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ORIGINAL ARTICLE

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Evaluation of Stress Distribution Among Two Different Pre-angled Abutments of Implants in Two Different Densities of Bone at Different Levels Along the Implant–*In Vitro* Study

[1]Nibha K Singh, [2]Suma B Chalapathy, [3]Roger P Thota, [4]Kiran Chakravarthula, [5]Ramesh Tirnati, [6]Kartheek Yenugupalli

ABSTRACT

Aim: The present study evaluated the stress distribution among two different pre-angled abutments of implants in two different densities of bone at different levels along the implant.

Materials and methods: The stress allocation was assessed and compared between the control group, i.e., 0° and two different pre-angled abutments, i.e., 10° and 20° in two different bone densities as D2 and D3, using the finite element analysis. The geometric configuration of the mandible was generated using Ansys version 14.5graphic pre-processing software. Young's modulus (E) of elasticity and Poisson's ratio (μ) of the material were integrated into the representation. Average vertical load of 150 N was applied on the central fossa and buccal cusp of the mandibular first molar. Highest values of von Mises stresses were observed in different bone densities and angulated abutments at different levels.

Results: With increase in the abutment angulation between D2 and D3 densities along implant abutment junction the percentage of stress concentration was maximum with the values being 0.05 %, 108.67% and 128% in 0°,10°, and 20° angulations respectively, whereas, along the implant, the percentage of stress was increased with 0.6 %, 98.55% and 115.6% in 0°,10°, and 20° angulation.

Conclusion: Stress concentration was observed maximum at the implant abutment junction irrespective of the angulations and the densities used and the value of stress concentration accumulated within the cortical bone increases with increase in bone density and angulation of the implant.

Clinical significance: These finding would aid in recognizing the importance of quality of cortical bone which and helps in avoiding the overloading of the implant abutment interface for the long-term prognosis of the implant.

Keywords: Bone density, Finite element analysis, Finite element models, Implant, Pre-angled abutments.

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[1,2,4,5]Department of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India

[3]Department of Oral And Maxillofacial Surgery, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India

[6]Department of Orthodontics, Lenora Institute Of Dental Sciences, Rajahmundry, Andhra Pradesh, India

Corresponding Author: Nibha K Singh, Department of Prosthodontics, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India, Phone: +919501544877, e-mail: drnibhakumari@gmail.com

INTRODUCTION

Dentistry aims at the replacement of missing teeth from the time it was first acknowledged as a career. Dental practitioners from centuries have depended on own abilities as well as relics to advance esthetic and useful substitutes to curtail sequelae that occur due to edentulism. Only a few archeological data have revealed efforts of fabricating prosthetic devices as more natural and functional alternates into edentulous jaws. Though, envisage of these approaches is not accomplished yet.[1]

The objective of modern dentistry is to reinstate the patient to the usual outline, utility, comfort, esthetics, speech, and health whether by removing caries or substituting numerous teeth. This would result from implant dentistry to achieve this aim irrespective of atrophy, disease or trauma to stomatognathicsystem.[2]

While planning fixed partial dentures (FPDs) biomechanical contemplations should play a central role supported by osseointegrated implants. Efficient loads applied on the prosthesis are conveyed through the

implants to the adjacent bone. However, under certain physiological limits a bone can tolerate stresses and strains, when it surpassed, alterations like resorption may occur.

The width and height of bone, accessible in the edentulous sites are the critical parameters which determine the location of an implant. Before the placement of the implant, it is also imperative to assess the angulation of the ridge. One of the major complications which is routinely encountered while implant placement is imperfect angulation.[2]

To overcome the complication of imperfect implant angulation, a technique called finite element analysis (FEA) which is a computer-based simulation and hence can be employed to evaluate strains and stresses positioned on solid objects. FEA comprises a mathematical calculation of physical properties that can be demonstrated. Though, that is arduous to generalize to humans as numerous assumptions essential to be made concerning biological factors. Other techniques available are like Photoelasticity and strain-gauge measurements. Photoelasticity method it provides restricted quantifiable evidence and strain-gauge measurements provide facts concerning strains only at the precise position of the gauge. So, FEA the one who is proficient in delivering comprehensive, quantifiable facts at any location within mathematical model.[3]

As per the collected work available, most of the finite element studies conducted on the angulated abutments was in the anterior maxilla[4,5] and minimal text is available on the study of stress distribution of angulated abutments in the mandibular first molar region and also it is the most common missing teeth to be replaced. Because of alveolar bone angulation and insufficient bone volume, there are frequent chances of offset placement of implants. In the view of above observations and the paucity of data the present study designed to appraise the distribution of stress among two different pre-angled abutments of implants in two different densities of bone at different levels along the implant.

MATERIALS AND METHODS

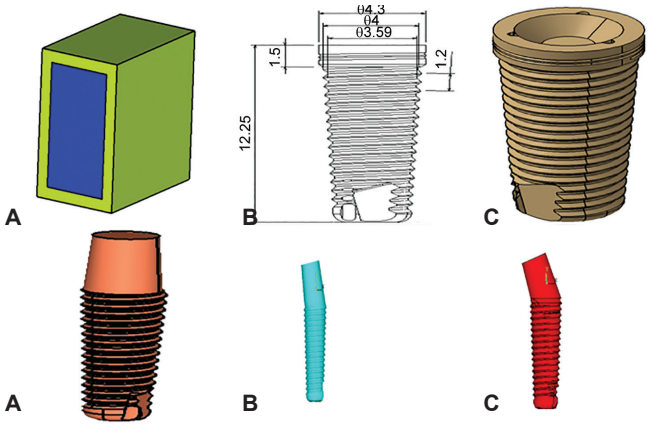
The current *in vitro* study was conducted in the department of prosthodontics in which distribution of stress was evaluated and equated among the control group, i.e., 0° and two different pre-angled abutments, i.e., 10° and 20° in two different bone densities as D2 and D3, using the finite element analysis. The required information was acquired from various sources like CT scan projection of the human mandible, Titanium endosseous root form implant (Noble biocare) and All ceramic crown (Cercon) are subjected to finite element procedure using software (Ansys version 14.5) which is a graphic pre-processing tool at Tejvi technical solution, Bengaluru, India for generating the geometric conformation of a segment of the mandible.

- Finite Element Modelling
- Finite Element Analysis

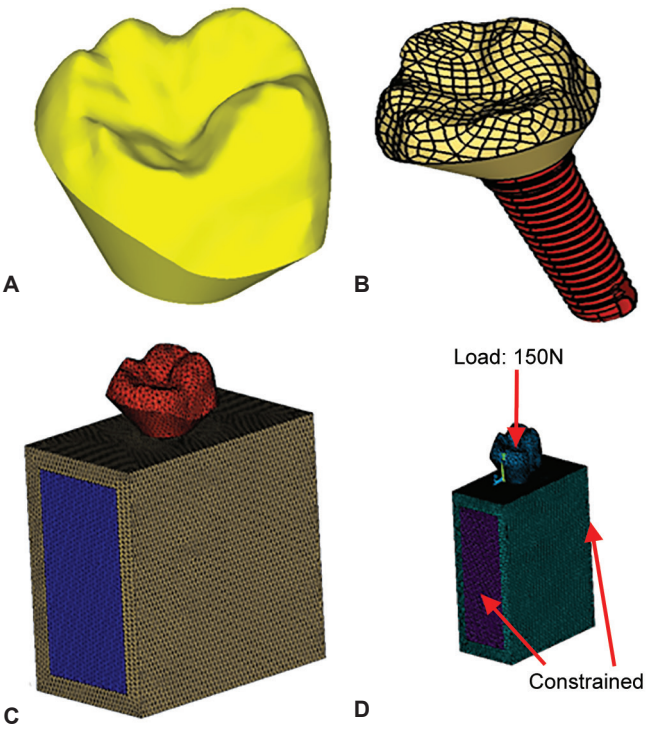
Finite Element Modelling

Computed tomography (CT) scan was used to acquire data at the mandibular first molar region which was further delivered to the computer, and a numeric template of the bone segment was generated for the production of a geometric template of bone. Two-millimeter thick cortical layer with a height of 25.6 mm and 16.3 mm width was present around the cancellous bone (Fig. 1). A three-dimensional (3D) template was generated of Nobel Biocare Replace implant with measurements comprising the diameter of 4.3 mm and length of 13 mm with a crest module of 1.5 mm consisting of microthreads at the side and the internal conical connection comprising thread pattern of "V" shaped. The data was procured from creators and implant was manufactured to the vital dimensions using CATIA software and located midway among the mesiodistal length of mandibular segment[5] (Fig. 2). Implant abutments of 5 mm height and 4.3 mm diameter with three different angulations of 0°, 10°, and 20° was generated on the implant model.[6]

The superstructure was fabricated on the mandibular first molar with the cervico-occlusal length of 7 mm, 10 mm mesio-distal diameter, 9.5 mm buccolingual width and an occlusal and lateral wall thickness of 2 mm. This geometry of the tooth was designed as per the data from the Wheeler's textbook of dental anatomy.[7] The implant, abutment and superstructure geometry was tetrameshed due to the complexity of the shapes of these structures using Solid 185 element program. Some



Figs 1: (A) Modelling of bone; (B) Dimensions of the implant Model; (C) Modelling of the Implant; (D) Implant with straight abutment; (E) Implant with 10° abutment; (F) Implant with 20° abutment



Figs 2A to D: (A) Modelling of crown; (B) Implant with abutment and crown; (C) Meshed structure; (D) Application of loads and constraints

calculations were done due to complexity in meshing. Meshing splits the body into a finite number of elements with each element having nodes and control points. The total number of elements and nodes are presented in Table 1.

For the precise analysis and elucidation of the program the material properties of cancellous bone, cortical bone, abutment, implant, and crown were incorporated. From the previously generated models, the Youngs modulus and Poissons ratio of all the materials were incorporated. Elastic parameters for various components were obtained from the manufacturer's specifications and literature. Two different types of bone densities were obtained by changing the elastic modulus of cancellous bone and compact bone, and it was presumed to be homogenous, linearly elastic and isotropic. Although anisotropic material characteristics are shown by cortical bone and has varied regional stiffness, it was modeled isotropically due to non-availability of adequate facts and trouble in instituting the principal axis of anisotropy. Table 2 illustrated the material properties of different components.[8]

The bone boundary regions, anterior and posterior both are constrained and bending of the model was permitted due to omitting of support at the bottom. In the vertical direction, the magnitude of the static load of 150 N was applied to mimic the clinical situation. Loads are applied at the central fossa and buccal cusps and displacement was analyzed at the nodes.[9] The modeled components, i.e., D2 and D3 (two different bone densities) with different abutment angulations of 0°, 10° and 20° through Finite element modeling, generated on to the implant model at the first molar region and 150 N axial load was applied at the central fossa and buccal cusps, followed by additional analysis.

Finite Element Analysis

The processor, i.e., solver was used to evaluating different models and results were demonstrated by postprocessor (ANSYS) using von Mises stress analysis in the form of color-coded maps. Von Mises stress values are demarcated as the commencement of distortion for ductile materials. When von Mises stress values are greater than the yield strength of an implant material, it leads to metallic implant failure. The FEA briefly studies

Table 1: Number of nodes and elements

	Control group	*10 degrees*	*20 degrees*			
Description	*Elements*	*Nodes*	*Elements*	*Nodes*	*Elements*	*Nodes*
Cortical bone	131409	30096	131901	30152	131636	30135
Cancellous bone	127742	26246	127830	26333	128249	26419
Implant-abutment	14950	3543	15959			
	3498	16800	4093			
Crown	12543	2971	12624	2969	12381	2904
Full model	286644	54359	287514	54461	289066	55129

Table 2: Material properties

Description	*Youngs moduli*	*Poissons ratio*
Cortical bone	13.7	0.3
Cancellous bone	1.30	30096
1.10	0.3	26246
0.3	14950	3543
Implant	117	0.28
Abutment	117	0.28
Crown	80	0.26

the overall state of stress at a point. Consequently, they are imperative for inferring the stresses that occur within the implant material. Stress distribution in the finite element model derives in mathematical value.

RESULTS

Table 3 demonstrates the von Mises stress along the implants in different bone densities and angulations at different levels, i.e., crown, implant-abutment junction and along the implant. At 0, 10 and 20° angulation, von Mises stresses at the crown region were recorded as 27.156 Mpa and 27.49 Mpa, 27.2297 Mpa and 34.5103 Mpa, 26.9196 Mpa and 41.1943 Mpa, at the implant-abutment junction as 39.822 Mpa and 39.8439 Mpa, 41.3331 Mpa and 86.25 Mpa, 43.0023 Mpa and 98.26 Mpa and along the implant body as 18.6685 Mpa and 18.7812 Mpa, 19.3065 Mpa and 38.333 Mpa, 20.2467 Mpa and 43.6711 Mpa in D2 and D3 bone density respectively.

Table 4 depicts the percentage of the stress along the implants in different bone densities and angulations at different levels. The percentage of stress in the crown was 1.23%, 26.74% and 26.74% in 0°, 10° and 20° angulations respectively. At the implant abutment junction was 0.05%, 108.67% and 128% in 0°, 10° and 20° angulations respectively, whereas, along with the implant, the percentage of stress recorded was 0.6%, 98.55% and 115.6% in 0°, 10° and 20° angulation.

Table 5 demonstrates the von Mises stresses around the implants with two different angulations in different bone densities. At 0, 10 and 20, von Mises stresses in the cortical bone for D2 and D3 bone densities were (7.9894 Mpa and 10.7688 Mpa), (9.5762 Mpa and 13.3517) and (9.6939 Mpa and 16.178 Mpa) whereas in the cancellous bone; it was (1.8160 Mpa and 3.1165 Mpa), (1.9824 Mpa and 3.2161 Mpa) and (3.0499 Mpa and 4.8496) Mpa respectively.

Table 6 demonstrates percentage of the von mises stresses around the implants in different angulations in different bone densities. In between D2 and D3 bone densities the percentage of stress concentration in the cortical bone was 34.79%, 39.43 %, and 66.89%, in the cancellous bone was 71.69%, 62.23% and 59.01% in 0, 10 and 20° respectively The percentage of stresses are 34.79% and 71.69% in cortical and cancellous bone with 0° angulation, In 10°, the stresses are 39.43% and 62.23% in cortical and cancellous bone respectively whereas in 20° the stresses are 66.89% and 59.01% respectively.

DISCUSSION

It is mandatory to establish an appropriate balance between anatomical and prosthetic structures while inserting an

Table 3: Comparative data of Vonmises stresses along the implants in different bone densities and angulations at different levels

Description (Stress in MPa)	*0° Angulation*		*10° Angulation*		*20° Angulation*	
Densities	*D2*	*D3*	*D2*	*D3*	*D2*	*D3*
Crown	27.1560	27.4900	27.2297	34.5103	26.9196	41.1943
Implant-abutment junction	39.8220	39.8439	41.3331	86.2500	43.0023	98.2600
Along the implant	18.6685	18.7812	19.3065	38.3333	20.2467	43.6711

Table 4: Percentage of the stress along the implants in different bone densities and angulations at different levels

Densities	*D2 TO D3*	*D2 TO D3*	*D2 TO D3*
Abutment angulations	0 degrees	10 degrees	20 degrees
Crown	1.23	26.74	26.74
Implant-abutment junction	0.05	108.67	128.50
Along the implant	0.60	98.55	115.69

Table 5: Comparison of Vonmisesstresses around the implants in different angulationsin different bone densities

Description (Stress in MPa)	*0° angulation*		*10° angulation*		*20° angulation*	
Densities	D2	D3	D2	D3	D2	D3
Cortical bone	7.9894	10.7688	9.5762	13.3517	9.6939	16.178
Cancellous bone	1.8160	3.1165	1.9824	3.2161	3.0499	4.8496

Table 6: Percentage of the Vonmises stresses around the implants in different angulations in different bone densities

Densities	*D2 TO D5*	*D2 TO D3*	*D2 TO D3*
Abutment angulations	0 degrees (%)	10 degrees (%)	20 degrees (%)
Cortical bone	34.79	39.43	66.89
Cancellous bone	71.61	62.23	59.01

implant, for the implant to be successful. The bone width can be a limiting factor; subsequently, the clinician can select an angled abutment to attain prosthetically desired parallelism between implants or teeth.

Several types of predesigned abutments with specific angles which vary from 5° to 35° are commercially are available. Besides, for a satisfactory prosthetic reconstruction, a laboratory technician can also fabricate custom abutments with needed contours. Moreover, in case of implants placed with buccolingual or mesiodistal misalignment, angled abutments facilitate restoration, and these angulated abutments pose problems of undesirable stress locations.[10]

Before one anticipates restoration utilizing pre-angled abutments, not only the function of the prosthesis, correspondingly its physiologic effects on the underlying bone should be considered.[11] Although the studies on bone qualities and angulated abutments to implant failure have been well established individually, however, the clear-cut association between quality of bone and distribution of stress in angulated abutments was not well recognized. In the present in-vitro study, a model of the implant and bone density was established in the mandibular first molar region to appraise the effect of two different angulated abutments in two different bone qualities around and along the implant using FEA.

In the present study, the observed von Mises stresses in D2, and D3 cortical bone was 13.35 Mpa and 16.18 Mpa which was lesser than the values observed by Sevimay et al.,[8] where the values were recorded as 90 Mpa and 113 Mpa in D2 and D3 densities respectively. This is most likely due to the differences in the moduli of elasticity of cortical and cancellous bone of D2 than D3 bone qualities and decreased implant-bone contact area. The "strength of materials" principle states that if the implant supporting tissues has homogenous elastic properties, the axial load transmitted from implant to bone concentrates highly in the upper region of bone and decreases rapidly towards implant base.[12] The load-bearing capacity of cancellous bone decreases while elasticity increases because of its low modulus of elasticity

This increased levels of von mises stresses in this study was concurring with the studies conducted by Lin and colleagues in which single implants were used to draw analysis and reported that in case of 20° angled abutment, implant and cortical bone strain was higher as compared to straight abutments and as bone density decreased, the bone strain increased. In another study, Clelland and colleagues used a 3D FEA model of the maxilla and reported that as abutment angulation increased, stress and strain becomes greater.[11-13]

In the current study, it was witnessed that with an increase in the abutment angulation between D2 and D3 densities along the implant the stress concentration in the crown was almost constant with the values being 1.23%, 26.74% and 26.74% in 0°, 10° and 20° angulations respectively. At the implant abutment junction the percentage of stress concentration was maximum with the values being 0.05%, 108.67% and 128% in 0°, 10° and 20° angulations respectively, whereas, along the implant, the percentage of stress was increased with 0.6, 98.55 and 115.6% in 0°, 10°, and 20° angulation. This observation clearly directs that with an increase in the angulation, the percentage of stress concentration will be greatest at the implant abutment junction. When compared with other studies, the values obtained in this study was comparatively lesser due to the implication of internal conical implant-abutment junction and due to the advantage of micro-threads on an implant collar, with threads it creates a heterogeneous stress field, changing the loading force vectors in the neighboring bone.[14] Disparaging tensile and shear forces on bone are converted by the threads into more favorable compressive forces which leads to an overall reduction of vectors of tensile and shear forces in the heterogeneous stress field.[15] These values are in agreement with the values obtained by Clelland et al.[12] etc. This may be because in implants joined by the internal screw creates a preload or over clamping forces between implant abutment and fixture and increase in shear forces because of the increase in angulation of abutments.

Like other studies, certain limitations of our present study were, firstly the consideration of vital anisotropic tissues as isotropic and during function, dynamic loading was seen even though the loads applied were static loads. Even though one type of implant design was used in the present study, however various implant designs could be studied to enhance the research. The mathematical calculations based on simulation of structure in the environment are the concept behind Finite element analysis. On the other side, as biology is not a compatible entity, therefore living tissues are beyond the limits of set values and parameters. Henceforth, although finite element analysis offers a theoretical basis of the behavior of a structure in a given environment, however, it should not be considered merely. Definite clinical trials and experimental methods must follow finite element analysis to institute the actual character of the biological system.

CONCLUSION

The present study concluded that, the clinicians who opt for the angled abutment should consider the quality of cortical bone and utmost importance should be given at the implant-abutment interface because in the present

it was clearly observed that accumulation of stress concentration was recorded highest at implant-abutment interface, so it is recommended to minimize overloading at this location for the long-term prognosis of the implant.

REFERENCES

1. Rodrigo F. Neiva, Horn-Lay Wang, Jianping Geng. Application of finite element in implant dentistry. Zhejiang University Press, Hangzhou and Springer; 2008.
2. Misch CE. Contemporary Implant Dentistry. 3rd Edition. USA: Mosby Elsevier Publication; 2008.
3. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature: J Prosthet Dent 2001; 85(6):585-598.
4. Saab Jason A, Griggs John M, Powersand Robert L, Engel meier. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: A finite element study: J Prosthet Dent 2007; 97:85-92.
5. Kallus T, Henry P, Jemt T, Jorneus L. Clinical Evaluation of Angulated Abutments for theBrånemark System: A Pilot Study. Int J Oral Maxillofac Implants 1990;5(1):39-45.
6. Malo P, de Araújo Nobre M, Lopes A, Moss SM, Molina GJ. A longitudinal study of the survival of All-on-4 implants in the mandible with up to 10 years of follow-up. The Journal of the American Dental Association. 2011 Mar 1;142(3): 310-320.
7. Nelson S. Wheeler's Dental Anatomy, Physiology and Occlusion10thEdition. USA: Saunders Elsevier Publication; 2014.
8. Sevimay M, Turhan F, Kilicarslan MA, Eskitascioglu G. Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown: J Prosthet Dent.2005; 93(3):227-234.
9. Richter EJ. In Vivo Vertical Forces on Implants: Int J Oral Maxillofac Implants. 1995 Jan-Feb;10(1):99-108.
10. Cavallaro J Jr., Greenstein G. Angled Implant Abutments: A Practical Application of available Knowledge. J Am Dent Assoc. 2011; 142:150-158.
11. Choi KS , Park SH, Lee JH, Jeon YC,Yun YC,Jeong Chang-mo, Stress Distribution on Scalloped Implants with Different-Microthread and Connection Configurations UsingThree-Dimensional Finite Element Analysis: Int J Oral Maxillofac Implants 2012;27:29-38.
12. Clelland NL, Gilat A, McGlumphy EA, Brantley WA. A photoelastic and strain gauge analysis of angled abutments for an implant system: Int J Oral Maxillofac Implants 1993;8(5):541-548
13. Tada S,Stegaroiu R, Kitamura E, Miyakawa O, Kusakari H. Influence of Implant Design and Bone Quality on Stress/Strain Distribution in Bone around Implants: A 3-dimensional Finite Element Analysis. Int J Oral Maxillofac Implants 2003;18: 357–368.
14. Brosh T, Pilo R, Sudai D. The influence of abutment angulation on strains and stresses along the implant/bone interface: comparison between two experimental techniques: J Prosthet Dent 1998; 79(3): 328-334.
15. Quaresma SE, Cury PR, Sendyk WR, Sendyk C. A finite element analysis of two different dental implants: stress distribution in the prosthesis, abutment, implant, and supporting J Oral Implantol. 2008;34(1):1-6.