Original Article ISSN (O):2395-2822; ISSN (P):2395-2814

Effect of Vertical Interarch Space, Implant Abutment Height and Diameter on Stresses in the Bone - A 3rd Finite Element Analysis

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Received: December 2019
Accepted: December 2019

ABSTRACT

Background: Transmission of stress to bone is affected by various clinical situations and implant/components related factors. The purpose of this 3- D FEA was to understand the stresses generated in the cortical and cancellous bone at different vertical interarch space, implant abutment height and diameter. **Methods:** Twelve models representing an osseointegrated single tooth implant (4.0 x11 mm) with a zirconia crown cemented with zinc phosphate luting cement (50 μm thickness) were generated in mandibular second premolar region with different interarch spaces (8 mm and 10 mm), abutment heights (5 mm and 6 mm) and abutment diameters (3.2 mm , 3.7 mm and 4.0 mm). All models were loaded axially and at 15° with a load of 100 N. **Results:** For interarch space of 8 mm the minimum stress was seen in model M1 (i.e. abutment height 6mm and diameter 3.2 mm) and for interarch space of 10 mm the minimum stress was seen in model M7 (i.e. abutment height 6mm and diameter 3.2 mm) irrespective of loading direction. There was an increase in stresses under oblique loading for all the models. **Conclusions:** Stresses increased with increased vertical interarch space and with decreased abutment height. Reduced abutment diameter decreased the stresses on the bone. Oblique loading worsened the stress distribution.

Keywords: FEA: Abutment diameter, Abutment height, Implant, Vertical interarch space.

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INTRODUCTION

Single tooth replacement by an implant is a successful clinical treatment if strict surgical and prosthodontic procedures are followed. Preservation of surrounding structures especially the alveolar bone and predictability of the treatment are essential in selecting the treatment plan. Undoubtedly, alveolar bone plays a key role in providing support to the teeth as well as implants. Therefore, the treatment rendered should be planned with the ultimate goal to preserve alveolar bone and surrounding structures.[1] Success of implant depends on various factors like quality and quantity of bone, masticatory load and type of restoration and implant design. Besides the above-mentioned factors, stresses, regardless of its cause increases the bone resorption.[2] The quantitative evaluation of vertical interarch space is one of the guiding parameters for choosing an abutment and optimizing biomechanical conditions of success.[3-5] Misch,[6] proposed the term "crown height space (CHS)" for implant dentistry which is measured from the rest of the bone to the plane of occlusion in the posterior region and the incisal edge of the arch in question in the anterior region. The biomechanics of vertical interarch space/CHS is related to lever mechanics, and is a vertical cantilever and therefore is also a force magnifier. Numerous studies observed force distribution in peri-implant bone as a function of implants geometry but few among them analysed the relationship between the vertical interarch space and abutment dimensions.[3,4,7-10] Excessive masticatory load due to improper selection of abutment height and diameter can result in early crestal bone loss as well as early implant failure. Some clinical observations have indicated that bone preservation is possible when the narrower diameter of abutment is connected to the implant known as platform switching.[11] According to the study by Lazzara and

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Porter,[12] radiography follow-up shows that platform switching reduces the loss of crestal bone height. They attribute this to the shifting inflammatory cell, which instead of infiltrating gets reduced and eventually dissipates from the crestal bone. For problems involving complicated geometries, it is very difficult to achieve an analytical solution. Therefore, the use of numerical methods such as finite element analysis (FEA) is required. In the past two decades, finite element analysis (FEA) has become an increasingly useful tool for the prediction of the effects of stress on the implant and surrounding bone. FEA allows researchers to predict stress distribution in the contact area of the implants with cortical bone and around the apex of the implants in trabecular bone.[8] The purpose of this study is to understand the influence of the three variables on bone stresses and to guide the clinician in choosing the abutment dimensions in different interarch distances, in order to limit stresses and preserve the crestal bone.

MATERIALS & METHODS

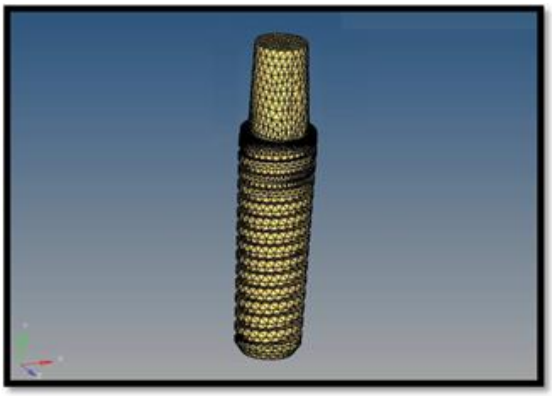


Fig 1: Single tooth implant model and abutment

Table 1: FEA Model dimensions

Model	Interarch Space	Abutment Height	Abutment Diameter
M1	8 mm	6 mm	3.2 mm
M2			3.7 mm
M3			4.0 mm
M4	8 mm	5 mm	3.2 mm
M5			3.7 mm
M6			4.0 mm
M7	10 mm	6 mm	3.2 mm
M8			3.7 mm
M9			4.0 mm
M10	10 mm	5 mm	3.2 mm
M11			3.7 mm
M12			4.0 mm

Table 2: Young's modulus and Poisson's ratio values

Material	Young's modulus (e)	Poisson's ratio (v)
Cortical bone	13.7	0.30
Cancellous bone	7.9	0.30
Implant body, abutment (Ti, 6Al, 4V alloy)	117	0.33
Ceramic crown	96	0.28
Zinc phosphate cement	13.5	0.35

For the purpose of this study, twelve models, representative of single tooth space restored with titanium implants and all ceramic crowns were constructed using ANSYS software with antagonistic teeth for determining the vertical interarch space of 8mm (M1-M6) and 10mm (M7-M12) respectively were generated. Each model was represented as in [Figure 1]. These models were of established dimensions [Table 1] possessing physical properties of Young's modulus and Poisson's ratio [Table 2].[13] The implant was positioned in the centre of bone structure and surrounded by isotropic and homogenous cortical and cancellous bone.

The implant was assumed to be embedded at its base, completely integrated. All models were mechanically loaded with 100 N force, both in axial and 150 non-axial direction. 3D FEA was used to create the models and to evaluate the stresses generated under loading. Graphic pre-processing software – ANSYS version 14.5 was used for creating the geometric representation of all the models. Each part of the model was divided into local volumes called "elements". These elements are connected at specific points called nodes. The mechanical properties of various anatomic structures and prosthetic materials used in the study were assigned at the nodes and elements. Each model was meshed by elements defined by 4 - 12 nodes. Each of these models was subjected to a force of 100 N applied to the buccal cusp of the crown in axial and 150 non-axial direction. The load was applied at a point where functional cusps come in contact with each other. The displacement of each of these nodes was calculated to determine the maximum Von Mises stress throughout the structure. Output was in the form of numerical values and plotted results such as contour maps of stress and graphs of the output parameters. Maximum Von Misses stress equivalent were observed and compared. The type of elements and nodes used for this study were tetrahedron and 4-noded shell elements in configuration. Number of elements and nodes used in models were 688378 and 108353 respectively. The results obtained in the study are depicted in colour coded pictures, where red is area of maximum stress concentration and blue is the area of minimum stress.

RESULTS

Graph 1: Maximum stress produced in all models under vertical & oblique load

The maximum Von Mises stress produced in models M1 to M12 under axial and non-axial loading were observed and tabulated. Also, maximum Von Mises stress in cortical bone, cancellous bone were observed and compared. The results were interpreted and are presented:

Overall Stress Distribution

Here, maximum stresses produced in models M1 to M12 under 100N force in axial and non-axial direction were observed and are presented in [Graph 1].

It can be inferred from the graph that as the diameter of the abutment increased, the maximum stresses generated also increased under both axial and non-axial loading. As the height of the abutment increased, the stresses generated decreased under axial and non-axial loading [Figure 2]. In similar dimensions of abutments, increased interarch distance generated increased stresses under axial and non-axial loading. There was increase in stresses by 197.2% for interarch space 8 mm and 220.7% for interarch space 10 mm, under oblique loading for all the models. In all the models, compressive stresses were observed in cervical area on the applied cusp side, while tensile stresses were on the opposite side. Highest stress occurred mainly around the implant neck and decreased progressively through the abutment and finally in the crown cervical area.

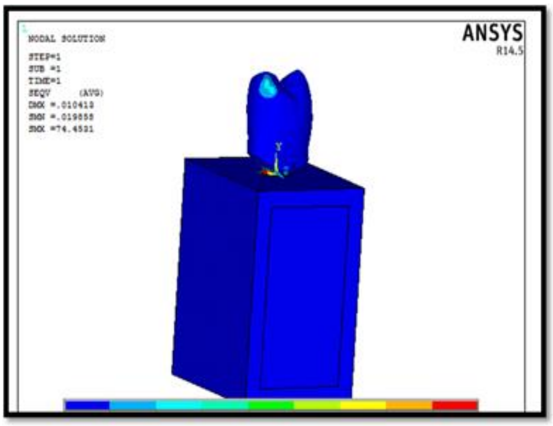


Figure 2: FEA model depicting overall stress

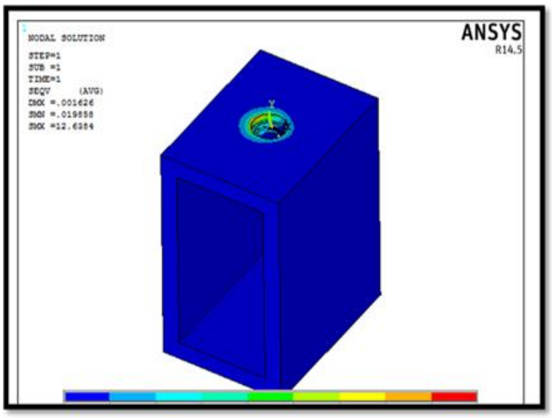


Figure 3: FEA model depicting stress in cortical bone

Bone Stress Intensity [Figure 3 & 4]

Here, maximum stresses produced in cortical and cancellous bone of models M1 to M12 under vertical load (100 N) and oblique load (100 N at 150) were observed and are presented in [Graph 2] (cortical bone) and [Graph 3] (cancellous bone).

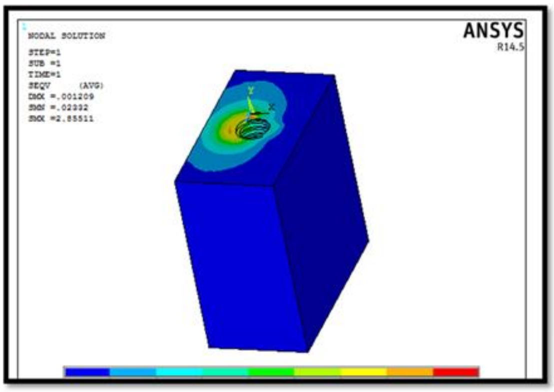
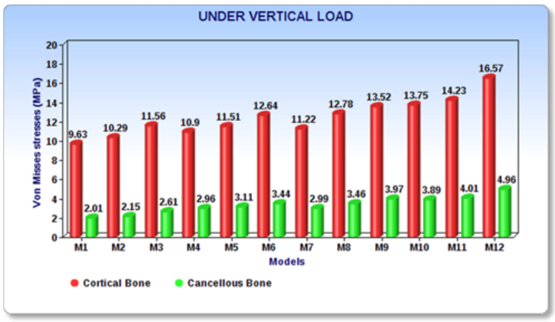
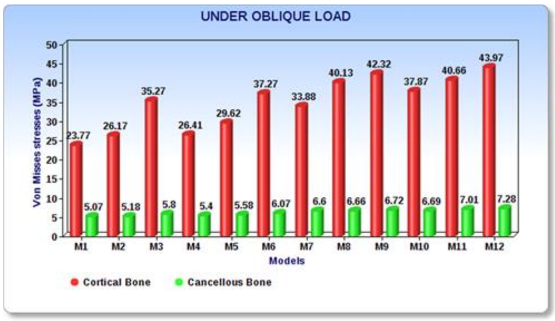


Figure 4: FEA model depicting stress in cancellous bone



Graph 2: Stress produced in cortical and cancellous bone under vertical load



Graph 3: Stress produced in cortical and cancellous bone under oblique load

As for the stress distribution in the peri-implant bone region, the stresses in all models were concentrated in the cortical bone. In all the models, compressive stress intensities at the implant cervical area showed higher values in cortical bone than cancellous bone. In the platform switched models, the stresses in bone were lower than in the standard models, and in all models, the stress distribution was greater in the cortical bone than in comparison with the cancellous bone. There was increase in stresses by 168.5% for interarch space 8 mm and 191.1% for interarch space 10 mm under oblique loading for all the models.

DISCUSSION

The evaluation of vertical inter arch space is one of the guiding parameters for choosing the height and diameter of the abutment and optimizing biomechanical conditions of success. Bidez and Misch[14] evaluated the effect of a cantilever on an implant and its relation to crown height. When a cantilever is placed on an implant, there are 6 different potential rotation points (i.e., moments) on the implant body. For every 1 mm crown height increase, force increase may be 20%.[15] When the crown height is increased from 10 to 20 mm, 2 of 6 of these moments are increased 200% and consequently crestal bone loss increases. A 12° force to the implant will increase the force by 20%. This increase in force is further magnified by the crown height. For example, a 12° angle with a 100-N force will result with a 315-N m force on a crown height of 15 mm.[16] The study results showed that in similar sizes of abutments, increased interarch distance generated increased stresses under axial and non-axial loading. Therefore, implant system/components dimensions should be designed so that it can best distribute stress to bone. This can be achieved by selecting appropriate height of abutment and/or reducing the diameter of abutment (platform switching).[9,17] Maeda et al,[18] also revealed in a finite element analysis that the platform switching configuration leads to a decrease of the shearing stress at the bone-implant surface. Because platform switching involves a change in the implant system design structure, this feature may also have a role in stress transfer from implant to bone. This suggests that smaller the diameter /platform switch results to lesser overall stresses.

For the analysis portion of this study, it was determined that a vertical and oblique loading model should be tested because the latter represents more realistic occlusal directions.[19]. A 15 degree angle and a loading force of 100 N were chosen because this force was shown in other implant in-vitro and in vivo studies to be more comparable to mastication.[19-24] In the present study, the location of force application was on the buccal cusp inclines of the crown, as described in other studies.[18,25,26] In the present study, stress produced in cortical bone and cancellous bone individually was evaluated and it was observed that the stresses in all models were concentrated in the cortical bone. In all the models, compressive stress intensities showed higher values in cortical bone than cancellous bone, which may be because of porous trabecular pattern of cancellous bone, resulting in lower Young's modulus. These findings are similar to the majority of previously reported results.[27,28] In the present study, mean value of stresses for cortical and cancellous bone was found in the range of 3.88 MPa to 39.80 MPa which was well within the threshold range (1.6 MPa to 60 MPa) for crestal bone proved by previous studies based on histologic examination and FEA results.[29,30] The results showed that, high vertical interarch space (10 mm) leads to stress transmission in bone and implant components more significant than height or diameter of abutment, and this was similar to study done by Naveau et al.[9] These results were also in accordance with the literature that describes the influence of increase in crown height on the transference of occlusal forces and lever biomechanics of vertical interarch space or increased crown height as mentioned earlier.[31-35] It was seen that stresses increased with abutment shortness, and this was in correlation to the study done by Naveau et al.[9]

This study suggested that when the abutment diameter was reduced (platform switched models), it resulted in less stress transferred to the crestal bone, regardless of the direction of force (vertical or oblique), as shown in previous studies.[36] However, a recent animal study indicated that a smaller-diameter abutment (platform switching) reduced crestal bone loss only for 28 days.[37] After 28 days, the matching and platform- switching abutments showed the same amount of bone loss. This finding was further supported by a recent study published by Jung et al.,[38] who showed implants with non-matching implant-abutment diameters (platform switching) demonstrated some bone loss; however, it was a small amount. The bone loss that occurred in the study was more related to implant placement depth rather than to platform switching. For example, the greatest bone loss occurred when the implant-abutment junction was placed 1 mm below the bone crest.[38] These conflicting reports suggest that there is a need for more studies to validate the influence of platform switching on crestal bone level. Another limitation of the present study was the condition of complete osseointegration established for the bone-implant interface, which may not realistically simulate actual contact conditions. Also, more research needs to be done taking into account more abutment heights and interarch spaces. However, this methodology is supported by literature of bone biomechanics and reveals complementary data to clinical follow up. Further studies using modified 3D finite element models and animal experiments, as well as longitudinal clinical observations are necessary.

CONCLUSION

It can be concluded that in increased vertical interarch space cases, the implant abutment selected should be of smaller diameter and of longer height in order reduce the stresses on the bone.

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How to cite this article: Rao S, Agarwal V, Guru R, Jacob PC, Sarkar SM, Lamsang T. Effect of Vertical Interarch Space, Implant Abutment Height and Diameter on Stresses in the Bone - A 3rd Finite Element Analysis. Ann. Int. Med. Den. Res. 2020; 6(1):DE12-DE16.

Source of Support: Nil, **Conflict of Interest:** None declared