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Peri-implant stress distribution in axially loaded implant and angled corrected smart abutment in maxilla: 3d Finite Element Study

[1]Sejal Gopani, MDS, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

[2]J R Patel, Professor & Provost, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

[3]Vilas Patel, HOD & Dean, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

[4]Sareen Duseja, Professor, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

[5]Avani Patel, Reader, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

Corresponding Author: Sejal Gopani, MDS, Department of Prosthodontics, Crown, Bridge & Implantology Sankalchand Patel University, Visanagar

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Abstract

Aim: To evaluate peri-implant stress distribution in axially loaded implant and angled corrected abutment in posterior maxilla by finite element analysis.

Purpose of the study: Objective of this study was to comparatively evaluate the peri-implant stress distribution of dental implants with different angled placed implant corrected abutment.

Materials and method: To study implant stress distribution on maxillary bone, three finite element analysis models (A, B & C) were made in computer software; one model of conventional axially placed implants with straight abutment and two models of angled corrected smart abutment in posterior maxilla.

In all models, all titanium alloys 4 implant (noble bio-care) were placed in posterior maxilla with, 4mm diameter and 11mm length. In model A, all implant were placed axially in premolar region and molar region unilaterally. The distance between two premolar was 8 mm and 10 mm between molars. In model B 4 implants were placed with 15^0 angled abutments and in model C implant were placed with 30^0 angled corrected abutments.

The different structures used in FEA model were assigned as according to their respective material properties i.e. Young's modulus and Poison's ratio. Axial load of 35N, 70N and 100N was applied axially and obliquely into the central fossa of prosthesis. Restorations were placed on and tested under standard conditions.

Result: When vertical load (35N, 70N or 100N) was applied**,** stresses(overall displacement, overall stress, cortical stress) were more with 15^0 placed implant with 15^0 angled abutment followed by 30^0 placed implant with 30^0 angled abutment and axially placed implant. However, other stresses (cancellous stress & implant stress) were minimal in difference. With oblique load (35N,70N,100N) all stresses (overall displacement, overall stress, cortical stress, implant stress) were found to be more with 15^0 placed implant followed by 30^0 placed implant and axially placed implant.

Conclusion: Within the limitations of the present study, following conclusions were drawn:-

1. For the axially placed implant with the straight abutment (Model A), when vertical and oblique load (35N, 70N, 100N) were applied, all stresses (overall displacement, overall stress, cortical stress, implant stress, cancellous stress) were increased gradually as load was increased.
2. For the 15^0 & 30^0 placed implant with the angled (15^0, 30^0) abutment (Model B & C), when vertical and oblique load (35N, 70N, 100N) were applied all stresses (overall displacement, overall stress, cortical stress, implant stress, cancellous stress) were increased gradually as load was increased.
3. When overall stresses were compared in all 3 models, with applied vertical and oblique load, maximum stresses (overall displacement, overall stress ,cortical stress, implant stress, cancellous stress) were generated under 100N load in the 15^0 placed implant with 15^0 angled abutment followed by 30^0 placed implant with 30^0 angled abutment and axially placed implant.
4. When overall stresses were compared with 15^0 placed implant with 15^0 angled abutments (Model B) and 30^0 placed implant with 30^0 angled abutments (Model C), stresses were more in 15^0 placed implant.

Keywords: implant- abutment placement, stress distribution, angled abutment, straight abutment, vertical load, oblique load, Finite Element Analysis

Introduction

Dental implants are considered as one of the most successful treatment options for replacing missing teeth after discovery of the osseointegration concept by Branemark in the 1950s[1]. After the loss of teeth there will be a substantial amount of change in the morphology of alveolar bone. Bone quality is also important factor, with more failures found in bone of lower density.[2,3] A frequent barrier to optimal implant placement in posterior maxilla is the presence of bony irregularities. The operator may place the implant such that loading will be directed down the long axis of the implant, with the possible risk of decreased thickness of investing bone. lack of bone volume always result in exposure of implant surface, decreased bone–implant interface and finally implant failure. This can be managed either by surgical correction or by positioning the implant in the area with the greatest available bone, with the intention of correcting the implant alignment at the time of implant restoration.[4]

In clinical situations, severely resorbed bone may result in improper implant arrangement, which can cause inequalities between the implant long axis and the abutment long axis. Under such circumstances, difficulties will be certainly encountered in future prosthesis fabrication. Two options are available to overcome such problems: the angled implant and the angled abutment.[5] Angled implants are a quite recent solution aiming at a better adjustment of the implant shape to physiological bone characteristics, without decrease in functionality.[6] A variety of pre-angled abutments are available at specified divergence angles with the range of 15^0 to 45^0. Additionally, custom-angled abutments may be cast to the profile necessary for an acceptable prosthetic outcome.[7] The advent of angled abutments has simplified the management of situations when implant placements are suboptimal. Dentists understand the risks involved when restored prostheses are subjected to non-axial loading. It has always been recommended to direct occlusal loads as close to the long axis of the fixture as possible. However, it is known that the loading on angled abutments is mostly off-axis, which raises the concern of how angled abutments generally perform with such an unfavorable loading regimen.

Two- and three-dimensional finite element analyses have been used to evaluate the stresses around various dental implant systems using a model of the posterior maxilla. For the present study, a three dimensional finite element model of the maxilla was needed but had not been developed.[8] The purpose of the present study was to evaluate peri-implant stress distribution in axially loaded implant and angled corrected abutment in posterior maxilla by finite element analysis. the null hypothesis of the study was, there was no difference in peri-implant stress distribution between axially loaded implants and angled corrected abutment in posterior maxilla by Finite Element analysis.

Materials and method

A three dimensional finite element study was undertaken to create model and analyse the situation. Finite element analysis was chosen to determine the stress and strain around the dental implant and to study the mechanical behavior of complex structures easily by dividing the complex structures in to numerous small simple structures.[9]

Implant model

Three Models of edentulous posterior maxilla were prepared with 3-D Finite Element Models. Models were named as A, B & C (Table-1). In models, all Ti alloy implants (4mm width and 11mm length) were placed axially with straight abutments and different angled implants are placed in 15^0 and 30^0 with angled corrected abutment in the region of premolar and molar area in maxilla. Two implants were placed 8 mm away from each other on premolar area, other two implants placed 10 mm apart from each other in molar area on one side of the arch with cement retained prosthesis. Computerized tomography of maxilla was used to obtain the finite element model of the maxillary bone.

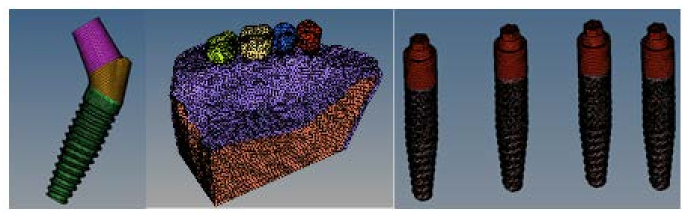
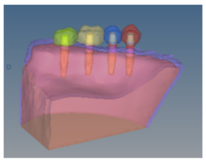
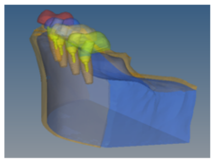
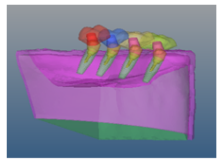


Fig.1: Implant geometry & outer model for all the configurations

A three dimensional finite element model of posterior maxilla was created using a computerized tomography image. The scanned image was entered into a computer software program (ANSYS R18.8). Cross-sections were reassembled to get the three dimensional model of the posterior maxilla. Thus total number of three simulated maxillary models were generated. All the materials used in the models were considered to be isotropous, analogous, and linearly elastic. The osseointegration of implant was accepted as 100%. Since there are no universally accepted properties of the biologic materials available in the literature, a mean value of the material properties has been used in the present study and has been tabulated in **Table 2.**

Table 1: Model A, Model B, Model C

Model-A	Model-B	Model-C
Axially loaded implant with straight abutment	15° angled loaded implant with smart (15° angled) abutment	30° angled loaded implant with smart (30° angled) abutment
		

The bone-implant interface was assumed to be perfect, simulating complete osseointegration. Therefore, the connections between implant-cortical and implant-cancellous bones were designed to be bonded as the interface between cancellous and cortical bones. Within the implant system, FEM modeling was performed by applying bonded situations on the abutment-implant interfaces. The entire structure was presented by setting all 6 degrees of freedom of mesio-distal surfaces of cancellous and cortical bones to zero.

Table 2: Material properties assigned to material simulated

Material	Young's modulus (MPa)	Possion's Ratio
Cortical bone	14,700	0.3
Dense trabecular bone	1470	0.3
Low density trabecular bone	231	0.3
Gold alloy (prosthesis)	90,000	0.3
Titanium(implant system)	110,000	0.35

Loading condition

In this study, axial and oblique load of 35 N, 70N, and 100N applied over the central fossa of the maxillary posterior tooth simultaneously.

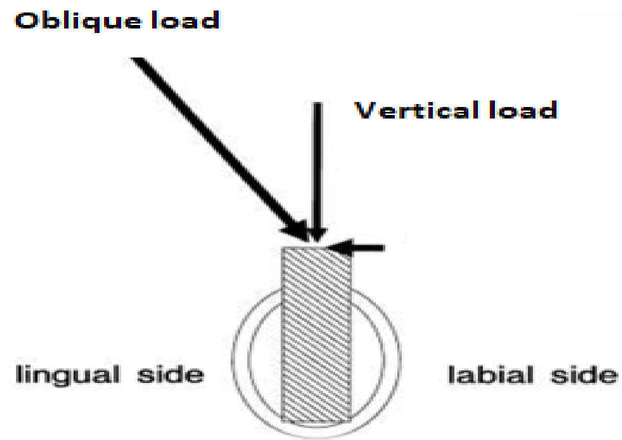


Fig.2: Loading direction

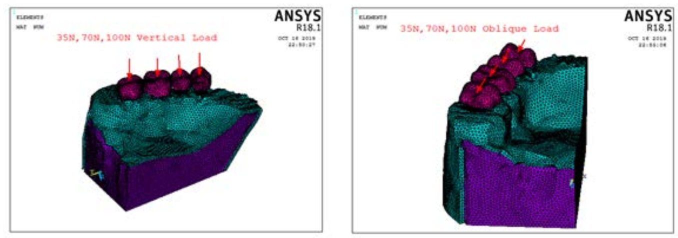


Fig.3: Direction of load

Results

In Model A, implants were placed axially with straight abutments & axial and oblique load of 35N, 70N and 100N were applied in central fossa of the maxillary premolar and molar teeth. In Model-B, implants were inclined 15^{o} with angled abutment (15^{o}) axial and oblique load of 35 N, 70 N and 100N were applied in central fossa of the maxillary premolar and molar teeth. In Model C, implants were inclined 30^{o} with angled abutment (30^{o}) & axial and oblique load of 35 N, 70 N and 100N were applied in central fossa of the maxillary premolar and molar teeth.

Table 3: Values for model A, B & C

Models		35 N Vertical	70N Vertical	100N Vertical	35N Oblique	70N Oblique	100N Oblique
Model A	Overall Displacement(mm)	0.007149	0.014297	0.020425	0.017151	0.0343	0.049053
	Overall Stress (Mpa)	11.3572	22.7145	32.4493	31.6605	63.32	90.5489
	Cortical Stress (Mpa)	8.71608	17.4322	24.9031	18.6711	37.3421	53.3992
	Cancellous Stress (Mpa)	1.58273	3.16546	4.522	1.689	3.378	4.8308
	Implant Stress (Mpa)	19.3125	38.625	55.1785	30.0063	60.0126	85.818
Model B	Overall Displacement(mm)	0.015115	0.03023	0.043186	0.037225	0.07445	0.106463
	Overall Stress (Mpa)	15.9122	31.8245	45.4635	45.4007	90.8013	129.846
	Cortical Stress (Mpa)	15.9122	31.824	45.4635	29.748	59.497	85.0809
	Cancellous Stress (Mpa)	1.35274	2.70547	3.864	2.5516	5.10321	7.2975
	Implant Stress(Mpa)	17.7323	35.464	50.6638	40.7104	81.4208	116.432
Model C	Overall Displacement(mm)	0.008538	0.017075	0.024393	0.019446	0.038891	0.055614
	Overall Stress (Mpa)	13.3937	26.7874	38.2678	40.6102	81.2204	116.145
	Cortical Stress (Mpa)	10.7536	21.5072	30.7245	22.2018	44.4036	63.4972
	Cancellous Stress (Mpa)	1.21082	2.42164	3.4594	1.23706	2.47412	3.5379
	Implant Stress(Mpa)	12.3252	24.6504	35.2148	38.6149	77.2299	110.439

When Vertical of 35N load was applied, overall displacement, overall stress, cortical stress, are higher in model B compare to model A and C. Cancellous stress and Implant stress were higher in model-A. When oblique of 35N load was applied, overall displacement, overall stress, cortical stress, cancellous stress and Implant Stress all were high in model-B compared to other models.

When 70N of vertical load was applied, overall displacement, overall stress, cortical stress, were higher in model B compare to model A and C. Cancellous stress and implant stress were higher in model-A. When oblique of 70N load was applied, overall displacement, overall stress, cortical stress, cancellous stress and implant stress all were high in model-B compared to other models.

When 100N of vertical load was applied, overall displacement, overall stress, cortical stress, were higher in model B compare to model A and C. Cancellous stress and Implant stress were higher in model-A. When oblique of 100 N load was applied, overall displacement, overall stress, cortical stress, cancellous stress and Implant Stress all were high in model-B compared to other models. no significant difference was found on overall displacement, overall stress, cortical stress but cancellous stress and implant stress.

Discussion

The close relationship between the tooth and alveolar process continues throughout life. Wolff's law (1892) states that bone remodels in relation to the forces applied. Every time the function of bone is modified, a definite change will occur in the internal architecture and external configuration.[10]

The greater the magnitude of stress applied to the bone, greater will be the strain observed. Bone modelling and remodeling are primarily controlled by the mechanical environment of the strain. The density of alveolar bone evolves as a result of mechanical deformation from the micro-strain. In the theory of mechanostat, **H. M. Frost**[11] proposed that the bone mass is the direct result of the mechanical usage of skeleton. A model of four zones for the compact bone as related to mechanical adaptation to the strain has been proposed: The pathologic overload zone (greater than 3000 micro-strain), mild overload zone (1500-3000), adapted window (50-1500), and acute disuse window (0-50).

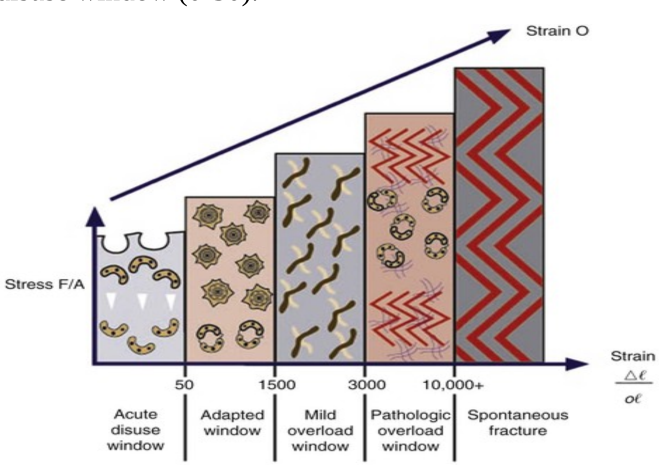


Fig. 4: Four zones for bone related to mechanical adaption to strain before spontaneous fracture

Crestal bone loss will be often evidenced during the early implant loading, as the result of bone in the pathologic overload zone (excess stress and strain at the implant–bone interface). Stress is seen to be highest at the crest, compared with other regions in the implant body. An excellent strain environs will exist for each specific anatomical area and the peak strains innate for that area should be maintained to optimize the bone's response.[12]

The bone morphology of maxilla often dictates placement of implants with the long axis in different and exaggerated angulations. The implant alignment is corrected at the time of restoration with the use of angled abutment. Due to the unfavorable loading direction that angled abutments have, it is important to understand the stresses transferred through angled abutment to the surrounding bone, through which we can prevent less than ideal stress transfer conditions. The correlation of poor bone quality and implant failure has been well established, but the precise relation between bone quality and stress distribution when angled abutment was used is not adequately understood. In the present study the stress distribution around implant with straight and angled abutments was studied in different bone qualities of D1, D2, D3 and D4 using three dimensional finite element analysis.[4]

The finite element analysis is a relatively recent regulation that has quickly become a mature method, especially for structural analysis. The costs of applying this technology to everyday design tasks have been realeasing, while the capabilities delivered by the method are expanding constantly. The method is fully experienced of implementing higher quality products in a shorter design cycle with a reduced chance of field failure, provided it is applied by a capable analyst. It is also a valid indication of thorough design practices, should an unexpected. Litigation crop up. The time is now for industry to make greater use of this and other analysis techniques.[13]

Classical methods of mathematical stress analysis are extremely limited in dental patients due to dental structures that have an irregular structural form and complex loading. The finite element analysis is a modern technique of numerical stress analysis that has the great advantage of being significant to solids of asymmetrical geometry and heterogeneous material properties. It is therefore ideally suited for the examination of structural behavior of the oral cavity. The development in main frame computers and availability of powerful microcomputers has brought this method within the reach of students and engineers. There are so many different methods available to study stress/strains in bone and dental implants. Photo elasticity is one of the methods which provide good qualitative information pertaining to the overall location of stresses but only limited quantitative information. Strain-gauge measurements also provide accurate data regarding strains only at the specific location of the gauge. But Finite element analysis (FEA) is capable of providing detailed quantitative data at any location within mathematical model. Thus, FEA has become a valuable analytical tool in the assessment of stress/strain in bone and implant systems in dentistry.[13]

A force applied to a dental implant rarely is directed completely longitudinally along a single axis. In fact, three presiding clinical loading axes exist in implant dentistry: (1) mesiodistal, (2) faciolingual, and (3) occlusoapical. A single occlusal contact most commonly results in a three-dimensional occlusal force.[10]

A vertical movement or force placed on a posterior implant joined to a healthy posterior tooth causes mesial tension on the implant.[14] A load administered along the long axis of the implant body decreases the amount of stress in the crestal bone region differentiated with an angled load.

The noxious effect of offset or angled loads to bone is exacerbated further because of the anisotropy of bone. ***Anisotropy*** refers to the character of bone whereby its mechanical properties, including ultimate strength, depend on the direction in which the bone is loaded and the type of force applied[10]. Any occlusal load registred at an angle to the implant body may be separated into normal (compressive and tensile) and shear forces. As the angle of load to an implant body increases, the amount of compressive and tensile forces is modified by the cosine of the angle. Hence, the force is slightly reduced. In finite element analysis, when the direction of the force changes to a more angled or horizontal load, the magnitude of the stress is increased by three times or more. In addition, rather than a primarily compressive type of force, tensile and shear components are increased more than 10-fold compared with the axial force.[10]

An angled load to the implant long axis increases the compressive forces at the crest of the ridge on the opposite side of the implant, increasing the tension component of force along the same side as the load. The greater the angle of force to the long axis of the implant body, the greater the potentially damaging load at the crest of the bone.[10] The angled implants allow better oral hygiene and esthetics; the abutments and the restorations can be placed more buccally to compensate for buccal atrophic bone loss. The disadvantages are the difficulties involved in the operative techniques and the fact that there is no chance of correction after placement. If the alveolar process is angled and limited in width, to secure full esthetics and function, use of the angled implant should be considered.

A higher cellular response, including osteoblasts and inflammatory cells, was observed next to implants under non axial shear loading conditions compared with axial loads[14]. An animal experimental study, could not demonstrate negative effects of non-axial loading[8]. It showed statistical significant differences in remodeling response between centric and eccentric loading. Centric loading tended to cause a uniform remodelling response whereas eccentric loading induced a more dynamic remodelling response. The comparison of different loading conditions in all Models revealed similar amounts of implant displacement at lower forces during axial and oblique loading. Therefore, oblique loading had no negative outcome in the present in vitro study.

When off-axis loading is applied to an implant, the magnitude of the stress will be increased 3 times or more.[10] Over loading can cause bone loss around the implant neck[15]. Other studies showed that excessive stresses may cause implant failure, component fracture, and/or crestal bone loss around the implant neck.[16] However, with all the clinical successes and survival rate from the articles in this review, it seemed reasonable to assume that stress distributions around the bone surrounding implants restored with angled abutments are favorable or at least comparable to those of straight abutments, even though the loading mechanisms of angled abutments in anterior teeth and posterior teeth vary in terms of force direction and magnitude. Most of the success/survival rate analyses in the literature combined anterior and posterior data together, which gives it impossible to committed to the exact performance of anterior angled abutments.

Stresses and strains increase as the abutment angulation increases.[10,17] In this present study for the vertical load, stress increase as the angulation increase with increasing load in15^0 placed implant while in 30^0 placed implant stress is decreased due to engagement of implant is more in cortical bone(Table-3). Similarly, A fivefold increase in stress in the platform of an angled implant versus that of a straight implant[6]. Few study showed similar results with respect to angled implants[18-20]. However, another study indicated that stresses in an angled implant were lower than in a straight implant[21]. The effect of the distal offset configuration of a single implant supported prosthesis on bone stress distribution with that of straight alignment using Finite Element Analysis They indicated that the offset implant placement produced less stress compared to the straight configuration[22]. There is no general consensus about how much stresses/strains increase with regard to the unit increase in abutment angulation to date. Further studies are required for clarification.

The use of angled abutments to correct implant position in fixed prostheses can provide a correct insertion trajectory facilitating the implant-supported prosthesis installation.[23] But, at the same time those abutments can make the biomechanics response more fragile due to the increase of stresses concentration in the implants and bone strain. An analysis of stress on single implants noted that the cortical bone strain was higher for an angled abutment of 20^0 than that for straight abutments and the bone strain increased as bone density decreased[24], this present study followed the same for 15^0 angled abutment followed by 30^0 angled abutment(Table-3). The stress distribution around a spiral implant with a straight abutment, 15^0 and 25^0 angulated abutment in D1 and D4 bone using 3D FEA and found out that maximum bone stress was obtained with 15^0 angulated abutment which was resemble to this present study for the oblique load(Table-3). Results of finite element analysis showed that abutment angulation up to 25^0 can increase the stress in the peri-implant bone by 18 % and the micro-motion level by 30 % which is resemble to this study[25]. The results of the study leads to the inference that, if a case is planned for angled abutment, sufficient thickness and better quality (D1, D2, or D3) of bone should be available on the site opposite to that of abutment.

Axial and oblique loading conditions influence implant mobility. For example, the maxilla is a dilemma for surgeons with respect to whether the implant should be placed at a buccal angle along the residual maxillary ridge or along the occlusal load axis. Placement of implants according to the direction of occlusal force is advantageous for reducing lateral loads on the implant. This danger can be reduced by placing the implant at an angle parallel to the buccal cortical plate and using angled abutments, which induces oblique loading.

Most significant is the increased strain at the coronal implant bone surface and fixture level for these off-axis loaded implants. The functional hyperactivity of the masticatory system, for example, obtruded increased pressure on the bony forms of the craniofacial complex with possible influences on its structure. Some research has demonstrated a 3 to 4 times greater increase in the strain at the cortical bone relative to similar axially loaded implants for each 30° loading angle increase[25].

In the reviewed finite element study done for angled abutments, loading was applied along the long axis of the abutments in the anterior maxilla area. However, the real loading condition for the teeth is mostly at a certain angle toward the long axis of the abutments/restorations. Stresses/strains generated through such loading may be more detrimental to the surrounding bone since it is more off-axis. When future finite element analytical studies are conducted, this factor should be considered and carefully designed[8].

Since, it was FEA study, so clinical results might be different as compared to this study which implicates the need of this study under clinical condition.

So, the result of this study encourages further research with exact clinical simulation to identify factors that reduce or magnify stress associated with tilted implants in All-on-four system.

Conclusion

Within the limitations of the present study, following conclusions were drawn:

1. For the axially placed implant with the straight abutment (Model A), when vertical and oblique load (35N, 70N, 100N) were applied, all stresses (overall displacement, overall stress, cortical stress, implant stress, cancellous stress) were increased gradually as load was increased.
2. For the 15^0 & 30^0 placed implant with the angled (15^0, 30^0) abutment (Model B & C), when vertical and oblique load (35N, 70N, 100N) were applied all stresses (overall displacement, overall stress, cortical stress, implant stress, cancellous stress) were increased gradually as load was increased.
3. When overall stresses were compared in all 3 models, with applied vertical and oblique load, maximum stresses (overall displacement, overall stress, cortical stress, implant stress, cancellous stress) were generated under 100N load in the 15^0 placed implant with 15^0 angled abutment followed by 30^0 placed implant with 30^0 angled abutment and axially placed implant.
4. When overall stresses were compared with 15^0 placed implant with 15^0 angled abutment (Model B) and 30^0 placed implant with 30^0 angled abutment (Model C), stresses were more in 15^0 placed implant.

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