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Evaluation of Stress Patterns in Bone Around Implants for Different Abutment Angulations Under Axial and Oblique Loading in Anterior Maxillary Region—A Finite Element Analysis

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Abstract

Introduction Replacing missing anterior teeth with a prosthesis that resembles natural form and function has always been challenging for a prosthodontist. Removable and fixed options both have been extensively studied and researched upon. In modern dentistry, implants have proved to be a more logical option for the same. The morphology of bone present in the premaxilla serves as guide to plan implant angulation during osteotomy. Factors such as age-related bone resorption, trauma or pathologic bone resorption due to periodontitis, etc. causes implants to be placed at angles that are difficult to restore with conventional straight abutments. Angled abutments can help build up favorable functional prosthesis in such cases, but they experience the drawback of transferring unfavorable forces to the implant or bone, thereby compromising the prognosis of the treatment. Clinically, the effect of these forces is difficult to evaluate, so a finite element analysis was done to estimate stress distribution at the bone implant interface.

Materials and Methods In this study, premaxilla was modeled with 15 mm in bone height, 7 mm in bone length, and 12 mm in bone width with 1.5 mm thick cortical bone surrounded by a core of cancellous bone. The implant was modeled as a cylindrical, round-ended device with dimensions, 4.3 mm × 11.5 mm. Abutments with angulations 0°, 10°, 15° and 25° were used. To simulate clinical conditions, a 100 N load axially and 30 N load obliquely was applied.

Result It was seen that, as the abutment angulation changes from 0° to 25°, both the compressive as well as tensile stresses increased; however, they were within the tolerance limit of the bone.

Conclusion The study suggests angled abutments can be used with reasonable success, keeping in mind the basics of implant prosthodontics intact.

Keywords
- angulated implant abutment
- dental implant
- finite element analysis
- Osseo integration
- stress analysis

Introduction

Appearance plays an important role in lives of most individuals, and any dental restoration in esthetic zone with less than optimal aesthetics is probably not accepted by the patient. Replacing missing anterior teeth in form and function presents considerable challenges to the prosthodontist because of the patient's high-expectation and complex anatomy of the maxillary anterior zone. To preserve remaining natural teeth and creating a life-like emergence profile for

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the prosthesis dental implants have gained favor with regard to restoring patients' function and aesthetics and hence his or her confidence.[1]

Temporomandibular joint is one of the most dynamic joints in the human body and can produce varying degrees of complex forces on both the tooth and its supporting structures. Once a tooth is lost in oral cavity, rehabilitating it with any kind of prosthesis is even more challenging. Among all prosthetic options available, implants provide the most conservative approach; however, they have limitations. Implants are placed within the cortex of the residual bone, and in patients with unconventional bone morphology where either the bone is deficient or at angle to the occlusal plane, they have to be placed at angles difficult to rehabilitate. By nature, bone is a self-adaptive material, where bone deposition and resorption is part of a continuous process influenced by external force factors and bone physiology. This is known as bone remodeling. This bone remodeling includes both bone density and bone shape. Bone remodeling caused by physiologic biological stress is one of the major factors causing implant failure. This is defined as stress-shielding effect.[2]

Aesthetic as well as anatomic limitations sometimes can affect placement of implants at angles that are not easy for prosthetic restorations. The amount of available bone, bony defects such as dehiscence or undercuts, interarch jaw relation, and residual arch contours are important considerations in implant placement. The morphology of existing bone in the premaxilla and angulations of adjacent teeth often cause implants to be placed at angles that can affect the success of prosthetic treatment if restored with conventional straight abutments. This problem can be managed by using angled abutments available with angles ranging between 10 to 45 degrees.

Also, customized angled abutments can be casted and used to create an acceptable profile.[3] Angled abutments have advantages like facilitating paralleling nonaligned implants; helping the dentist in placing the implants away from anatomical critical areas; and avoiding need to perform complex bone regeneration procedures.[4]

However, the angulated abutments have the disadvantage of transferring unfavorable forces to the bone implant abutment interface, thereby affecting treatment outcome. Due to the complex biomechanical behavior of oral musculature, clinically, it is impossible to assess the biologic forces generated on the implant and nearby bone.[5]

Since, it is clinically not feasible to assess the functional forces generated, a three-dimensional (3D) finite element analysis was conducted in the present study to evaluate mathematical stress distribution at implant abutment interface with different abutment angles.

Materials and Methods

The present 3D finite element analysis was done in the Department of Prosthodontics, Bhojia Dental College and Hospital, Baddi, in collaboration with ATC Rediff Cadd Centre S.C.O. 128–129, 2nd floor, HUDA, Sector–17, Jagadhari Yamunanagar, Haryana, using image scanner. Scanning of implant was done by 3DSS (Imetric 3D GmbH, Germany), surface data of the bone model was generated using Fusion 360 (Autodesk), and stress analysis was performed using ANSYS 15.0v software (ANSYS 15.0v, Inc, and USA). The maxilla was virtually modeled with a core of cancellous bone encapsuled inside cortical bone with a thickness of 1.5 mm (►**Fig. 1A, B**). Bone composition representing D3 bone was used (65% of bone in anterior maxilla is D3).[6] Implant shape were created as cylindrical and round-ended, with dimensions 11.5 mm × 4.3 mm (►**Fig. 2**). Finite element mesh of implant model (►**Table 1**) and bone (►**Table 2**) were generated by a network of fine elements and nodes, and then the mechanical properties of the material (►**Table 3**) and physical properties of bone model (►**Table 4**) were assigned. Four abutment angulations—0°, 10°, 15° and 25°—were used.

The implants models were then subjected to oblique and axial loadings. An axial load of 100 N (►**Fig. 3A** and **3B**) and oblique load of 30 N was kept constant. The axial load of 100 N and oblique load of 30 N were selected on the basis average force generated in natural dentition during function.

Results

After load application in software compressive and tensile stresses were interpreted and evaluated within the bone, test load was applied in four groups. In the first group, the implant model was configured in the section of the bone and 0° abutment was placed onto it. Similarly, in the second and third and fourth groups, 10°, 15° and 25° abutments were used on the same implant configuration and the von mises, compressive and tensile stresses were calculated at 100 N axial load (►**Fig. 4A,B**) and at 30 N oblique load (►**Fig. 5A,B**). Data collected was statistically analyzed. (►**Tables 5** and **6**, ►**Figs. 6** and **7**)

Discussion

Evolution in material and science of dental implants has led to its use in modern dentistry as an everyday procedure. Replacement of missing teeth with dental implants has been reported to be highly successful, although it comes with its own share of failures and complications. Bone loss around implants, fracture of implant prosthetic components, etc. are commonly faced complications in implant procedures.

During the course of evolution of dental implant, the focus has shifted from mere placing an implant in bone to long-term successful osseointegration of implant and finally

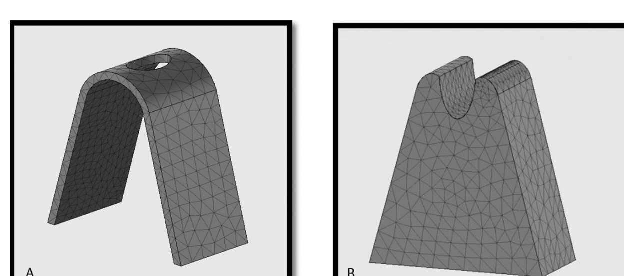

Fig. 1 (**A**) 3D finite model (cortical bone). (**B**) 3D finite model (cancellous bone).

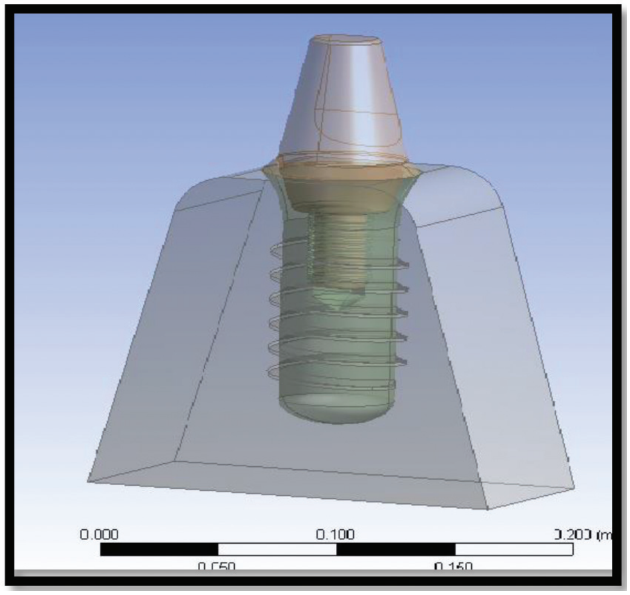

Fig. 2 Implant model with abutment inserted in the bone model.

Table 1 Number of element and nodes generated for implant model

Model	Number of elements	Number of nodes
Implant	13823	20790

Table 2 Number of element and nodes generated for bone model

Model	Number of elements	Number of nodes
Cortical Bone	15167	23488

Table 3 Material properties of implant Nobel biocare implants

Mechanical Properties	S.I Units
Tensile strength	1085 Mpa
Yield strength	945 Mpa
Elastic modulus	106 Gpa
Poisson's ratio	0.35
Elongation	22%
Outer thread diameter	4.3 mm
Inner thread diameter	3.5 mm
Thread depth	0.4 mm
Thread pitch	1.6 mm

Table 4 Physical properties of component of bone model

Bone type	Young's modulus (Mpa)	Poisson's ratio
Cortical bone	14700	0.3
Dense trabecular bone	1470	0.3
Low density trabecular bone	231	0.3

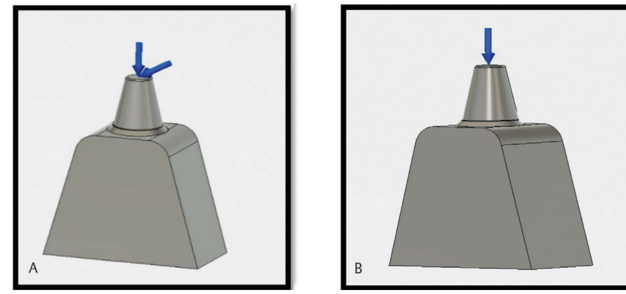

Fig. 3 (**A**) Finite element model and definition of load direction at oblique load of 30 N. (**B**) Finite element model and definition of load direction at axial load of 10 0N.

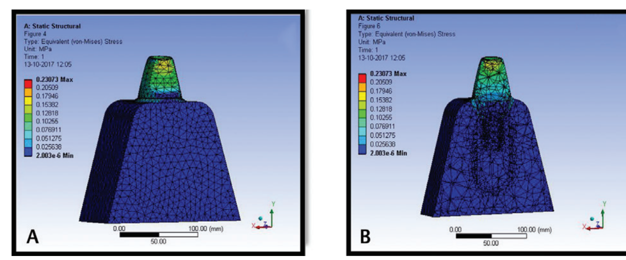

Fig. 4 Finite element model showing IFP of stress distribution for 100 N axial load on 0°of implant abutment with nodes. (**B**) FE model showing IFP of stress distribution for 100 N axial load on 0°of implant abutment with nodes (cross-section). IFP, isochromatic fringe patterns.

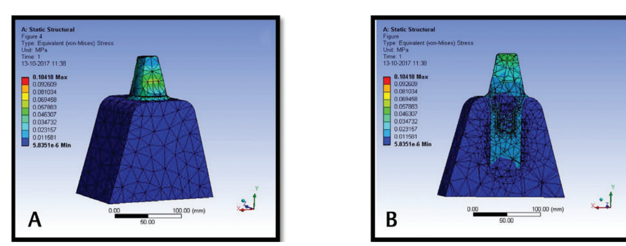

Fig. 5 (**A**) Finite element model showing IFP of stress distribution for 30 N oblique load on 0°of implant abutment with nodes. (**B**) FE model showing IFP of stress distribution for 30 N oblique load on 0°of implant abutment with nodes (cross-section). IFP, isochromatic fringe patterns.

placing an implant, with the main goal to be able to restore it aesthetically in order to be as close to nature as possible.

Bone morphology sometimes restricts placement of implants in the bone at angles that are not ideal for prosthetic rehabilitation. Due to slight inclination in bone morphology in anterior maxilla, implants are often placed at angles not parallel to natural tooth.[7] Customized preangled implant abutments have been designed as a prosthetic option for dentists to restore implants that are otherwise difficult to load.

To determine the precise degree of angulated abutment best suitable for longevity of prosthetic, rehabilitation involves in-depth evaluation of anatomical and functional parameters for every individual case. Mechanical factors influence the internal and the external structure of bone. Effect of external forces on bone response can be evaluated by either the stress

Table 5 Descriptive Von Mises stress values with axial load (100 N) on implants with different abutment angulations in bone (considered as one body)

Group	N	Mean	SD	Standard error mean
0 degree	10	.315	.596	.188
10 degree	10	.412	.983	.311
15 degree	10	.991	.661	.212
25 degree	10	1.29	1.68	.533

Table 6 Descriptive Von Mises stress values with oblique load (30 N) on implants with different abutment angulations in bone (considered as one body)

Group	N	Mean	SD	Standard error mean
0 degree	10	.635	1.82	.577
10 degree	10	.443	1.06	.337
15 degree	10	.326	0.97	.292
25 degree	10	.937	1.15	.365

Abbreviation: SD, standard deviation.

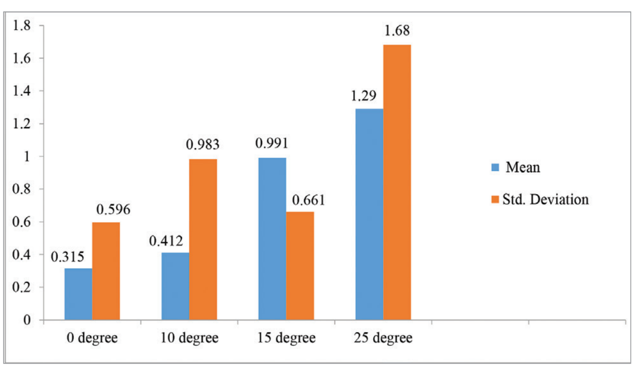

Fig. 6 Descriptive statistics of all of the groups in the direction.

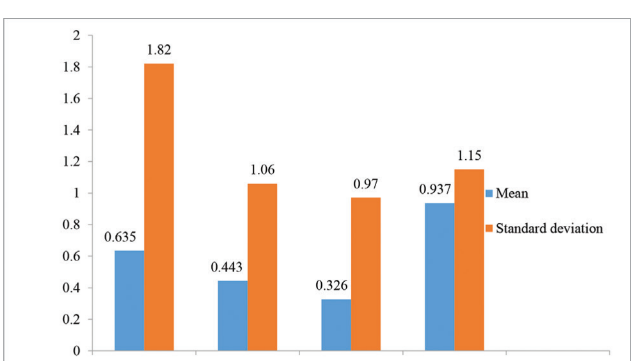

Fig. 7 Descriptive statistics of all of the groups in the oblique direction.

or the strain applied. Bone cells deform on strains applied beyond their strength.[8] The purpose of this investigation was to compare stress and strain produced through three different abutment angulations for a specific implant system.

Implants placed at angles not ideal for prosthetic rehabilitation can affect treatment outcomes in terms of esthetics, biomechanics and postop complications in hygiene maintenance. An angled abutment may come to our rescue in such situations. Angled abutments may affect the kind of loads transferred to the bone.

In premaxilla region, due to insufficient bone, implants are often placed at angles where abutments reflect too labially, affecting lip position, function and phonetics. In such cases, customized or premilled angled abutments can be used to correct abutment angulations for a better prognosis. However, placing angled abutments might transfer undue stress on the crestal bone, risking the prognosis of treatment.

The stresses incorporated in the biologic environment can be studied by using one of the following methodologies:

1. Photoelastic method.
2. Strain gauge analysis.
3. Finite element method/analysis.

Among the three methods in the present study, finite element analysis was used since it is capable of mathematically providing detailed quantitative and qualitative data. The finite element analysis helps in estimating stress distribution around implant abutment interface. With the help of finite element analysis, the mechanical behavior of the bone and implant system under stress can be evaluated.

Finite element analysis is an analysis dependent on multiple factors such as simulation of biologic factors in study models like bone contours, bone geometry, implant design, bone–implant interface, and precise application off load masticatory load on the study model. The finite element analysis findings should be further verified in clinical environment on long-term and short-term study basis. In the study, results were generated both numerically and graphically. For principle stresses, the negative values reflected compressive stresses and positive values reflected tensile stresses.

In the present study, when an axial load of 100 N was applied on implant abutment placed parallel to the implant body, that is, at 0 degree, it was observed that a Von Mises stress of 0.19421 maximum and 1.9121 minimum were recorded. Also, when an oblique load of 30 N was applied, von miss stress of 0.10418 maximum and 5.8351 minimum was recorded (►**Table 7**). These stress figures were found to be in tolerable limit to have any kind of pathologic effect on crestal bone surrounding the implant. These findings are in contrast to what Bahuguna et al observed.[1] In his research for stress around implant in 0 degree-angled abutment, maximum compressive stress was 1.106 and tensile strength was 1.410.

Table 7 Maximum and minimum stress on axial and oblique load at various angulations

	Axial–100 N		Oblique–30 N	
	Maximum stress	Minimum stress	Maximum stress	Minimum stress
0 degree	0.194	1.912	0.104	5.8351
10 degree	0.184	3.208	0.191	3.480
15 degree	0.198	0.00012	0.252	0.00012
25 degree	1.399	5.955	1.051	4.1157

Celland[8] et al in their study used only axial loading of 178 N. The results of their study correlated with the observations of the present study for 100 N axial loading. In the present study, compressive forces of 3.271 Mpa and 5.9 Mpa were recorded for 20° abutments and for 25°, respectively.

Ming-Lun Hsu[5] et al in their study assumed the occlusal force to be 178 N. This force was applied to an implant-supported prosthesis to simulate a real loading condition. In dentate individuals, it has been observed that there is a range of variation in maximum biting force generated among different individuals and at different regions in the same arch and in same individual.

In his study Ming used bite force recorder; average forces of more than 800 N for young male adults and 600 N for young female adults were recorded in the molar region. Forces of 290 and 240 N, respectively, were recorded in the incisal region. The variation may be related to many factors such as muscle size, bone shape, age, sex, degree of edentulism and parafunction.

Application of functional forces mathematically on implant model in 3D finite element analysis reflected stresses and strains produced within the implant–prosthesis complex to be within a range that the bone can tolerate; however, it has been observed that certain biologic factors like patient oral habits, quality and quantity of bone around implant affects the bone remodeling process around the implant with angled abutments. Excessive forces on implant-supported prostheses can also impair osseointegration or induce bone resorption. Therefore, when evaluating the stresses and strains in the bone, it is essential to consider the occlusal force.

To reduce the risk of biomechanical overload and increase the long-term success of the dental implant, the magnitude of the occlusal force, even the direction and the duration, must be considered in the treatment planning stage. In a comparative analysis, the complexity of real-life situations can be simplified, assuming that proportions and relative effects accurately reflect reality.

In their study, the author varied the direction of the force to create an unfavorable loading situation in the anterior maxilla. In reality, unfavorable loading situations are more due to increased bone resorption after tooth loss. Varying the bone geometry and implant inclination, according to various levels of maxillary resorption, would have more accurately simulated situations observed clinically.

Conclusion

On the basis of the finite element analysis conducted to evaluate stress patterns in bone around implants for different abutment angulations under axial and oblique loading in anterior maxillary region, it can be concluded that the functional forces produced during mastication and other eccentric movements can be well-tolerated by bone loaded with implants having angled abutments (up to 25 degree). However, a complete assessment of every patient should be done for bone and force factor analysis before planning angled abutments to minimize postoperative risk factors.

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Conf ict of Interest
None declared.

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