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Original Article

3-Dimensional finite element analysis of stress distribution of dental implants on the bone tissue around the neck region of the implant and on the implant surface with respect to bone density

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Abstract

Aim: The aim of this study was to investigate the maximum Von Misses stress values of implants with different diameters in patients with different bone densities depending on the forces that are applied with different angles to the bone around the implant neck and implant surface, by using finite element analysis method.

Material and Methods: 3.8 mm and 4.6 mm diameter dental implants of an implant system that had an in vitro laser-microtextured neck design were used in this study. Computational models were generated for implants with different diameters which were placed in the maxillary and mandibular 1st molar teeth using flat and oblique (20° angled) abutments. Vertical and oblique (30° angled) forces of 300 N were applied to all models and the results were evaluated by finite element analysis.

Results: The results show that both vertical and oblique forces on the implants and placement of abutments in the flat and oblique position caused tension in the bone around the neck of the implant and the implant surface. When the oblique and vertical loads applied to the bone models were compared, the forces applied in the oblique direction exhibited a significant increase of Von Misses stress values in the cortical bone around the crest module of the implant compared to the other group. In our study, the minimum stress distribution with respect to the direction of the applied forces and placement positions of the abutments was obtained by applying the implant and the force in the same direction (abutment straight, force vertical). However, in the groups with the angled application of the force direction and the angled placement position of the abutments, the maximum Von Misses stress value increased in the bone around the implant neck and implant surface.

Conclusion: Placing the implants at the right angle and within bone tissues with adequate cortical bone density around the implant will ensure minimal stress values on both the supporting bone and the implant surface.

Keywords: Bone density; dental implant; finite element stress analysis; stress distribution

INTRODUCTION

The success of a dental implant is determined by the amount of tension applied to the surrounding bone. Many biomechanical factors have been identified for the long- and short-term success of the commonly used dental implants (1,2). Although the success rate of these implants is known to depend on the density and quality of the jaw bone, implant design, surface structure and surgical procedures, the importance of biomechanical factors on long-term success of implants is indisputable (2,3).

Several modifications have been made to the implants to increase the crestal bone levels and reduce its loss. One of these is to create a micro-turing ablated, micro-cavity containing implant surface on the neck of the implant by laser-microtexturing. The widths of these microcavities range between 8-12 µm (micrometer). Direct contact of connective tissue with the implant neck must be promoted in order to reduce the crestal bone loss by preventing epithelial tissue withdrawal (4).

Clinically, it has been shown that probing depths and crestal bone losses of the implants with laser-microtextured micro-cavities on the neck are lower than those of control implants with polished coronal parts (5,6).

Finite element analysis (FEA) is a method that evaluates stress, tension and distortion in structures. The FEA

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method is performed by dividing structures with complex geometry into a number of smaller elements that show similar characteristics to the original model (7,8). In oral implantology, FEA method allows researchers to interpret the stress distribution between the dental implants and bone (9).

In the present study, we evaluated the stress distributions of two implants of an implant system with different diameters on the crestal bone around the implant neck and on the implant surfaces by using the FEA method.

MATERIAL and METHODS

Laser-microtextured implants (Tapered Internal Laser-Lok, Biohorizons®, USA) which are 3.8 mm or 4.6 mm in diameter and 10.5 mm in length were used with two types of abutments (20° angle (oblique) or straight). In order to eliminate the effects caused by uneven deformation in each region during modeling, images obtained through MR or CT devices may be utilized (10). Thus, we also utilized CT images for this purpose. Rhinoceros 4.0 software was used to transfer the CT images to the computer. First, upper and lower jaw bones that are 20 mm in height, 30 mm in mesiodistal length and 10 mm in buccolingual width were modeled (Figure-1a, b). In this model, a cortical bone that was 2 mm thick in the mandible and 1 mm thick in the maxilla was integrated. The inner surface of the cortical bone was defined as spongy bone. Maxillary and mandibular bone models in which the implants will be placed were designed, scanned with the Next Engine 3D laser scanner (NextEngine Inc., Santa Monica, California, USA), and endosteal implants, abutments (straight and 20° angled) and prosthetic upper-structures have been transformed into a 3D solid model by using the Rhinoceros 4.0 software (Mc Neel & Associates, Seattle, USA).

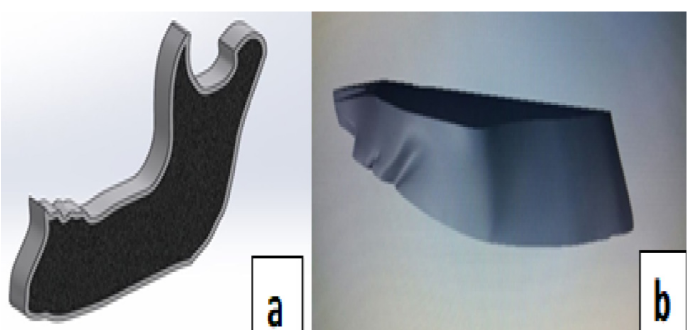


Figure 1. a: 3D bone model of mandible b: 3D bone model of maxilla

By mimicking centric occlusion; a total of 300 N (Newton) force was applied as 100 N forces to each palatinal tubercle, and mesial and distal fossa of the 1st molar tooth of the maxillary both vertically (Figure 2a) and obliquely with a 30º angle. Similarly, a force of 300 N (100 N each) was applied to the buccal tubercle and mesial and distal fossa of the 1st mandible molar tooth in a vertical (Figure 2b) and oblique direction and a total of 16 models were obtained (Table 1).

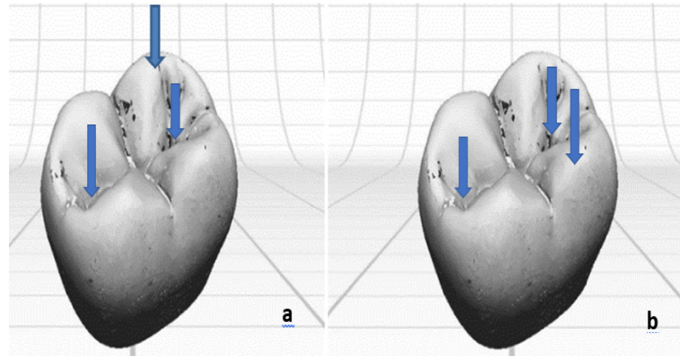


Figure 2. a: Application points of 3-dimensional images and forces obtained by scanning maxillary 1st molar teeth b: Application points of 3-dimensional images and forces obtained by scanning mandibular 1st molar teeth

Table 1. Total experimental groups and conditions

Models	Implant	Implant Diameter	Abutment Angle	Force Direction	Bone Type
Model 1	Laser-Lok	3.8 mm	straight	vertical	maxilla
Model 2	Laser-Lok	3.8 mm	straight	30 angled	maxilla
Model 3	Laser-Lok	3.8 mm	20 angled	vertical	maxilla
Model 4	Laser-Lok	3.8 mm	20 angled	30 angled	maxilla
Model 5	Laser-Lok	3.8 mm	straight	vertical	mandible
Model 6	Laser-Lok	3.8 mm	straight	30 angled	mandible
Model 7	Laser-Lok	3.8 mm	20 angled	vertical	mandible
Model 8	Laser-Lok	3.8 mm	20 angled	30 angled	mandible
Model 9	Laser-Lok	4.6 mm	straight	vertical	maxilla
Model 10	Laser-Lok	4.6 mm	straight	30 angled	maxilla
Model 11	Laser-Lok	4.6 mm	20 angled	vertical	maxilla
Model 12	Laser-Lok	4.6 mm	20 angled	30 angled	maxilla
Model 13	Laser-Lok	4.6 mm	straight	vertical	mandible
Model 14	Laser-Lok	4.6 mm	straight	30 angled	mandible
Model 15	Laser-Lok	4.6 mm	20 angled	vertical	mandible
Model 16	Laser-Lok	4.6 mm	20 angled	30 angled	mandible

The implants were placed symmetrically on the bone models and were assumed to be 100% osseointegrated into the bone models. In order to obtain optimum results, elastic modules and Poisson ratios of all materials to be used (cortical and spongy bone, titanium implants, chromium-cobalt alloy, feldspathic porcelain, polycarboxylate cement) were entered to the computer model as shown in Table 2 (11-15). Then, FEA results were evaluated and interpreted using ANSYS 14.0 (ANSYS Inc., Canonsburg) program on a computer (ASUS Intel Core i7; Asus Computer International, Fremont, CA, USA).

Table 2. Material properties

Material	Elasticity modulus (Gpa)	Poisson ratio
Implant&Abutment	11.5	0.342
Cortical bone	13.7	0.3
Spongy bone	1.1	0.3
Feldspathic porcelain	82.8	0.35
Cr- Co alloy	218	0.33

The reason that we used two bone models with different densities was to see how the stress distribution in the implants with different diameters occurs in the bone around the implant neck and surface with respect to the forces applied at different angles and to analyze the bone resorption depending on the stress distribution.

RESULTS

Laser-pretextured implants that were 3.8 mm and 4.6 mm in diameter (Tapered Internal Laser-Lok, Biohorizons®, USA) were placed in the maxilla and mandible at different positions and force was applied at different angles. The maximum Von Misses stress values were calculated when the implant abutments were placed at an angle of 20° and when the force was applied at 30° oblique angle. These values were 67.10 MPa in the maxillary bone (crest module) around the implant neck in the application of an implant with a diameter of 3.8 mm, 57.72 MPa in the case of application of an implant with a diameter of 4.6 mm. In the mandible, the 3.8 mm diameter implant was determined to exert a 74.62 MPa force in the bone tissue around the implant neck, while this force was calculated to be 46.49 MPa for the 4.6 mm diameter implant. Maximum Von Misses stress values on the surface of the implant were obtained by oblique application of the angled force of the abutment. In the maxillary bone, the maximum Von Misses value was 239.2 MPa for the implant with 3.8 mm diameter and 108.15 MPa for the 4.6 mm diameter implant (Figure 3, Figure 4). We observed that the maximum Von Misses stress values for the 4.6 mm diameter implant was lower than that of the 3.8 mm diameter implant, on the bone tissue both around the implant neck and the implant surface (Figure 3).

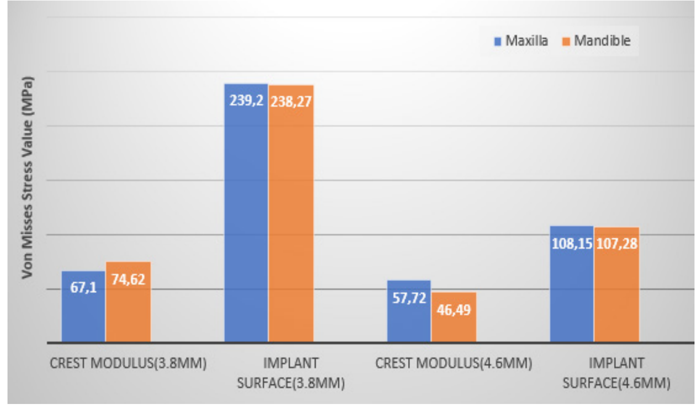


Figure 3. Maximum Von Misses stress values in the bone around the neck (crest modulus) and implant surface with angled placement of the abutment and oblique application of force

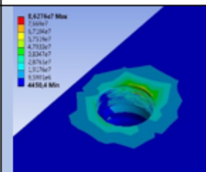
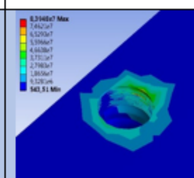
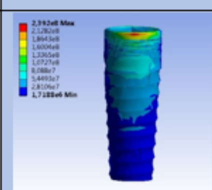
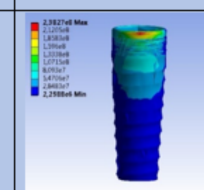
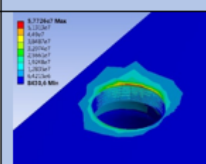
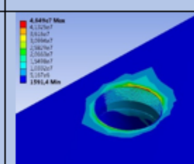
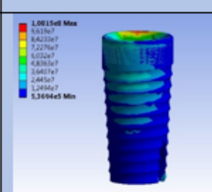
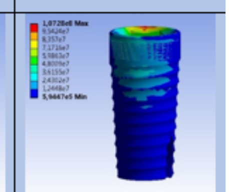
Implant Diameter	Stress Distribution	Maxilla	Mandible
3.8 mm	Bone Around The Neck of The Implant		
	Implant Surface		
4.6 mm	Bone Around The Neck of The Implant		
	Implant Surface		

Figure 4. Von Misses stress distribution in the bone around the neck (crest modulus) and implant surface with angled placement of the abutment and oblique application of force

The minimum Von Misses stress value was calculated and when the implant application direction and the force direction was the same for both implant diameters and in both types of bones: That is, it was observed when the abutment was placed straight and the force was applied vertically. Von Misses stress values calculated after vertical application of the force on a straight placed 3.8 mm diameter implant into the mandible was 9.33 MPa in the bone around the implant and 21.34 MPa on the implant surface.

For the 4.6 mm diameter implant placed in the mandible, the Von Misses stress values that occur were 6.2 MPa in the bone around the implant neck and 14.34 MPa on the implant surface when the force was applied vertically (Figure 5). The maximum Von Misses stress values were observed to increase as the implant position and the angle of application of the force diverged from the vertical angle.

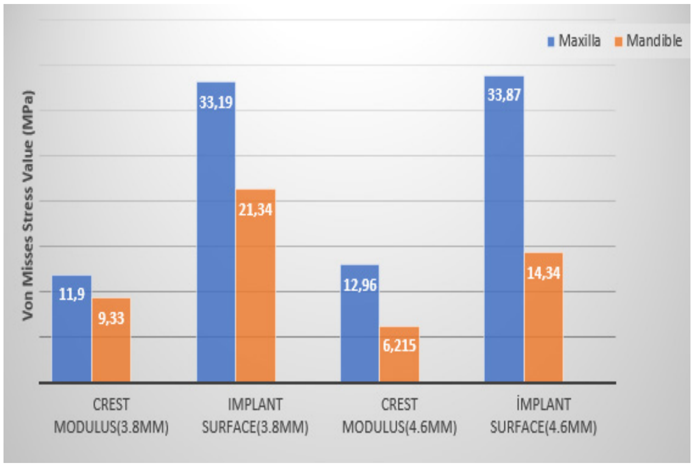


Figure 5. Von Misses stress values that occur in the bone around the neck and implant surface as a result of the vertical application of the abutments with straight force.

DISCUSSION

Dental implants have been successfully used in the treatment of dental deficiencies for the last two decades (16). However, dental implants are not 100% successful in the long term. Clinical and experimental studies have showed that the stress transmitted to the bone around the implant may lead to bone resorption and consequently loss of implants (17,18). Functional and parafunctional forces generated in the intraoral area are transmitted to the implants via the upper-structures of the implants and from there to the adjacent bone. These forces cause stress and deformation in the implant-bone contact area, and may affect remodeling of the bone around the implant (17).

In a study by Papavasiliou et al., stress occurring around a single dental implant at different bone densities was evaluated by using the FEA method. They reported that the stress was concentrated on the compact bone and that the oblique loads on the occlusal surface increased the stress on the bone around the implant by ten times (13). In another study, Sevimay et al. examined the distribution of stress in bones with different densities by finite element analysis and reported that the stress increased in the bone around the neck of the implant in low-density bones (19). In their study using different implant designs and bone models with different densities, Yalcın et al. reported that when the crestal bone surrounding the neck of the implant has lower density, the stress levels are increased (20). Premnath et al., Maximum Von Mises stress was observed at the crestal region of the bone in all the models (21). Chang et al. found that especially oblique forces cause more tension in the bone and this tension increased by 58.8% in the low density bones (22). Chiang et al. reported that the cortical bone thickness around the implant and the direction of force applied changed the stress levels. They also concluded that the elevated thickness of the cortical bone and vertical application of force will reduce bone loss (23). Kitamura et al. reported that as bone resorption progresses, increased stress in the cancellous bone and implant under lateral load may fail the implant (24). In many studies, it has been reported that the greatest tension was observed in the bone region around the implant's neck (25-29). In our study, with the vertical application of the force in the mandible, the stress levels in the bone in the neck region of the implant was 6.215 MPa, whereas the oblique application of the force in the same region resulted in an increase to 46.49 MPa. In the maxilla, it increases from 12.96 MPa to 57.72 MPa. Our results, which are in parallel with other studies, showed us that direction of the force and bone quality affect the stress value.

Himmlova and colleagues examined the distribution of Von Misses stress value around implants with different diameters and lengths by finite element analysis, and they reported that the diameter of the implant is more important than the length of the implant to reduce the Von Misses stress levels (30). Petrie et al. reported that long diameter and long implants will have longer life in low density bones (31). Raaj et al. reported that when in axial and non-axial loads, amount of stress distribution around implant-bone interface is influenced by diameter and length of implant in cortical and cancellous bone, respectively. In addition, increased diameter of the implant produced the minimum stress in cortical bone (32). Pelizzer et al. evaluated implants with different diameters with FEA under standard force and reported that the stress distribution became more efficient as the implant diameter increased (33). Implant dimensions are very important in transmission of the force to surrounding tissues. Considering that the maximum stress is concentrated around the neck region of the implant, the length/diameter ratio is an important parameter (34). In their study where they applied forces mimicking chewing muscles, Ding and colleagues reported that stress and tension in the neck of the implant decreased as the diameter increased (35). Eazhil et al. reported that there was a statistically significant decrease in Von Mises stress as implant diameter increased (36). Anitua et al. found that the use of wider implants would be better to dissipate impact forces and thus reduce stress in the bone surrounding the implant (37). Mohammed et al. analyzed the stress distributions of implants with different designs and diameters and reported that the stress in the peri-implant area decreases with increasing implant diameter (38). In our study, especially in the mandible where the cortical bone density is high, the stress levels in the crestal bone around the implant decreased as the implant diameter increased. In the maxilla, as the diameter increased, the stress levels decreased both on the surface of the implant and on the bone around the implant.

Among the models created in our study, the minimum Von Misses stress values were calculated by applying the implant and force in the same direction. In contrast, in models obtained with angled application of force and angled abutment, we observed the maximum Von Misses stress values on the bone around the neck of the implant, which we think will clinically increase crestal bone resorption.

CONCLUSION

Increased maximum Von Misses stress values on the bone around the implant neck and the implant surface indicates that bone resorption will be increased. We believe that stress analysis studies related to commonly used implant types will guide the clinicians in terms of implant surface, neck characteristics and application protocols and increase awareness in implantology and the success rate of dental implants.

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REFERENCES

1. Branemark PI. Osseointegration and its experimental background. J Prosthet Dent 1983;50:399-410.
2. Akagawa Y, Sato Y, Teixeira ER, et al. A mimic osseointegrated implant model for three-dimensional finite element analysis. J Oral Rehabil 2003;30:41-5.
3. 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.
4. Nevins M, Nevins ML, Camelo M, et al.Human histologic evidence of a connective tissue attachment to a dental implant. Int J Periodontics Restorative Dent 2008;28:111-21.
5. Botos S, Yousef H, Zweig B, et al. The effects of laser microtexturing of the dental implant collar on crestal bone levels and peri-implant health. Int J Oral Maxillofac Implants 2011;26:492-8.
6. Pecora GE, Ceccarelli R, Bonelli M, et al. Clinical evaluation of laser microtexturing for soft tissue and bone attachment to dental implants. Implant Dent 2009;18:57-66.
7. Farah JW, Craig RG, Meroueh KA. Finite element analysis of a mandibuler mode. J Oral Rehabil 1988;15:615-24.
8. Torcato LB, Pellizzer EP, Verri FR, et al.. Influence of parafunctional loading and prosthetic connection on stress distribution: a 3D finite element analysis. J Prosthet Dent 2015;114:644-51.
9. Clift SE, Fisher J, Watson CJ. Finite element stress and strain analysis of the bone surrounding a dental implant: effect of variations in bone modulus. Proc Inst Mech Eng H 1992;206:233-41.
10. Magne P. Efficient 3D finite element analysis of dental restorative procedures using micro-CT data. Dent Mater 2007;23:539-48.
11. Baggi L, Cappelloni I, Di Girolamo M, et al. 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 Prosthet Dent 2008;100:422-31.
12. Cibirka RM, Razzoog ME, Lang BR, et al. Determining the force absorbtion quotient for restorative materials used in implant occlusal surfaces. J Prosthet Dent 1992;67:361-4.
13. Papavasiliou G, Kamposiora P, Bayne SC, et al. 3D-FEA of osseointegration percentages and patterns on implant-bone interfacial stresses. J Dent 1997:25:485-91.
14. Hojjatie B, Anusavice KJ. Three-dimensional finite element analysis of glass-ceramic dental crowns. J Biomech 1990;23:1157-66.
15. Bishara SE, Saunders WB. Textbook of orthodontics. Saunders Book Company, 15st Edition, Philadelphia, 2001;592.
16. Isidor F. Loss of osseointegration caused by occlusal load of oral implants: a clinical and radiographic study in monkeys. Clin Oral Implants Res 1996;7:143-52.
17. Hoshaw SJ, Brunski JB, Cochran GVB. Mechanical loading of Brånemark fixtures affects interfacial bone modeling and remodeling. Int J Oral Maxillofac Implants 1994;9:345-60.
18. Celebi A, Gulsun B. Investigation of tension distribution of bone in the neck of the implant with switching platform by using 3-D finite element analysis. J Dent Dicle 2018;19:1-6.
19. Sevimay M, Turhan F. Three-dimensional finite element analysis on the effect of different bone quality on stress distribution in implant-supported crown. J Prosthet Dent 2005;93:227-34.
20. Yalcin M, Kaya B, Lacin N, et al. Three-dimensional finite element analysis of the effect of endosteal implants with different macro designs on stress distribution in different bone qualities. Int J Oral Maxillofac Implants 2019;34:43-50.
21. Premnath K, Sridevi J, Kalavathy N, et al.Evaluation of stress distribution in bone of different densities using different implant designs: a three-dimensional finite element analysis. J Indian Prosthodont Soc 2013 ;13:555-9.
22. Chang SH, Lin CL, Hsue SS, et al. Biomechanical analysis of the effects of implant diameter and bone quality in short implants placed in the atrophic posterior maxilla. Med Eng Phys 2012;34:153-60.
23. Chiang C, Shyh-Yuan L, Ming-Chang W, et al. Finite element modelling of implant designs and cortical bone thickness on stress distribution in maxillary type IV bone. Comput Methods Biomech Biomed Engin 2014:17:516-26.
24. Kitamura E, Stegaroiu R, Nomura S, et al. Influence of marginal bone resorption on stress around an implant: a three-dimensional finite element analysis. J Oral Rehabil 2005;32:279-86.

25. Schwitalla AD, Abou-Emara M, Spintig T, et al. Finite element analysis of the biomechanical effects of peek dental implants on the peri-implant bone. J Biomech 2015;48:1-7.
26. Duyck J, Ronold HJ, Van Oosterwyck H, et al. The influence of static and dynamic loading on marginal bone reactions around osseointegrated implants: an animal experimental study. Clin Oral Implants Res 2001;12:207-18.
27. Pilliar RM, Deporter DA, Watson PA, et al.Dental implant design effect on bone remodeling. J Biomed Mater Res 1991;25:467-83.
28. Holmes DC, Loftus JT. Influence of bone quality on stress distribution for endoosseos implants. J Oral Implantol 1997;23:104-11.
29. Akca K, Cehreli MC. Biomechanical consequences of progressive marginal bone loss around oral implants: a finite element stress analysis. Med Biol Eng Comput 2006;44:527-35.
30. Himmlová L, Dostálová T, Kácovský A, et al. Influence of implant length and diameter on stress distribution: a finite element analysis. J Prosthet Dent 2004;91:20-5.
31. Petrie CS, Williams JL. Comparative evaluation of implant designs: influence of diameter, length, and taper on strains in the alveolar crest: a three-dimensional finite-element analysis. Clinical Oral Implants Research 2005;16:486-94.
32. Raaj G, Manimaran P, Kumar CD, et al. Comparative evaluation of implant designs: influence of diameter, length, and taper on stress and strain in the mandibular segment: a three-dimensional finite element analysis. J Pharm Bioallied Sci 2019;11:347-54.
33. Pellizzer EP, Verri FR, de Moraes SL, et al. Influence of the implant diameter with different sizes of hexagon: analysis by 3-dimensional finite element method. J Oral Implantol 2013;39:425-31.
34. Demenko V, Linetskiy I, Nesvit K, et al. Importance of diameter to length ratio in selecting dental implants: a methodological finite element study. Comput Methods Biomech Biomed Engin 2014;17:443-9.
35. Ding X, Zhu XH, Liao SH, et al. Implant-bone interface stress distribution in immediately loaded implants of different diameters: a three-dimensional finite element analysis. J Prosthodont 2009;18:393-402.
36. Eazhil R, Swaminathan SV, Gunaseelan M, et al.Impact of implant diameter and length on stress distribution in osseointegrated implants: a 3D FEA study. J Int Soc Prev Community Dent 2016;6:590-6.
37. Anitua E, Tapia R, Luzuriaga F, et al. Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. Int J Period Rest Dent 2010;30:89-95.
38. Mohammed Ibrahim M, Thulasingam C, Nasser KS, et al. Evaluation of design parameters of dental implant shape, diameter and length on stress distribution: a finite element analysis. J Indian Prosthodont Soc 2011;11:165-71.