-9.
18. Shetty S, Pathak N, Bhat SV, Shenoy KK. Short implants: a new dimension in rehabilitation of atrophic maxilla and mandible. J Interdiscip Dent 2014;4:66-70.
19. Misch CE. Implant design considerations for the posterior regions of the mouth. Implant Dent 1999;8:376-86.
20. Rasouli-Ghahroudi AA, Geramy S, Yaghobee S, Khorsand A, Youssefikahr H, Rokn A, et al. Evaluation of platform switching on crestal bone stress in tapered and cylindrical implants: a finite element analysis. J Int Acad Periodontol 2015;17:2-13.
21. Salimi H, Savabi O, Nejatidinesh F. Current results and trends in platform switching. Dent Res J 2011;8:530-6.
22. Palacios-Garzón N, Velasco-Ortega E, López-López J. Bone loss in implants placed at subcrestal and crestal level: a systematic review and meta-analysis. Materials 2019;5:12.
23. Gaviria L, Salcido JP, Guda T, Ong JL. Current trends in dental implants. J Korean Assoc Oral Maxillofac Surg 2014;40:50-60.
24. O’Brien WJ. Dental materials and their selection. 2nd ed. Chicago, IL: Quintessence; 2002. p. 347.
25. Yang HS, Lang LA, Molina A, Felton DA. The effects of dowel design and load direction on dowel-and-core restorations. J Prosthodont 2001;85:558-67.
26. Soto-Maior BS, Lima Cde A, Senna PM, CamargosGde V, Del BelCury AA. Biomechanical evaluation of subcrestal dental implants with different bone anchorages. Braz Oral Res 2014;28:1-7.
27. Huang CC, Lan TH, Lee HE, Wang CH. The biomechanical analysis of relative position between implant and alveolar bone: finite element method. J Periodontol 2011;82:489-96.
28. de Faria Almeida DA, Pellizzer EP, Verri FR, Santiago JF Jr, de Carvalho PS. Influence of tapered and external hexagon connections on bone stresses around tilted dental implants: three-dimensional finite element method with statistical analysis. J Periodontol 2014;85:261-9.
29. Moraes SLD, Verri FR, Santiago JF Jr, Almeida DAF, LemosCAA, Gomes JML, et al. Three-dimensional finite element analysis of varying diameter and connection type in implants with high crown-implant ratio. Braz Dent J 2018;29:36-42.
30. Shamami DZ, Karimi A, Beizadeh B, Derakhshan S, Navidbakhsh M. A Three-dimensional finite element study to characterize the influence of load direction on stress distribution in bone around dental implant. J Biomat Tissue Eng 2014;4:1-7.
31. Bagli L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. J Prosthodont 2008;100:422-31.
32. Von Recum A, editor. Handbook of biomaterials evaluation: scientific, technical and clinical testing of implant materials. New York, NY: MacMillan; 1986.
33. Himmliová L, Dostalová T, Kácovký A, Konvicková S. Influence of implant length and diameter on stress distribution: a finite element analysis. J Prosthodont 2004;91:20-5.
34. Misch CE, Bidez MW. Contemporary implant dentistry. 2nd ed. St. Louis, MO: Mosby; 1999.
35. Petrie CS, Williams IL. Comparative evaluation of implant designs: influence of diameter, length, and taper on strains in the alveolar crest. A three-dimensional finite-element analysis. Clin Oral Implants Res 2005;16:486-94.
36. Dundar S, Topkaya T, Solmaz MY, Yaman F, Atalay Y, Saybak A, et al. Finite element analysis of the stress distributions in peri-implant bone in modified and standard-threaded dental implants. Biotechnol Biotechnol Equip 2016;30:127-33.

37. Danza M, Palmieri A, Farinella F, Brunelli G, Francesco Carinci F, Ambra Girardi A, et al. Three-dimensional finite element analysis to detect stress distribution in spiral implants and surrounding bone. Dent Res J 2009;6:59-64.

38. Moraes SLD, Verri FR, Santiago JF Junior, Almeida DAF, Lemos CAA, Gomes JML. Three-dimensional finite element analysis of varying diameter and connection type in implants with high crown-implant ratio. Braz Dent J 2018;29:36-42.

39. Bozkaya D, Muftu S, Muftu A. Evaluation of load transfer characteristics of five different implants in compact bone at different load levels by finite elements analysis. J Prosthet Dent 2004;92:523-30.

40. Uehara PN, Matsubara VH, Igai F, Sesma N, Mukai MK, Araujo MG. Short dental implants (≤7mm) versus longer implants in augmented bone area: a meta-analysis of randomized controlled trials. Open Dent J 2018;12:354-65.

41. Alonso-González R, Aloy-Prósper A, Peñarrocha-Oltra D, Peñarrocha-Diago MA, Peñarrocha-Diago M. Marginal bone loss in relation to platform switching implant insertion depth: an update. J Clin Exp Dent 2012;4:e173-9.

42. Mezzomo LA, Miller R, Triches D, Alonso F, Shinkai RS. Meta-analysis of single crowns supported by short (<10mm) implants in the posterior region. J Clin Periodontol 2014;41:191-213.