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Pattern of Stress and Strain Distribution in Bone Around Standard and Short Bone-level Splinted Implants Using Three-Dimensional Finite Element Analysis

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Abstract: Short implants can be used as a substitute for standard implants to prevent invasive surgical procedures. However, high risk of complications calls for studies on 1their biomechanical characteristics and improved treatment planning. Splinting is one method to decrease the risk of fracture of short implants. This study sought to assess the pattern of stress and strain distribution in bone around standard and short, bone-level splinted implants using Finite Element Analysis (FEA). Computer-Aided Design (CAD) was used to create models of an edentulous posterior mandible including two short or standard implants in the mesial and distal areas and a pontic in-between them. In these models, the short and the standard implants measured 4×6 and 4×10 mm, respectively. Cortical bone thickness was constant (2 mm) in the models. ANSYS simulation software was used for FEA; 100 and 300 N loads were applied to implants at zero (parallel to the longitudinal axis of implants) and 30° angles. Maximum strain and strain values, site of maximum stress and the uniformity of stress distribution in different designs were assessed. Stress in cortical bone around standard implants was less than that around short implants under axial loads. The situation was reversed under 30° angulated loads and stress around short implants was less. The same was true for strain. Strain in cancelous bone around short implants was higher than that around standard implants. Pattern of stress and stress distribution in bone around splinted short and long implants due to the application of load at different angles was not the same. By splinting short implants better stress distribution in peri-implant bone can be achieved under oblique loads.

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INTRODUCTION

Osseointegrated dental implants are a suitable and practical treatment modality for replacement of the lost teeth[1]. In some cases, implant placement in the posterior areas has some limitations due to alveolar ridge resorption and presence of anatomical landmarks such as the inferior alveolar nerve and maxillary sinuses[2-5]. Thus, several surgical techniques have been proposed to overcome these complexities and enable placement of standard length implants. However, these methods prolong the course of treatment and increase the risk of complications, patient complaints and treatment cost. Moreover, the skills and expertise of the surgeons play an important role in successful implementation of these techniques[6].

In the recent years, use of short implants as an alternative to standard implants has increased in order to prevent invasive surgical procedures. In preliminary studies, 10 mm length implants were considered standard and shorter lengths were considered as short implants[7, 8]. However, in the sixth workshop of the European Association of Dental Implantologists in 2011, the classification by Olate[5]. was accepted. Accordingly, implants shorter than 8 mm were considered as short, 9-13 mm were considered as standard and longer than 13mm were regarded as long implant[5]. Short implants with 7 mm height were first introduced by Branemark in 1979[9]. The success rate of short implants in a review study was reported to be 83.7-100%; the highest survival rate belonged to short implants with irregular surfaces compared to those with smooth and machined surfaces and also implants used in the mandible. The highest rate of failure belonged to implants with 5 mm length[9].

However, use of short implants, at least theoretically, is not recommended in some cases; whereas, occlusal loads distributed along the standard implants result in bone preservation[10]. But decreased contact area in short implants results in transfer of functional loads to crestal bone and may lead to crestal bone loss due to the distribution of load over a small area[6]. It has been reported that following the use of short compared to standard implants, strain in cancelous bone and stress in cortical bone significantly increase[11, 12]. However, recent clinical studies have demonstrated that the success rate of short implants is comparable to that of conventional standard implants[3, 14]. Some reports have mentioned an overall success rate of 98.1-99.7% for short implants placed in different areas, similar to the values for conventional implants[7].

Biomechanical methods to decrease the stress applied to bone around short implants are critical for achieving an acceptable level of treatment success. These methods include decreasing the load applied, preventing lateral contacts in lateral movements of the mandible, elimination of cantilevers, increasing the diameter and number of implants and splinting the implants[3, 6].

Misch showed that stress in bone around splinted implants was less than that around single unit implants[4]. Increasing the number of implants supporting denture increases the bone contact area and prevents excessive load application; the load transferred to bone decreases as such[15].

Review of the literature shows that many of the FEA studies have been conducted on single unit implants; while strain and stress values may be widely variable when several implants are splinted. Thus, this study assessed the pattern of stress and strain distribution in bone around standard and short splinted implants in two different treatment plans.

The results of this study may improve treatment planning by maintaining the level of stress in bone within the physiologic threshold because improving the distribution of stress in bone is necessary for long-term preservation of bone around implants and increases the success rate of implant treatment.

MATERIALS AND METHODS

Three-dimensional Finite Element Method (FEM) is a computer-aided method for calculation and observation of stress and strain distribution patterns in complex structures under applied loads. In this study, Computer Aided Three-dimensional Interactive Application (CATIA) was used to fabricate two finite element models of an edentulous posterior mandible (according to tomographic scans) requiring two crowns. The first model had two short implants and the second model had two standard length implants placed in the mesial and distal areas. The two crowns were splinted by a cobalt-chromium metal bar measuring 6×4 mm. Implants modeled in this study had abutments with 5 mm length, a micro-thread coronal surface and a divergent macro-thread body with an equal diameter of 4 mm and variable lengths (10 mm for standard implants and 6 mm for short implants) (3. 1). Implant-bone contact was considered 100%, indicating complete functional uniformity (osseointegration) (Fig. 1 and 2).

To calculate mechanical variables in the created models, knowledge about the mechanical properties of the materials used such as their modulus of elasticity or Young's modulus (E) and Poisson's ratio (v) is necessarily. Bone has several mechanical variables and there are variable data for biomechanical properties of bone. In this study, the modulus of elasticity was considered 13.7 GPa for cortical bone, 1.37 Gpa for cancelous bone[16], 110 GPa for implants[17] and 218 GPa for Cr-Co metal bar (18). Implants in the two models of A and B were placed in compact and cancelous supporting bone. Model A included two standard splinted

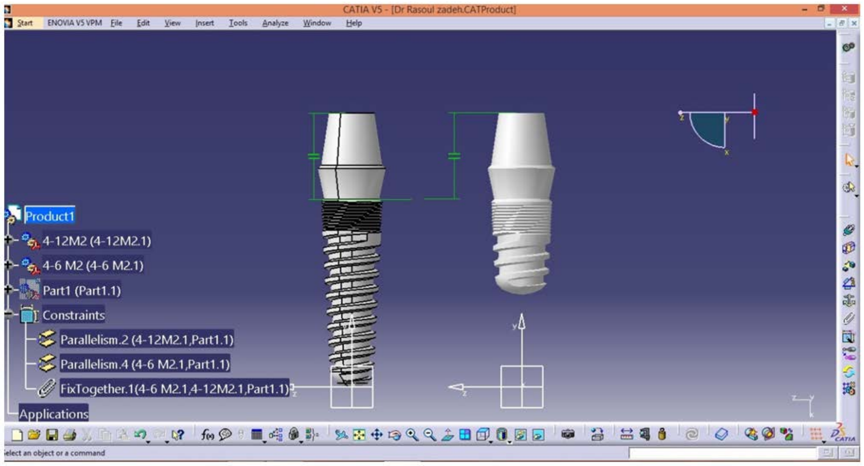

Fig. 1: Modeled implants with 5 mm long abutments with a micro-thread coronal surface and a tapered macro-thread body with equal 4 mm diameters and variable lengths

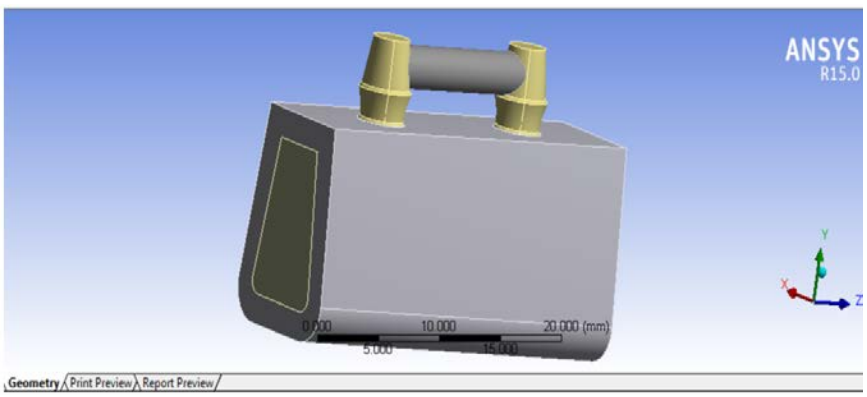

Fig. 2: Splinting of two implants with a metal bar

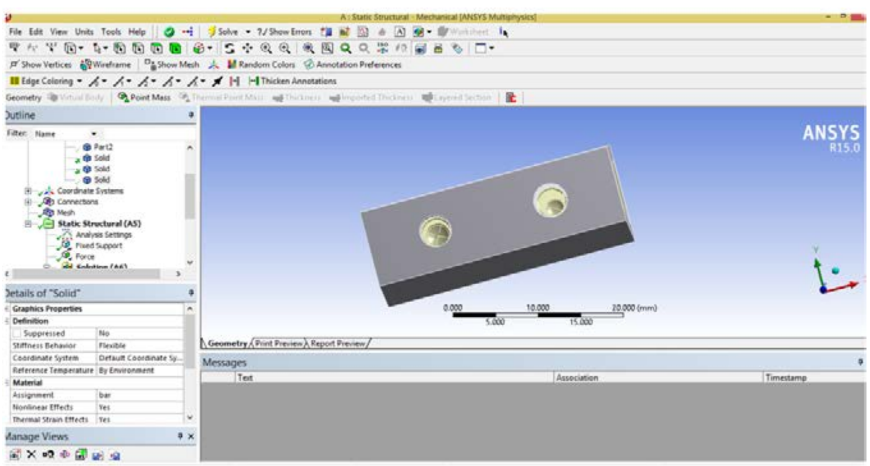

Fig. 3: Bone model including 2 mm of compact cortical bone and the cancelous bone

implants in bone and model B included two short splinted implants in bone. Implant neck in both models was within the 2 mm layer of compact cortical bone and the body of implant was surrounded by cancelous bone (Fig. 3).

For FEM, since, ANSYS Software has higher capabilities for a faster analysis than CATIA, the models designed in CATIA were saved in files with a format compatible for use in ANSYS. Then, 100 and 300 N loads were applied in zero (parallel to the longitudinal axis of implants) and 30° angles relative to the implants and FEA was carried out using ANSYS Software. The results of FEA were evaluated in two groups of stress and strain at two areas:

- Implant-cortical bone interface
- Implant-cancelous bone interface

Following FEA calculations, pattern of stress and strain distribution in the above-mentioned areas was assessed and used for the comparison of maximum stress, site of maximum stress and uniformity of stress distribution in different models. Also, stress and strain values in each design were compared considering the threshold of tolerance of tissues and elements.

RESULTS AND DISCUSSION

Table 1 and 2 show the analysis of the results of the two simulated models using ANSYS software. Table 1 and 2 show stress and strain in cortical and cancelous bone, respectively due to different load applications.

Figure 4 and 5 show stresses created in models A and B following loadings based on the results of Table 1 and 2. Figure 4 indicates the level of stress in cortical bone and Fig. 5 indicates the level of stress in cancelous bone. Comparison of the two diagrams shows that total stress in the cortical bone was significantly higher than that in cancelous bone (>10 times).

Figure 4 shows the location of maximum stress in cortical bone. As seen in Fig. 4, the highest level of stress was estimated to be in the superior part, adjacent to the implant neck.

As seen in Fig. 4 and 5 in both models, stresses due to a specific load were lower in axial compared to angulated direction of load and by changing the angulation of load from vertical to 30°, the level of stress increased by three folds. Thus as seen in Fig. 4, level of stress due to the application of 300 N axial load was close to that due to the application of 100 N load at 30° angle. Figure 1 shows that under axial loads, shear stress in cortical bone around standard implants was less than that around short implants whereas, under 30° angulated load, the reverse was true and shear stress around short implants was found to be less. The same results were obtained for shear strain in the two models.

Assessment of cancelous bone around implants in Fig. 5 shows that stress around short implants was often higher and this was more significant for axial loads. Thus, it can be stated that around short implants, a significant portion of stress is transferred to cancelous bone. Table 1 and 2 indicate that the pattern described for von Mises stresses was also true for shear stress. Figure 6-8 show total deformation of cortical and cancelous bone around implants in the two models under different loads. As seen in Fig. 6 and 7, the total deformation in cortical and cancelous bone was pretty much similar. The degree of deformation in model A was often less than that in model B, except for the application of 300N load at 30° angle.

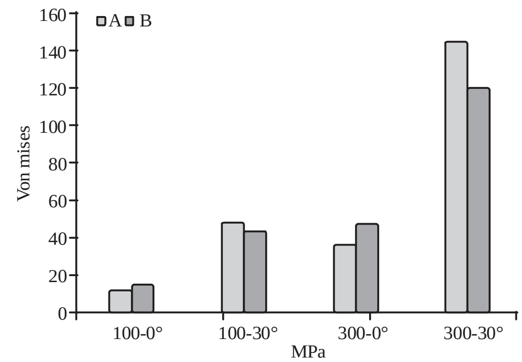

Fig. 4: The stress concentrated in cortical bone due to the application of different loads

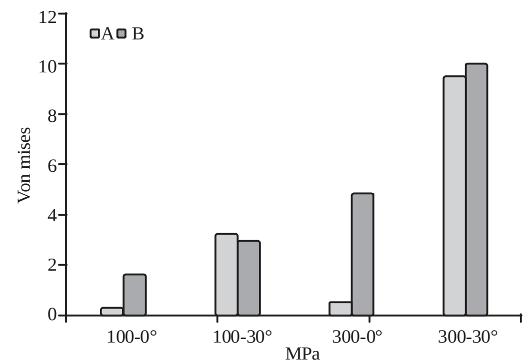

Fig. 5: The stress concentrated in cancelous bone due to the application of different loads

Using FEM, a series of analyses with different designs are performed about the pattern of load transfer from short implants to alveolar bone and the resultant pattern of stress and strain. However, to date, no scientific analysis has been published regarding the biomechanical and mechanical effects of length and diameter of short implants.

Stress distribution in peri-implant bone is evaluated in cortical and cancelous bone. The results of FEA with ANSYS Software showed that, assuming that the implant was in complete contact with bone and the 2 mm cortical bone adjacent to the implant neck was the main anchorage for implant, the stress distributed in cortical bone was

Table 1. Maximum stress and strain in cortical bone adjacent to the implant

MAXIMUM (cortical)	Unit direction	Model A 100 N 0°	100 N 30°	300 N 0°	300 N 30°	Model B 100 N 0°	100 N 30°	300 N 0°	300 N 30°
Equivalent stress (von mises)	(Mpa)	12.1	47.7	36.22	144	15.7	43.4	48	120
Shear stress	(Mpa)	3.6	15.1	10	45	4.45	13.4	13.3	40
Equivalent elastic strain (von mises)	(mm mm^{-1})	0.000875	0.0035	0.0026	0.01	0.001	0.003	0.0027	0.009
Shear elastic strain	(mm mm^{-1})	0.00069	0.00273	0.002	0.0086	0.0008	0.0025	0.0025	0.0076
Total deformation	(mm)	0.001891	0.0086	0.0057	0.036	0.0027	0.01	0.008	0.03

Table 2. Maximum stress and strain in cancelous bone adjacent to the implant

MAXIMUM (cortical)	Unit direction	Model A 100 N 0°	100 N 30°	300 N 0°	300 N 30°	Model B 100 N 0°	100 N 30°	300 N 0°	300 N 30°
Equivalent stress (von mises)	(Mpa)	0.22	3.2	0.52	9.5	1.6	2.9	4.8	10
Shear stress	(Mpa)	0.04	1.72	0.5	5.2	0.3	0.64	1.06	1.9
Equivalent elastic strain (von mises)	(mm mm^{-1})	0.00192	0.002	0.0057	0.0026	0.0017	0.0026	0.004	0.0077
Shear elastic strain	(mm mm^{-1})	0.00188	0.0032	0.0034	0.0098	0.00065	0.002	0.002	0.003
Total deformation	(mm)	0.0018	0.0068	0.0054	0.02	0.0029	0.008	0.0078	0.025

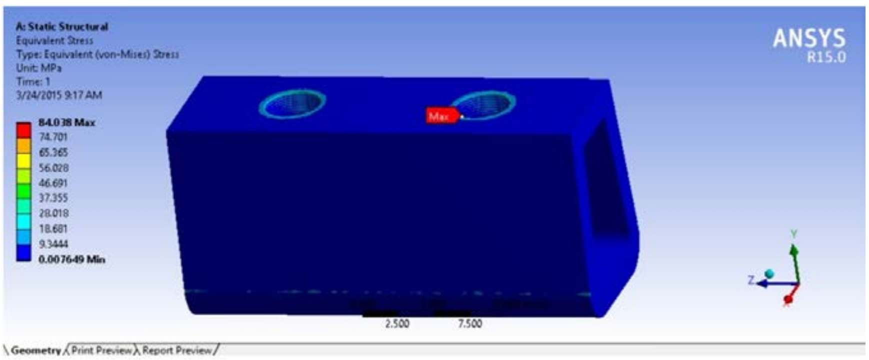

Fig. 6: Location of maximum stress concentration in cortical bone

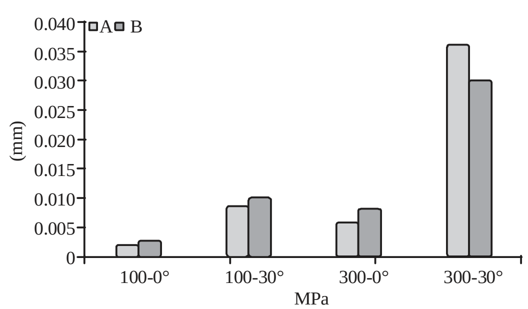

Fig 7: Total deformation of cortical bone around implants

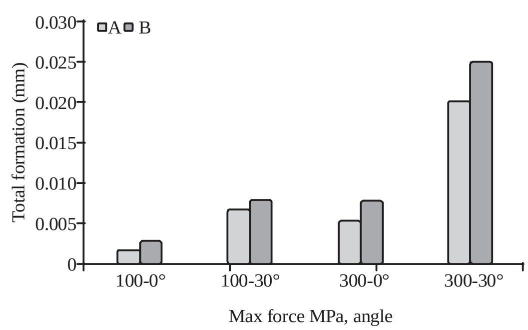

Fig. 8: Total deformation of cancelous bone around implants

much higher than that in cancelous bone. Sotto-Maior[19] in their FEA study in 2012 stated that the highest amount of stress, irrespective of occlusal load, was concentrated at the cervical and first thread of implant[19]. In other words, the highest stress was always concentrated at the implant neck[20]. Himmlova[21] in a FEA in 2004 evaluated the effect of implant length and diameter on stress distribution and reported that the maximum stress in all implants with different lengths and diameters was concentrated at the implant neck and the mesiolingual rim of the bony socket[21]. Thus, the cervical area plays a critical role due to the concentration of high level of stress in this area especially when the implant is subjected to lateral loads. It means that the first three to five implant threads are more involved in stress absorption[22].

Based on previous studies, level of stress around short and thin implants increases compared to standard implants. Hasan[12] reconstructed three-dimensional models of short implants with 5.5mm diameter and 5 and 7 mm lengths and standard implants with 5.5 mm diameter and 9, 11 and 13mm lengths using a FEA. All implants were subjected to 300N loads applied at a 308° angle relative to the implant axis. The maximum stress was noted around short implants; standard implants showed wider distribution of stress in cortical bone compared to short implants[24]. The current study demonstrated maximum stress in bone around short implants due to axial loads. Thus, level of stress in cortical bone around the cervical area of short implants was the highest.

Toniollo *et al*.[23] evaluated stress distribution in alveolar ridge around implants with variable dimensions using FEA and reported greater stress concentration by 50 and 80% in cortical bone and cancelous bone, respectively around short implants compared to standard implants. Although short implants were capable of transferring the stress to the bone, the above-mentioned values were close to the threshold between elastic and plastic deformation of cancelous bone. They recommended accurate occlusal adjustment for patients requiring short implants associated with increased proportions of implant prostheses because overloading of short implants can create stress exceeding the physiological threshold of bone and compromise the entire system[23].

Also, in the current study stress distribution pattern was different under loads of different directions. Stress due to axial load in cortical bone was lower around standard compared to short implants. However, the situation was reversed under 30° angulated loads and stress around short implants was less. Assessment of stress in cancelous bone under application of load at different angles revealed that stress around short implants was always higher than around standard implants. Balkaya in 2014 suggested that a lower level of stress could be obtained in cancelous bone by increasing the diameter of short implants; however, this would result in greater stress concentrated at the implant surface[24].

An important finding of the current study was level of deformation of the pre-implant bone shown in Figure 6 and 7. These diagrams showed that level of bone deformation in model B (short implant) was higher in most cases. This is expected considering Fig. 5 indicating greater stress around short implants compared to standard implants. This finding is in accord with the results of previous studies showing the greatest movement in the abutment of the shortest implant (290 mm in 5.5×5 mm short implants) and by increasing the length of short implant, movement significantly decreased[24].
Limitations and suggestions.

One limitation of this study was lack of accurate simulation of anatomical conditions. In this study, ideal geometry of bone was only defined by considering the thickness of cortical bone, quality of cancelous bone and their modulus of elasticity. But, factors such as bone loss and individual differences in the quality and thickness of bone, which may affect the results were not considered. Also, the implants were designed by only a hypothetical abutment on the fixtures. For more accurate designing, other elements such as the abutment screw and crown must be included in the model as well.

Considering the fact that the position of implant relative to the crestal bone affects stress distribution, future studies must include this factor in modeling too.

CONCLUSION

Pattern of change in stress and strain in bone around splinted short and long implants due to the application of load at different angles was not similar and this issue must be considered in treatment planning. In case of equal diameter, use of standard splinted implants is amore appropriate compared to short implants. By splinting standard and even short implants, stress beyond the physiological threshold of the surrounding bone under oblique loads can be prevented.

REFERENCES

01. Bragger, U., S. Aeschlimann, W. Burgin, C.H. Hammerle and N.P. Lang, 2003. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. Clin. Oral Implants Res., 12: 26-34.
02. Renouard, F. and D. Nisand, 2006. Short implants in the severely resorbed maxilla: A 2-year retrospective clinical study. Clin. Implant Dent. Related Res., 7: s104-s110.
03. Mezzomo, L.A., R. Miller, D. Triches, F. Alonso and R.S.A. Shinkai, 2013. Meta-analysis of single crowns supported by short (<10mm) implants in the posterior region. J. Clin. Periodontol., 41: 191-213.
04. Misch, C.E., 2005. Short dental implants: A literature review and rationale for use. Dentistry Today, 24: 64-66.
05. Olate, S., M.C.N. Lyrio, M. de Moraes, R. Mazzonetto and R.W.F. Moreira, 2010. Influence of diameter and length of implant on early dental implant failure. J. Oral Maxillofacial Surg., 68: 414-419.
06. Shetty, S., N. Puthukkat, S.V. Bhat and K.K. Shenoy, 2014. Short implants: A new dimension in rehabilitation of atrophic maxilla and mandible. J. Interdiscip. Dent., 4: 66-70.
07. Fugazzotto, P.A., 2008. Shorter implants in clinical practice: Rationale and treatment results. Int. J. Oral Maxillofacial Implants, 23: 487-496.

08. Lai, H.C., M.S. Si, L.F. Zhuang, H. Shen, Y.L. Liu and D. Wismeijer, 2012. Long-term outcomes of short dental implants supporting single crowns in posterior region: A clinical retrospective study of 5-10 years. Clin. Oral Implants Res., 24: 230-237.
09. Tutak, M., T. Smektala, K. Schneider, E. Golebiewska and K. Sporniak-Tutak, 2013. Short dental implants in reduced alveolar bone height: A review of the literature. Med. Sci. Monit., 19: 1037-1042.
10. Lum, L.B., 1991. A biomechanical rationale for the use of short implants. J. Oral Implantol., 17: 126-131.
11. Bourauel, C., M. Aitlahrach, F. Heinemann and I. Hasan, 2012. Biomechanical finite element analysis of small diameter and short dental implants: Extensive study of commercial implants. Biomed. Eng., 57: 21-32.
12. Hasan, I., F. Heinemann, M. Aitlahrach and C. Bourauel, 2010. Biomechanical finite element analysis of small diameter and short dental implant. Biomed. Eng., 55: 341-350.
13. Kotsovilis, S., I. Fourmousis, I.K. Karoussis and C. Bamia, 2009. A systematic review and meta-analysis on the effect of implant length on the survival of rough-surface dental implants. J. Periodontol., 80: 1700-1718.
14. Misch, C.E., J. Steigenga, E. Barboza, F. Misch-Dietsh, L.J. Cianciola and C. Kazor, 2006. Short dental implants in posterior partial edentulism: A multicenter retrospective 6-year case series study. J. Periodontol., 77: 1340-1347.
15. Duyck, J., H. Van Oosterwyck, V.J. Sloten, M. De Cooman, R. Puers and I. Naert, 2003. Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: An in vivo study. Clin. Oral Implants Res., 11: 465-475.
16. Ko, C.C., D.H. Kohn and S.J. Hollister, 1992. Micromechanics of implant/tissue interfaces. J. Oral Implantol., 18: 220-230.
17. Ciftci, Y., 2000. The effect of veneering materials on stress distribution in implant-supported fixed prosthetic restorations. Int. J. Oral Maxillofacial Implants, 15: 571-582.
18. Anusavice, K.J., 2003. Phillips Science of Dental Materials. 11th Edn., W.B. Saunders Company, USA., pp: 255-280.
19. Sotto-Maior, B.S., M.P. Senna, W.J. da Silva, E.P. Rocha and D.B.A.A. Cury, 2012. Influence of crown-to-implant ratio, retention system, restorative material and occlusal loading on stress concentrations in single short implants. Int. J. Oral Maxillofacial Implants, 27: e13-e18.
20. Meijer, H.J.A., J.H. Kuiper, F.J.M. Starmans and F. Bosman, 2006. Stress distribution around dental implants: Influence of superstructure, length of implants and height of mandible. J. Prosthetic Dent., 68: 96-102.
21. Himmlova, L., A. Kacovsky and S. Konvickova, 2004. Influence of implant length and diameter on stress distribution: A finite element analysis. J. Prosthetic Dent., 91: 20-25.
22. Rangert, B., 1993. Mechanical and biomechanical guidelines for the use of Branemark system-general principles. Aust. Prosthodontic J., 7: 39-44.
23. Toniollo, M.B., A.P. Macedo, R.C.S. Rodrigues, R.F. Ribeiro and M.D.G.C. de Mattos, 2012. Three-dimensional finite element analysis of stress distribution on different bony ridges with different lengths of morse taper implants and prosthesis dimensions. J. Craniofacial Surg., 23: 1888-1892.
24. Balkaya, M.C., 2014. Investigation of influence of different implant size and placement on stress distribution with 3-dimensional finite element analysis. Implant Dentist., 23: 716-722.