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Comparative evaluation of peri-implant stress distribution in implant protected occlusion and cuspally loaded occlusion on a 3 unit implant supported fixed partial denture: A 3D finite element analysis study

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PURPOSE. To assess peri-implant stress distribution using finite element analysis in implant supported fixed partial denture with occlusal schemes of cuspally loaded occlusion and implant protected occlusion. **MATERIALS AND METHODS.** A 3-D finite element model of mandible with D2 bone with partially edentulism with unilateral distal extension was made. Two Ti alloy identical implants with 4.2 mm diameter and 10 mm length were placed in the mandibular second premolar and the mandibular second molar region and prosthesis was given with the mandibular first molar pontic. Vertical load of 100 N and and oblique load of 70 N was applied on occlusal surface of prosthesis. Group 1 was cuspally loaded occlusion with total 8 contact points and Group 2 was implant protected occlusion with 3 contact points. **RESULTS.** In Group 1 for vertical load , maximum stress was generated over implant having 14.3552 Mpa. While for oblique load, overall stress generated was 28.0732 Mpa. In Group 2 for vertical load, maximum stress was generated over crown and overall stress was 16.7682 Mpa. But for oblique load, crown stress and overall stress was maximum 22.7561 Mpa. When Group 1 is compared to Group 2, harmful oblique load caused maximum overall stress 28.0732 Mpa in Group 1. **CONCLUSION.** In Group 1, vertical load generated high implant stress, and oblique load generated high overall stresses, cortical stresses and crown stresses compared to vertical load. In Group 2, oblique load generated more overall stresses, cortical stresses, and crown stresses compared to vertical load. Implant protected occlusion generated lesser harmful oblique implant, crown, bone and overall stresses compared to cuspally loaded occlusion. [J Adv Prosthodont 2021;13:79-88]

KEYWORDS
Implant protected occlusion; Dental implant; Finite element analysis; Fixed partial denture

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INTRODUCTION

Osseointegrated implants were introduced for the rehabilitation of completely edentulous patients in the late 1960s, and a huge demand and awareness have arisen in this field.[1] Unlike natural teeth which are supported with PDL that provides mechanoreceptors as well as shock-absorbing function, implants are rigidly connected to underlined bone.[2] Hence, there is a difference in mechanism of load distribution and transmission. Owing to this difference, understanding of biomechanics in implants becomes necessary.

A study has suggested that occlusal overload results in implant bone loss and/or loss of osseointegration of successfully integrated implants.[3] In contrast, other believed that peri-implant bone loss and/or breakage of osseointegration are associated with biological complications such as peri-implant infection.[3]

The choice of occlusal scheme for implant-supported prosthesis is broad and often controversial. Almost all concepts are based on those developed with natural dentition and are transposed to implant support systems with a few modifications. The probable reason for this practice is the similarity (during mandibular movement) in the velocity, the pattern of movement, and the operating muscles that are used by patients with implants and those with natural dentitions.[4] Implant protected occlusion is an occlusal plan which was designed to provide an improved longevity of both the implant and the prosthesis.[5]

There is minimal understanding of occlusal schemes in implant fixed prosthesis. Hence, it becomes necessary to study various aspects of implant protective occlusion. There are minimal to no comparative evaluations of implant protective occlusion and cuspally loaded occlusion which is the natural teeth occlusion with functional cusp contacts in implant fixed partial denture. There are no studies that emphasize on the occlusal scheme specifically designed for implant fixed partial denture with different loads. The understanding of the axial load and non axial load and their effect on implant and surrounding structures for implant supported fixed partial denture is really low. Hence a finite element analysis study was conducted to compare implant protective occlusion and cuspally loaded implant supported fixed partial denture with axial and non axial loads.

The null hypothesis for this study is that there is no difference in peri-implant stress distribution in implant protected occlusion and cuspally loaded occlusion in implant supported fixed partial denture.

Therefore, the aim of this study is to assess peri-implant stress distribution using finite element analysis in implant supported fixed partial denture and surrounding bone having two different occlusion schemes.

MATERIALS AND METHODS

Model Geometry: The present study was based on commercially available implants. Implants from different systems did not possess similar dimensions. Therefore, in order to decrease confounding factors, it was decided to model implants with similar dimensions; as a result, two implants with diameters and lengths of 4.2 mm & 10 mm were selected (Nobel Biocare dental implants, Zurich, Switzerland) (Fig. 1). Titanium was used for implant, abutment, and abutment screws.

The implants were placed in the mandibular second premolar and the mandibular second molar region with straight abutments, and a 3 unit bridge was given with the mandibular first molar as pontic (Fig. 1, Fig. 2).

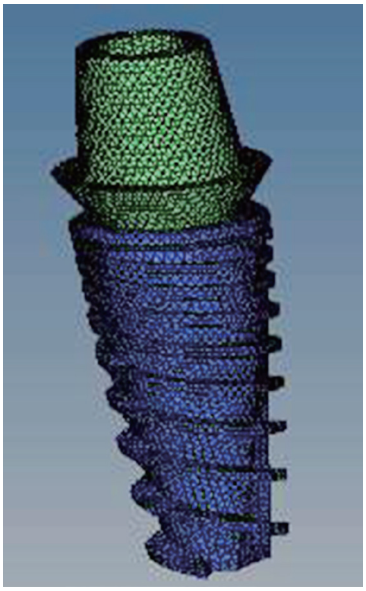

Fig. 1. Model geometry.

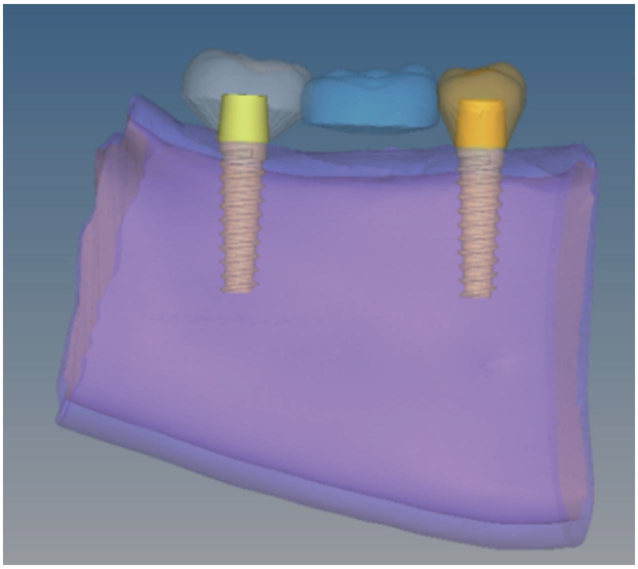

Fig. 2. FEA model outline.

A computerized model was created for this finite element analysis (FEA) study. In order to model compact and cancellous bone, a cone beam CT image of a human mandibular bone was used. The real dimensions of cortical bone were modelled in using a computer in order to create a model of bone as close to the clinical form as possible. However, since the model of the implant may reach the lingual cortex of bone, the lingual plate was designed to be as convex as the buccal plate. According to the CT scan image sample, the cortical bone thickness was assumed to be 2 mm. The overall dimensions of bone were 18 mm in height, 10 mm in mesiodistal length, and 7 mm in buccolingual width (Fig. 3). The applied forces were static.

The model was made with a few limitations assuming that patient does not have any medical history. Only block of bone for edentulous area was used to give better understanding of the occlusal loading points and better evaluation of the stress area and also the implants are considered fully osseointegrated. All the materials used in the models consisted of implants, abutments, and abutment screws; compact and cancellous bones were presumed to be as homogeneous, isotropic and linearly elastic as one another. 100% implant-bone interface was established, which does not necessarily simulate clinical situations.[6]

Prosthesis geometry: In the prosthesis, the retainers and a pontic were made with metal ceramic material. The cuspal angles and diameters are kept as ideal.[7] The diameters of which are as follows[7]:

Mandibular second premolar: Cervico-occlusal length of retainer- 8.0 mm, Mesiodistal diameter of retainer- 7.0 mm, Mesiodistal diameter of retainer at cervix- 5.0 mm, Buccolingual diameter of retainer- 8.0 mm, Buccolingual diameter of retainer at cervix- 7.0 mm.

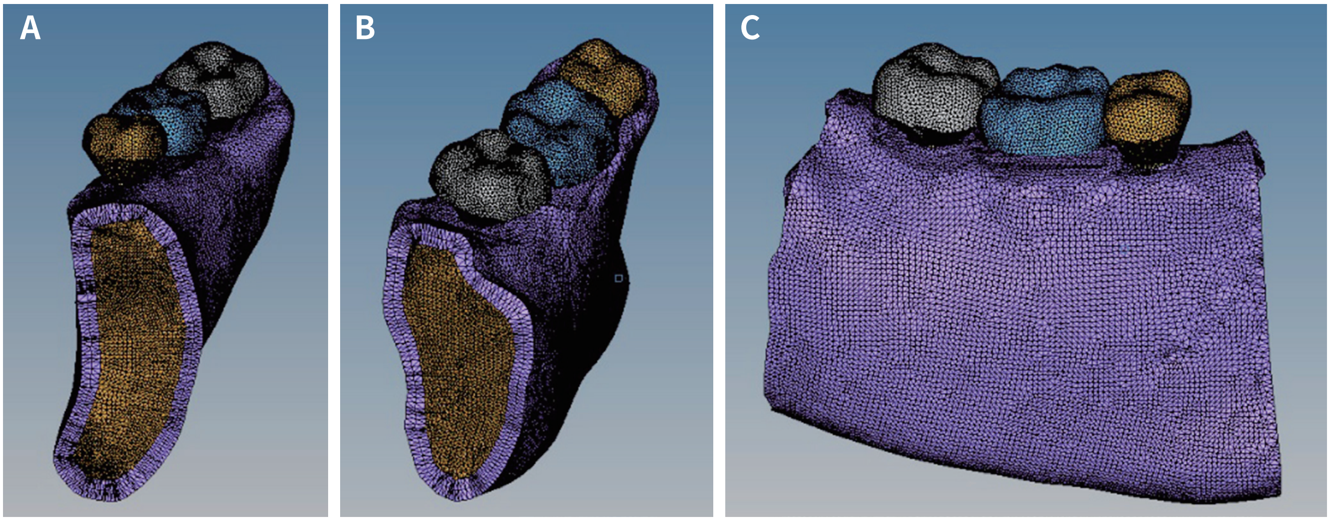

Fig. 3. Mandibular model with implant supported fixed partial denture. (A) mesial view, (B) distal view, (C) buccal view.

Mandibular first molar: Cervico-occlusal length of retainer- 7.5 mm, Mesiodistal diameter of retainer- 11.0 mm, Mesiodistal diameter of retainer at cervix- 9.0 mm, Buccolingual diameter of retainer- 10.5 mm, Buccolingual diameter of retainer at cervix- 9.0 mm.

Mandibular second molar: Cervico-occlusal length of retainer- 7.0 mm, Mesiodistal diameter of retainer- 10.5 mm, Mesiodistal diameter of retainer at cervix- 8.0 mm, Buccolingual diameter of retainer- 10.0 mm, Buccolingual diameter of retainer at cervix- 9.0 mm.

Pontic design: The pontic design for the mandibular first molar is a sanitary pontic, which has no tissue contact and is helpful in maintaining hygiene in posterior edentulous region. It is convex mesiodistally and faciolingually. The space between the pontic and gingiva is kept 2 mm, which acts as a self cleansing area (Fig. 4).

Material properties: All the materials used in the models consisted of implants, abutments and abutment screws; compact and cancellous bones were presumed to be as homogeneous, isotropic, and as one another. The material properties, including modulus of elasticity and Poisson's ratio used in finite element analysis (FEA) model[8,9] are listed in Table 1.

The bone-implant interface was assumed to be perfect, simulating complete osseointegration. Therefore, the connections between implant-cortical bone and implant-cancellous bones were designed to be bonded as the interface between cancellous and cortical bones. Within the implant system, FEM modelling was performed by implementing bonded conditions on the abutment-implant interfaces.

Loading condition: in this model, two different types of loads were applied, which are oblique loads and axial loads.

Vertical load applied at the contact point is 100 N and oblique load was 70 N.[8,9] These two different types of loads were given to mimic the implant occlusal forces in patient's mouth. The loads were given on different contact points to create the model occlusion as it was in natural dentition. The following are the groups: (Table 2)

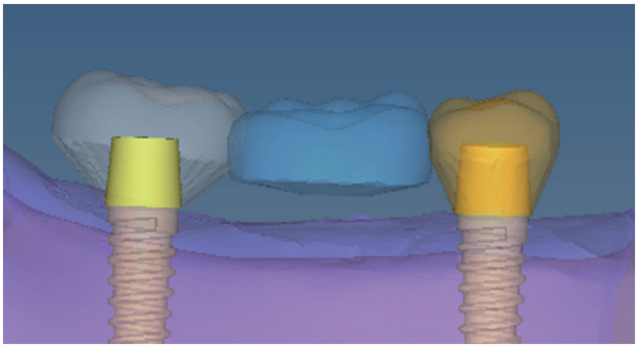

Fig. 4. Sanitary pontic.

Table 1. Physical properties of different materials used in the present study

Material	Elastic modulus (E) (GPa)	Poisson's ratio (V)
Feldspathic porcelain	82.8	0.35
NiCr alloy	206	0.33
Titanium (implant, abutment)	110	0.35
Cortical bone	13.7	0.3
Spongy bone	1.37	0.3
Glass ionomer cement	9.8	0.3

Table 2. Occlusal contact point for Group 1 and Group 2

Prosthesis on which load is applied	Group 1	Group 2
Second premolar retainer	2 contact points: first on central fossa and other on functional cusp (buccal cusp)	1 contact point: on central fossa
First molar pontic	4 contact points: first on central fossa and others on functional cusps (3 buccal cusps)	1 contact point: on central fossa
Second molar retainer	3 contact points: first on central fossa and others on functional cusps (2 buccal cusps)	1 contact point: on central fossa

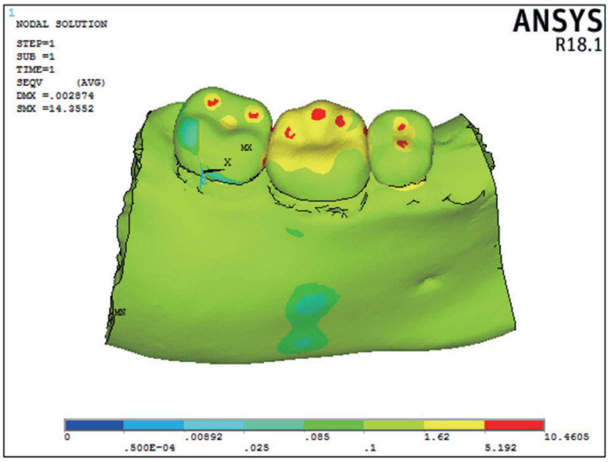

Fig. 5. Occlusal loads in cuspally loaded occlusion in Group 1.

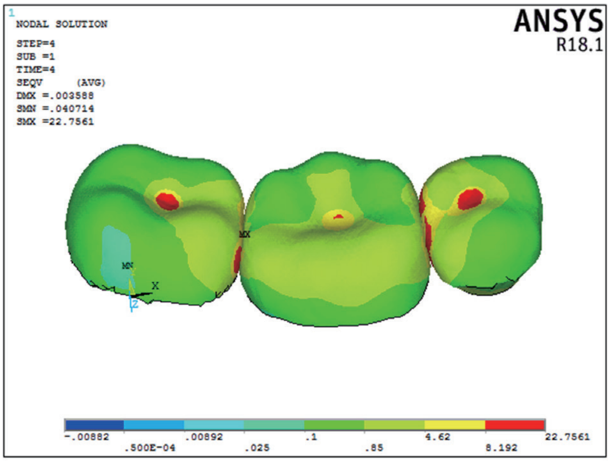

Fig. 6. Occlusal loads in cuspally loaded occlusion in Group 2.

Group 1: cuspally loaded occlusion with cusp to fossa contact and the load is given on functional cusp and central fossa

Group 2: implant protective occlusion with single central fossa contact.

As described in abovementioned table (Table 2) both axial and oblique loads were given on different occlusal contact points according to different occlusal systems. Restorations were placed and tested under standard condition (Fig. 5, Fig. 6).[8,9]

Stress analysis: Stress levels were calculated using von Mises stresses values with the help of finite element analysis. ANSYS 18.1 software was used for analysis and 3D mesh was created by Hypermesh V11 and Solid Edge V19 was used for implant modelling.

Table 3. The value of various parameters when vertical and oblique loads are applied on Group 1 model

Results for Group 1	100 N Vertical	70 N Oblique
Overall displacement (mm)	0.002874	0.004402
Overall stress (MPa)	10.4605	28.0732
Cortical stress (MPa)	6.2293	10.5975
Cancellous stress (Mpa)	0.586477	0.484773
Cement stress (Mpa)	6.66392	4.09267
Crown stress (Mpa)	10.4605	28.0732
Implant stress (Mpa)	14.3552	13.5016

RESULTS

This FEA study compares all occlusal loads on two different types of occlusal schemes which are Group 1 and Group 2 (Table 3, Table 4).

Compared to the stress generated by the vertical loads, oblique load had more influence on the stress generation in both Group 1 and Group 2. Stress increase on the bone structure could be observed while comparing vertical and oblique loads. This could be mainly attributed to the bending effect on the structure due to lateral component of oblique loads. Lateral loads will generate more stresses compared to the vertical loads, which creates axial stresses. The stress generation increases with the lateral loads up to the centre of resistance (Table 3, Table 4).

Table 4. The value of various parameters when vertical load and oblique load is applied on Group 2 model

Results for Group 2	100 N Vertical	70 N Oblique
Overall displacement (mm)	0.002491	0.003588
Overall stress (MPa)	16.7682	22.7561
Cortical stress (MPa)	4.50529	7.75762
Cancellous stress (Mpa)	0.662177	0.42004
Cement stress (Mpa)	5.13347	3.44637
Crown stress (Mpa)	16.7682	22.7561
Implant stress (Mpa)	11.2257	10.6297

DISCUSSION

Dental implants are subjected to occlusal loads when placed in masticatory function. Such loads differ dramatically in magnitude, frequency, and duration, depending on the patient's parafunctional habits. Forces applied to dental implant are rarely directed absolutely longitudinally along a single axis. In fact, three dominant clinical loading axes exist in implant dentistry: (1) mesiodistal, (2) faciolingual, and (3) occlusoapical (Fig. 7). A single occlusal contact most commonly results in a three-dimensional occlusal force. Importantly, this three-dimensional force may be described in terms of its component parts (fractions) of the total force that are directed along the other axes.[10-13]

Occlusion can be critical for implant longevity because of the nature of the potential load created by tooth contacts and the impact on the attachment of the bone to the titanium implant. The periodontal ligament has the capacity to absorb stress or allow for any tooth movement in natural dentition, but in implant, bone-implant interface has no capacity to allow movement of the implant. Load transfer at the bone-implant interface depends on (1) the type of loading, (2) the material properties of the implant and prosthesis, (3) the nature of the bone-implant interface, (4) the quality and quantity of the surrounding bone, (5) the implant geometry, length, diameter, and shape, and (6) the implant surface structure. So, implant occlusion is very much important, and it should be selected to generate less amount of stresses.[14]

Different cuspal inclinations (10, 20, and 30 degree) have different effect on stresses generated on implants. It is proved that stresses on the implant and implant/abutment interface increased with increasing cusp inclination and stresses on the cortical bone decreased with increasing cusp inclination.[15]

Materials of the prosthesis also affect the stress distribution. Sevimay *et al*.[16] compared porcelain fused to noble metal crown, porcelain fused to base metal crown, In-Ceram porcelain crown, and IPS Empress 2 porcelain crown. The highest stress values were found in the IPS Empress 2 porcelain crown design. In-Ceram and porcelain fused to base metal framework designs transferred less stress to abutment. So, different occlusal materials and different cuspal inclination affects the stress distribution in implant and the surrounding structures. In this study, an attempt has made to understand the effect of different occlusal contact points on implant supported fixed partial denture.

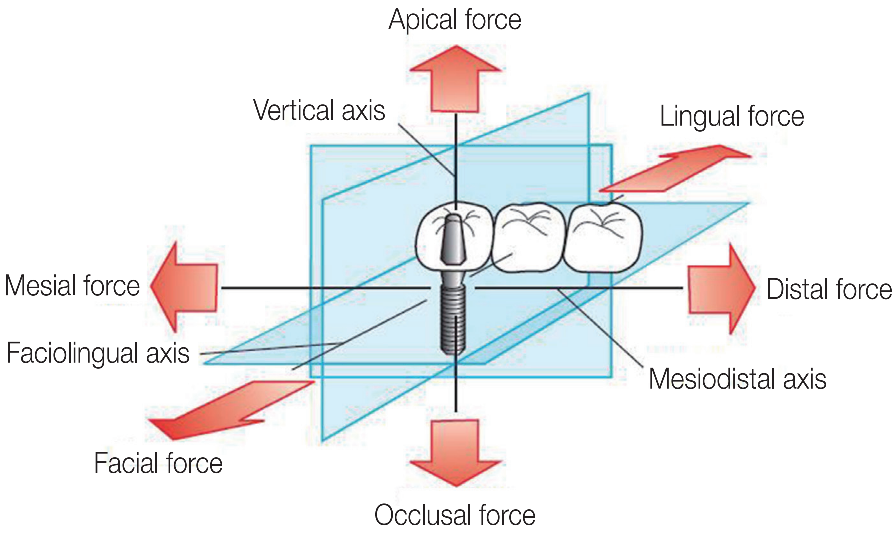

Fig. 7. Forces are three-dimensional, with components directed along one or more clinical coordinate axes: mesiodistal, faciolingual, and occlusoapical (vertical).

Both cuspally loaded occlusion and implant protected occlusion are widely used occlusal schemes for fixed partial dentures in natural teeth and in implant supported prosthesis. All the contact points are noted in both the schemes.[11]

Cuspally loaded occlusion is the natural teeth occlusion, which is given mainly in tooth supported fixed partial denture in which all the contact areas are mainly on the functional cusps. Natural teeth often have cusp angles of 30 degrees. Therefore, if a premature contact occurs on a cuspal incline, the direction of load may be 30 degrees to the implant body if the implant crown duplicates a natural tooth cusp angle.

So to give this occlusal scheme in implant supported prosthesis through a finite element analysis, the functional cusps taken as loading areas and axial and oblique loads were applied on that specific contact areas and the stresses were measured on implant and surrounding structures.

Implant protected occlusal scheme mainly follows principle of lingualized occlusion. In this occlusal scheme, only one contact area is present which is over the central fossa.[5,17,18] Implant protected occlusion considers many factors, such as premature occlusal contacts or interferences, mutually protected articulation, implant body angle, cusp angle of crowns (cuspal inclination), cantilever or offset loads, crown height (vertical offset), and occlusal contact positions.[18-22]

Premature occlusal contacts causes localized lateral loading of opposing contacting crowns because the surface area of a premature contact is small, and the magnitude of stress in bone increases. The contact occurs most often on an inclined plane, which increases the horizontal component of load and increases the tensile crestal stress. So premature contacts should be removed.[17,18]

When an angled load is applied to an implant body perpendicular to occlusal plane or the occlusal load is applied to an angled implant body, the biomechanical risk increases. As the angle of the load increases, the shear component of the load also increases. The implant body should be placed perpendicular to the occlusal plane and have the primary occlusal contact.[17,18]

The angle of force to the implant body is affected by cusp inclination, which increases crestal bone stress. So, the occlusal contact over an implant crown should be on a flat surface perpendicular to the implant body. This can be achieved by increasing the width of the central groove to 2 - 3 mm in posterior implant crowns, which are positioned over the center of the implant abutment.[17,18]

Cantilevers are class 1 levers, which increase the amount of stress on implants. Twice the load applied at the cantilever will act on the abutment farthest from the cantilever, and the load on the abutment closest to cantilever is the sum of the other two components. In general, the goal should be to reduce the length and hence the force on the cantilever. An increased crown height acts as a vertical cantilever and increases the stress at the implant-bone interface. It leads to angled load with a greater lateral component of force.[17,18]

The ideal occlusal contact should be over the implant body with the axial loading of implants. A posterior implant is therefore placed under the central fossa of the implant crown. A buccal cusp contact is also considered as an offset or cantilever load. A marginal ridge contact is also a cantilever load, as the marginal ridge may also be several millimeters away from the implant body.[17,18]

To analyze the stresses, all central fossa have been taken as loading areas and axial and oblique loads were given over this contact areas. With the help of finite element analysis, stresses were measured on implant and surrounding structures.

The model used in this study implied several assumptions regarding the simulated structures. The structures in the model were all assumed to be homogeneous and isotropic and to possess linear elasticity.[14] However, the properties of the materials modelled in this study, particularly the living tissues are different. 100% implant-bone interface was established, which does not necessarily simulate clinical situations.[14] Also, the stress distribution patterns simulated may be different depending on the materials and properties assigned to each layer of the model and the model used in the experiments. Thus, the inherent limitations in this study should be considered.

As it is shown in the results, oblique load generates more overall implant displacement (0.004402) as compared to axial load (0.002874) in Group 1. Similarly in Group 2, oblique loads (0.003588) generate more overall implant displacement than axial load (0.002491).

Overall stresses that are generated by oblique load (28.0732 in Group 1, 22.7561 in Group 2) are greater compared to axial load (10.4605 in Group 1, 16.7682 in Group 2). When oblique loads are applied on cortical bone, it generates more stresses (10.5975 in Group 1, 7.75762 in Group 2) compared to vertical loads (6.2293 in Group 1, 4.50529 in Group 2), but in cancellaous bone, oblique load generates less stress (0.484773 in Group 1, 0.42004 in Group 2) as compared to vertical load (0.586477 in Group 1, 0.662177 in Group 2) in both the Groups. Implant stress is also generated less by oblique load (13.5016 in Group 1, 10.6297 in Group 2) as compared to vertical load (14.3552 in Group 1, 11.2257 in Group 2) in both Groups, but this difference is very less.

Axial and oblique loading revealed significant differences in implant displacement in the cancellous bone, whereas oblique loading showed higher displacement (339 ± 47 Mm at 80 N) compared to axial loading (266 ± 39 Mm at 80 N). Axial and oblique loading showed no differences in overall load increments when implants were inserted in dense specimens (absolute displacement with an 80 N load: 147 ± 10 Mm axial and 126 ± 17 Mm oblique). Hence, it proved that bone density influences implant displacement. The loading character significantly influenced implant displacement in cancellous bone block specimens only.[23-26]

In this study, prosthesis generated more stresses by oblique load (28.0732 in Group 1, 22.7561 in Group 2) compared to vertical loads (10.4605 in Group 1 and 16.7682 in Group 2). Guven *et al*.[21] had done a study in which a total load of 300 N were applied in a vertical direction and oblique direction. Maximum and minimum von Mises stress values of the titanium structures and zirconia frameworks were calculated. The highest stress value was in the zirconia framework of the angled implant-supported model with an oblique loading force (731.46 MPa). The lowest stress values were concentrated in the straight implant-supported crown. The stress values in the angled implant-supported crown were higher than in the straight implant-supported crown. Stress values with oblique loading forces were increased than with the values with vertical loading forces.

When the stresses are compared in cuspally loaded and implant protected occlusion for vertical loading, they were lesser as compared to stress from oblique load. Overall implant displacement was lesser in Group 2 (0.002491 in vertical load and 0.003588 in oblique load) compared to Group 1 (0.002874 in vertical load and 0.004402 in oblique load). Cortical bone stresses were also lesser in Group 2 (4.50529 in vertical load and 7.75762 in oblique load) compared to Group 1 (6.2293 in vertical load and 10.5975 in oblique load). Implant stresses are lesser in Group 2 (11.2257 in vertical load and 10.6297 in oblique load) as compared to Group 1 (14.3552 in vertical load and 14.3552 in oblique load). While cancellous bone stresses were slightly higher in Group 2 (0.662177 in vertical load and 0.42004 in oblique load) as compared to Group 1 (0.586477 in vertical load and 0.484773 in oblique load).

All these results were associated with the fact that the implant protected occlusion generates less stress as it has less occlusal contact points. But, the crown stress is higher in implant protected occlusion (16.7682 in vertical load and 22.7561 in oblique load) compared to the cuspally loaded occlusion (10.4605 in vertical load and 28.0732 in oblique load) because the contact points are in center and all the loads are applied on one single center point; therefore, the crown stress will be more in Group 2 as compared to Group 1.

Stresses which were generated by vertical load were not as harmful as the stresses generated over oblique load. In Group 1, it was 10.4605 and in Group 2, it was higher which is 16.7682. But, the main harmful stresses are the ones which were generated when oblique load is applied. In implant protected occlusion (22.7561), it was less compared to cuspally loaded occlusion (28.0732).

So from the results of the study, it can be proved that the angled load creates more stresses compared to vertical load, and cuspally loaded occlusion generates more stresses compared to implant protected occlusion in implant supported fixed partial denture, and thus the null hypothesis is rejected.

CONCLUSION

Within the limitations of this study, following conclusions can be drawn:

In cuspally loaded occlusion, a vertical load generates high implant stress and oblique load generates high overall stresses. Oblique load generates more overall stresses, cortical stresses, and crown stresses compared to vertical load.

In implant protected occlusion, a vertical load generates high crown stresses and overall stresses and oblique load also generates high crown stresses and overall stresses. Oblique load generates more overall stresses, cortical stresses, and crown stresses compared to vertical load.

Implant protected occlusion generates lesser harmful oblique implant, crown, bone and overall stresses compared to cuspally loaded occlusion.

Thus, implant protected occlusion is a better occlusal scheme for implant supported fixed partial denture.

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