Comparative Evaluation of Stress Distribution Around Mandibular Overdentures Surrounded by Three and Four Implants: A Three-Dimensional Finite Element Analysis

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Abstract

Background and objectives: Placement of more than two implants in the interforaminal area may create a greater implant-to-bone contact area that allows for better stress distribution and minimizes crestal bone loss. The purpose of this study was to analyze and compare the stress distribution around implants of the three or four implant-retained mandibular overdenture.

Methodology: Two finite element models comprising an edentulous mandible with three and four implant supported mandibular overdenture with bar and clip attachment was used. A vertical load of 30 pounds was applied bilaterally to the first molar. Maximum and minimum von Mises stress values in the bone around the implants were evaluated.

Results: The highest stress value was observed in the bone around the distal implants and lowest stress value was concentrated in the middle implant in the molar region in three implant supported overdenture. The highest stress value was concentrated in the bone around the distal implants and lowest stress value was concentrated in the anterior implants in four implant supported overdenture. Stress values were more on four implant supported overdenture than three implant supported overdenture.

Conclusion: Within the limitation of the study, three implant supported overdentures demonstrated lesser stress in comparison to the four implant supported overdentures. The stresses generated were higher in the bone around the distal implants and lowest in the middle and anterior implants.

Key words: *Finite element analysis; overdenture; implant; cantilever; edentulous mandible*

Introduction

The prosthetic management of the completely edentulous patient has long been a major concern. Mandibular implant-retained overdentures are the most effective treatment for edentulous patients. [1-4]

Mandibular overdentures are usually supported by two to five implants between the mental foramina with soft tissue support in the posterior areas[5-7]. It has been concluded that the stress distribution pattern is more uniform when the load is applied over an increasing number of implants[8]. Also, it is useful for retaining and

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stabilizing dentures and has economic benefits.[5,9] More than two implants in the inter-foraminal area may create a greater implant-to-bone contact area allowing better stress distribution and minimizes crestal bone loss.[10]

Another point to be considered is the cantilever length which influence forces transferred to implants and bone and has direct clinical effect on marginal bone loss, so it is important that its effects on stress transfer to be investigated.[11-12]Regardless of the length of the cantilever, the greatest tensions will always be located on the region of the implant closest to the load application point.[13]

Finite element analysis (FEA) has been widely used to investigate the stress and strain distribution at the peri-implant bone interface in edentulous jaws. [2,14-15]Despite limitations of this theoretical method, FEA is acceptable in stress distribution analysis in complicated structures such as human alveolar bone.[16]Studies using FEA has several benefits as against studies with real models. The experiments are repeatable, there are no ethical considerations and the study designs may be modified and changed as per the requirement.[17]

Methodology

In this in vitro study, the experimental designs of simulated three and four implant-retained overdenture models were fabricated using Materialise MIMICS software (Materialise Interactive Medical Image Control System; Materialise, Leuven, Belgium). MIMICS uses the computerized tomography (CT) images to generate a 3Dimensional (3D) point cloud model which was then transferred to CATIA (Computer Aided 3D Interactive Application) software to obtain a 3-D solid model (Figure 1).In the first model, three implants and in the second one, four implants3.75 mm × 10 mm ((Nobel Biocare),were embedded.

In the first model, one implant was placed in the midline of the arch, and the others were placed approximately 12 mm from the midline. In the other model, the implants were placed 8mm apart. In the models, the implants were vertically oriented, perpendicular to the occlusal plane, and parallel to each other. Implants were connected using dolder bar and clip attachments (RHEIN 83 Co-Cr castable type). Two clips were placed in three implant□retained models and three clips in four implant□retained models.

The cantilever bars for each model was considered with 13 mm length. The mucosa and cortical bone were reproduced as a 2 mm and 2.5 mm layer, respectively to simulate D2 type bone[18]. The models were scanned with a profile projector to obtain reverse-engineered sketches. The numerical values obtained from the sketches were put in the CATIA software to create the geometric model of the components.

The overdenture prosthesis was created using a CT image of the denture and MIMICS software. The surface model was then transferred to CATIA software to obtain a 3D solid model of the overdenture. All the geometric models i.e, implant with attachment systems, overdenture prosthesis, and the bone were combined with a Boolean operation to create two 3D working models in the ANSYS Software. The implant-bone interface was assumed to be fully osseointegrated.

Geometric working models were then converted into the finite element model using ANSYS software. Table 1 represents numbers of elements and nodes in all study models. The analysis was performed on a computer with Windows 10/Intel Pentium DProcessor3.00+/CPU: 3.00 GHz/RAM: 32GB.

All materials were assumed linear, elastic, and isotropic; their properties were taken from the literature [13, 19-22][Table 2].The boundary conditions were set as fixed between the implant and the bone. The connection between the attachment system (patrix) and denture was modelled as fixed.

A vertical static load of 30 pounds was applied bilaterally in the central fossa region of the first molar tooth, and load distribution patterns were analysed[23].

Results

Maximum and minimum von Mises stress values were obtained for each model under bilateral vertical loading conditions. Data for von Mises stresses were produced numerically, color-coded and compared among the models. Stress analysis revealed that for three implants with cantilever, highest value of the stress was seen in the bone surrounding the distal implants placed approximately in the canine region. The stress distribution pattern around the middle implant was different from other regions. Stress distribution patterns in the distal implants were similar. The minimum stresses were concentrated in the middle implant. Maximum stresses in the bone around the implant were: 399.32 MPa and minimum stresses in the bone around the implant: 45.124 MPa.

Stress analysis revealed that for four implants with cantilever maximum stresses were concentrated at the bone surrounding the distal implants placed approximately in the premolar region. The minimum stresses were concentrated in the anterior implants placed approximately in the canine region. The stress distribution pattern around the implants placed approximately at the canine region was different from other regions. Stress distribution patterns in the distal implants were similar.Maximum stresses in the bone around the implant on bilateral vertical loading was: 495.74 MPa and minimum stresses in the bone around the implant on bilateral vertical loading was: 10.476 MPa. The stress distribution in the bone around the four implant supported overdenture with cantilever bar were higher than three implant supported overdenture with cantilever bar.

Table 1: Number of nodes and elements in all meshed components

Modelling situations	Three implants		Four implants	
	Nodes	Elements	Nodes	Elements
13mm cantilever	106235	95968	125986	98936

Table 2: Material properties used in the finite element model

Anatomic structure	Young's modulus (mpa)	Poisson's ratio	References
Cortical bone	13700	0.30	16
Cancellous bone	1370	0.30	16
Cobalt chromium alloy	218000	0.33	64
Overdenture	2700	0.35	63
Implant complex	110000	0.35	62

Discussion

The stress pattern around implants supporting overdentures is considered to be more complicated than in fixed prostheses due to the resiliency of the mucosa and movement of the prosthesis[5, 24-25]. In the present study, the load levels of 30 pounds were selected because they were within the range of normal occlusal mastication force and near the maximum load measured in implant overdenture patients.[5, 24-25]The first molar was selected as maximum bite forces are concentrated in the region where there is maximum contraction of all elevator muscles.[25-26]The vertical bilateral load was applied to simulate the masticatory forces. Also, loads were applied vertically as it was found by many studies that applying vertical loads on the overdenture generate more stresses than do oblique forces.[27]

In the models with three implant supported overdenture, applying 30 pounds load at the molar region increased the induced stresses in the bone around the distal implants and decreased the induced stresses in the bone around the middle implant. Under similar conditions, with four implant supported overdenture, induced stresses were more in the bone around the distal implants and less in the bone around the anterior implants. Cantilever is a class-1 lever, which increases the amount of stress around the implants closest to the force application and induces less stress around the farthest implants from the point of force application[10]. A study by Liu et al showed that in the three-implant-supported overdentures, no strain concentration was found in the cortical bone around the middle implant.[7]

These finding agree with findings of previously done studies[24,28] which concluded that implant retained overdenture associated with bar-clip anchor with two distally placed cantilevers displayed the greatest stress level, although cantilever extensions of bar attachments have been recommended for mandibular implant-retained overdentures to increase denture stability against non-axial loading.

When stress values were considered in implants, maximum stress concentration was seen around the neck of the implant in the present study. This is similar to the results obtained by various other studies which demonstrated that, bone loss begins around the implant neck due to higher bone stresses at the crestal region.[19]

The highest stress generation was noticed when four implants were used to support the mandibular overdenture. This is because the magnitude of stress distribution is directly proportional to implant number and inter implant distance based on leverage principle. This finding may not be, only related to the implant number but also to the unequal load reaching the distal and anterior implants and the supporting structures as the load was applied bilaterally on the molar region. This may also be due to premature contact between the acrylic denture base with the contra lateral implant. Hence, precise relief of the acrylic denture base around the overdenture abutments can be an important issue, especially when more resilient clips are used for the bar attachment.

Some authors believe that increasing the number of implants can reduce the stresses on the supporting implants.[29]In the triangular arches adding the middle implant may serve as an indirect retainer or as a vertical stop for preventing sitting of the anterior portion of over denture.[29] Therefore, a third implant can be placed between the original two when patients rehabilitated by two-implant overdentures report constant and obvious denture rotation around the fulcrum line.[7] Additionally, the risk of screw loosening is also reduced with a third implant, and the resultant greater surface area of implant to bone allows better distribution of forces and, therefore, minimizes the loss of crestal bone.[10]

Reliable clinical conclusions cannot be drawn from finite element studies as they are theoretical in nature and have some limitations when predicting the response of the biological tissues to applied loads,[19] therefore, reliable clinical conclusions cannot be drawn. It is important to know that peri-implant tissues are complex and their simulation in FEA is approximate.[19] In the current study, it was assumed that the bone-implant interface was completely osseointegrated. This assumption may not reflect the actual clinical situation[17].In addition, it was assumed that all the structures in the model are homogeneous and isotropic and they possess linear elasticity. But in reality living tissues behave differently, they are transversely isotropic and inhomogeneous. The design of occlusal surface also can influence the stress distribution.

Conclusion

Stress values in the bone around the four implant supported overdenture were higher than three implant supported overdenture.In three implant supported overdenture, stress values were higher in the bone around the distal implants and lowest in the middle implant. In four implant supported overdenture with cantilever, stress values were higher in the bone around the distal implants and lowest in the anterior implants.

Ethical Clearance: Obtained from AJIMS ethics committee, Mangalore for the study.

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