ORIGINAL ARTICLE

Evaluation of the stress distribution and displacement of the denture base in edentulous mandible with varied implant positions

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Abstract

Aim: To evaluate the stress distribution and displacement of the denture base in a three dimensional finite element edentulous mandibular model with varied implant positions. *Objectives:* 1)To evaluate the stresses induced by implants placed in the anterior region of the edentulous mandible. 2)To evaluate the stresses induced by implants placed in the anterior and posterior region of the edentulous mandible. 3)To compare the stresses induced by implants placed in the anterior and posterior region of the edentulous mandible. 4)To evaluate the displacement of the denture base with implants placed in the anterior and posterior region of the edentulous mandible.5)To compare the displacement of the denture base with implants placed in the anterior and posterior region of the edentulous mandible. *Materials and Methods:* The materials used were Nobel Biocare Mk III long implants 3.75x13mm and short 5.0x7.0 implants, with O-ball head attachment. ANSYS: Version 8.0 software was used to create a three-dimensional model of an edentulous mandible and the two implants. Three models were prepared having different implant positions and locations. MODEL 1 Two long implants were placed interforaminally in lateral incisor region one on either side, MODEL 2 Four long implants placed were interforaminally in the central incisor and canine region two on either side and, MODEL 3 Two long implants were placed interforaminally in lateral incisor region one on either side and two short implants were placed in premolar region 3mm posterior to the mental foramen, one on either side. Two types of load were given ie. vertical load of 325N was applied in second premolar and first molar region and 10N load at 150 angulation was applied in the anterior incisors area. The models were loaded separately and stress pattern, amount of stresses and amount of displacement were analysed for each model. *Results:* The observations obtained from the ANSYS software were analysed and evaluated. Model 3 showed the least amount of stress and displacement as compared to the other models. *Conclusion:* When the implants were spread across the arch both anteriorly and posteriorly, the stress induced in the bone and displacement of the denture base was seen to be less.

Key Words: Implant, Load, Displacement, Stress.

Introduction

Edentulism leads to an acknowledged impairment of oral function with both esthetic and psychological changes. Severe atrophy of the inferior alveolar process and underlying basal bone often results in other problems with a lower denture such as, intolerance to loading of the mucosa, pain, difficulty in eating and speech, loss of soft tissue support, and altered facial appearance.

It has been established through longitudinal clinical studies, that the survival of root form titanium implants is very high in the anterior mandible and that the incidence of surgical complications is very low. The superior bone quality in the anterior mandible along with the usual abundance of keratinized tissue makes it a suitable location for implant placement. Implants prevent alveolar bone resorption by about four fold, when placed and selected properly. This makes implant supported over dentures a very feasible treatment option that will aid in the establishment of stability and retention of the mandibular denture.

An implant retained overdenture with attachment to the implant can be supported and retained either fully by the implant or by a combination of a prosthesis retained both by implant and mucosa. In all incidences of functional loading, the occlusal forces are transferred to the bone implant interface and soft tissues by the implant supported prosthesis. Studies have shown that regardless of attachment type, patient satisfaction levels are the same with a bar, ball, or magnet-retained denture supported by implants.

Fabricating overdenture on implants placed in the anterior region between the foramen results in the cantilevering of the denture posteriorly leading to posterior bone resorption along with increased load on the implants. Since 1982, the evidence for mandibular

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overdentures supported by two implants has accumulated sequentially to see them now proposed as the standard service, when opposing maxillary complete dentures. Later, implant-supported dentures were constructed using four implants interconnected by a bar. It was a reliable option because it remained functional even after failure of one of even two implants. Also, placing four implants may reduce the amount of stress over individual implants and may also reduce the displacement of denture in the posterior region, but, the resorption in the posterior region may continue. It was suggested that a more "spread out" arrangement of the implants across the arch gave a "more favourable" distribution of bone stresses around the implants. But the height of bone in the posterior region many a times being inadequate, does not permit the placement of long implants. Therefore short implants could be an option. This would spread out the implants in anterior and posterior regions.

Therefore a finite element study was undertaken to compare the stresses in the bone and displacement of the denture base when implants were placed only in the anterior region and when the implants were spread out both anteriorly and posteriorly. These stresses were analysed by the finite element method by creating a three dimensional finite element model as it can more accurately simulate the geometric and material complexities that exist in real patients. These situations can be simulated in patients, when implant overdentures are planned.

Method

The study was divided into following steps:-

I **Introduction To The Finite Element Analysis**

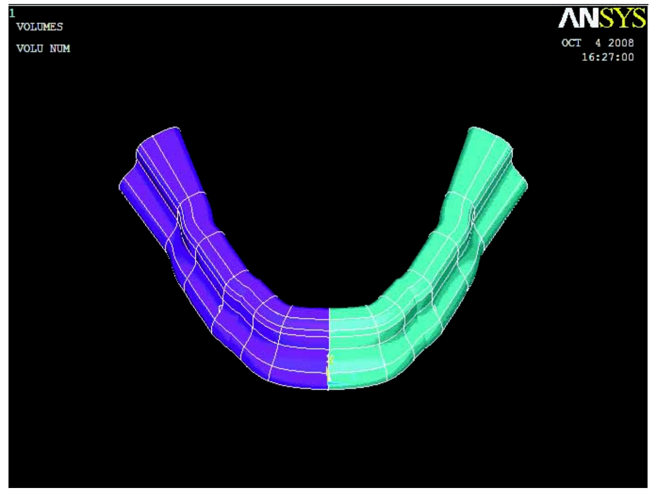
Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behaviour of engineering structures. The behaviour of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equations describing the behaviours of the individual elements are joined into an extremely large set of equations that describe the behaviour of the whole structure. The stresses will be compared to allowable or permissible values of stress for the materials to be used, to see if the structure is strong enough.

II **Construction Of The Fea Model : Pre-processor (Modelling)**

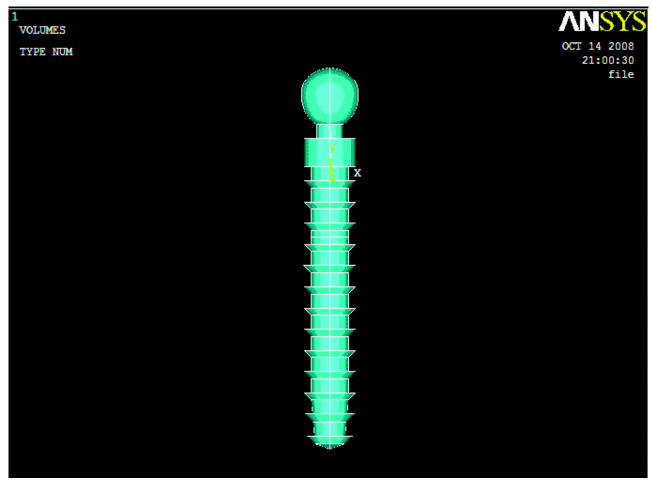
A. Construction of the geometric model of the edentulous mandible

1. *Modeling the alveolar portion of the bone*

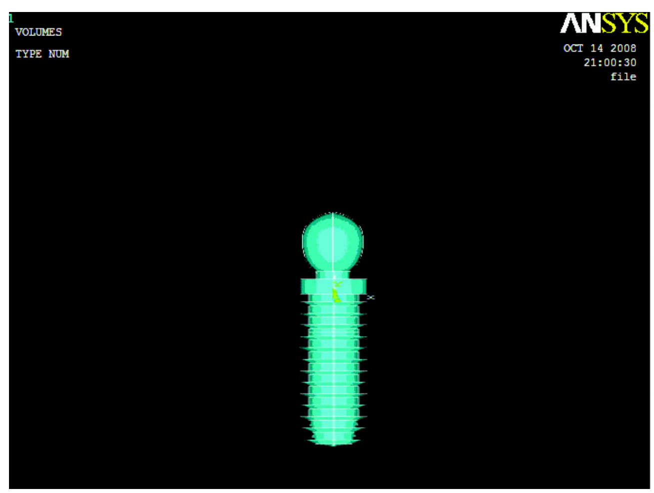
Modeling is done as 3D solid modeling. This model simulates bone with different material properties. An edentulous mandible was taken and measurements made at different points along the bone in the antero-posterior and supero-inferior



Three Dimensional Model of Complete Alveolar Portion of The Mandible



Model of Long Implant



Model of Short Implant

plane with the help of vernier callipers. The measurements were given co-ordinates in the x, y, and z planes.

The mandible was made eight mm in width and eighteen mm in height. The canal was modeled by creating a cylindrical volume and the alveolar part of the mandible was modeled till the ramal area. The mental foramen was located at a distance of 30.41mm from midline and 19.38mm from base of mandible.

2. *Modeling the implant and attachments*

Nobel Biocare Mk III implants were used in the study which were made up of Titanium-aluminium-vanadium (Ti-6Al-4V).

The implant dimensions used were
Long implants- 3.75x13.0mm
Short implants- 5.0x7.0mm

The threaded part of the implants was embedded in the bone with the 'O-Ball' attachment outside the bone on top of the implant. The 'O-Ball' attachment was modeled as a 1.5mm sphere at the platform of the implant. The external hex design and cylindrical portion of the overdenture attachment was not modeled so as to simplify the nodal configuration and thereby the analysis. The implants were constructed in a similar way to the bone.

3. *Placing the implants in bone*

The implants were placed in specific positions of the mandible. The mental foramen was taken as a guide for the placement of the posterior implants.

MODEL 1: Two long implants were placed interforaminally in lateral incisor region one on either side.

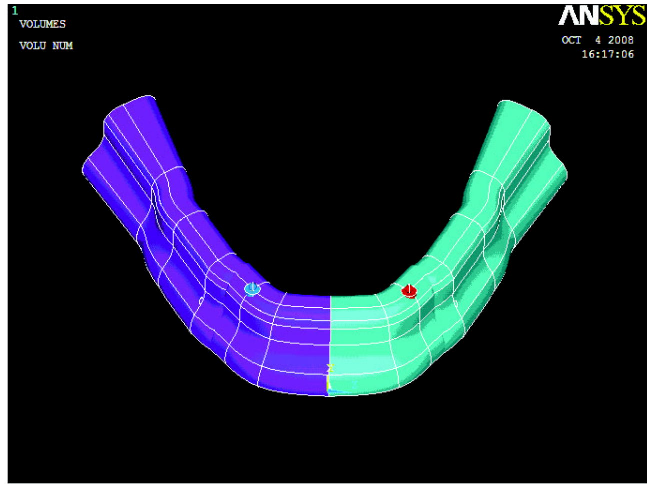
MODEL 2: Four long implants placed were interforaminally in the central incisor and canine region two on either side.

MODEL 3: Two long implants were placed interforaminally in lateral incisor region one on either side and two short implants were placed in premolar region 3mm posterior to the mental foramen, one on either side.

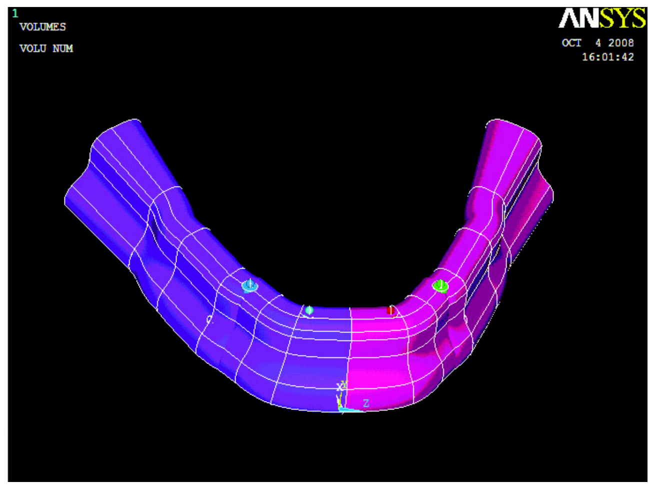
Complete bond (ankylosed) between implant and bone was considered. The models were loaded separately and stress pattern and amount of stresses were analysed for each model.

4. *Modeling the mucosa*

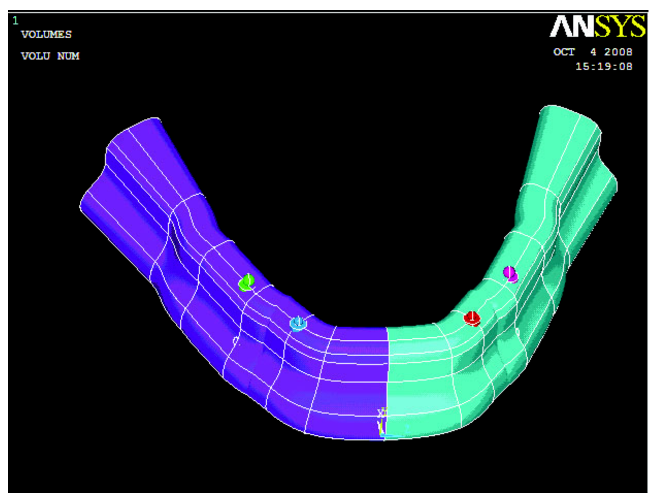
Since 'Poissons ratio' for the mucosa was almost negligible as compared to the bone and the implant, it was considered not to create a significant impact on the result and was not modeled.



Model 1- Volume Modelling of Mandible



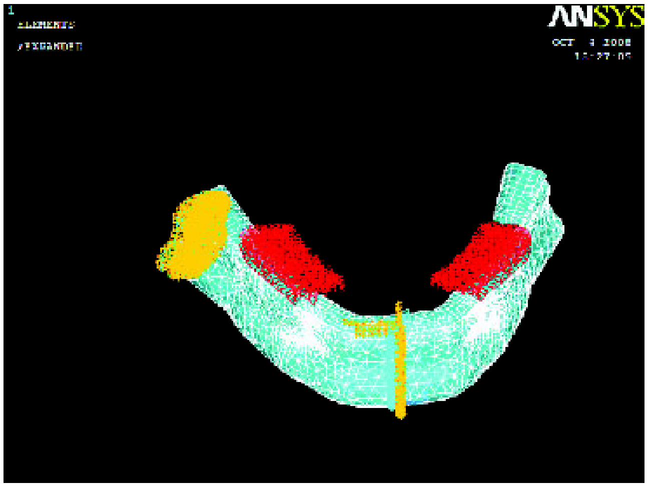
Model 2- Volume Modelling of Mandible



Model 3- Volume Modelling of Mandible

5. *Modeling of the denture base*

The overdenture was modeled as a SHELL element (Shell 63 element). It had a modulus of elasticity of 1.022x105 N/mm^2 and poisons ratio of 0.3. It was modeled as a two dimensional structure. The



Simulated Load In Molar Area

plate was 3 mm in thickness and kept at a distance of 2 mm from the bone to compensate for the mucosal thickness. The plate touched the overdenture attachments and covered the top part of the alveolar bone and implants.

6. *Splitting the mandible into two symmetric parts*

Since the mandible is symmetric about its midline, the mandible was sliced through the centre. This simplifies the solving process as less computational data would be generated.

B. Meshing the model

A three dimensional Finite Element Mesh was created using the Ansys pre-processor. Care was taken to concentrate the mesh pattern in the region where we wanted to study the distribution (i.e. around the implant). For this reason the SOLID 45 element (brick element) type was selected. The element had a 8 node element with quadratic displacement behaviour and was well suited for modeling irregular meshes. Each node had freedom to move in the x, y and z planes. The elements were constructed to be as accurate as possible within the limitations of the software. The completed model consisted of 28889 elements and total of 6223 nodes (4956 for bone and 1267 for implants) with 18669 degrees of freedom.

C. Assigning the material properties

All the structures depicted in the model (cortical bone, cancellous bone, and the implant) were assumed to be linearly elastic, homogenous and isotropic. The Young's modulus and Poisson's ratio for the different materials used in the study were given by Pierrisnard L, Hure G, Barquins M, Chappard D1. The models were given the properties of Cancellous Type A bone.

Material Properties

Materials Poisson's		Young's Modulus (Mpa)	Ratio
Implant		114	0.34
Cortical Bone		14	0.35
Cancellous Bone	Type A	2.5	0.3
	Type B	1.5	0.3
	Type C	0.5	0.3

D. Applying the boundary conditions

Symmetric boundary conditions were imposed at the mid-symphyseal region since only half the mandible was modeled. The rear end of the mandible was fixed for displacement in all three translations.

E. Loading of the model

Beam loading was used to put the load. Two loads were applied.

LOAD 1 - A vertical load of 325 N was applied in second premolar and first molar region.

LOAD 2 - A tipping force of 10 N at 150 angulation was applied in the anterior incisor area.

II PROCESSOR (SOLVER)

Once the geometry is converted to the finite element form, it is to be solved by the solver which is a part of the software. The results were generated after all the equations were solved. The solver does the following: it generates element matrices, computes nodal displacement values and derivatives, and solves governing matrix equations.

II POST PROCESSOR (RESULT)

The results for the stress and displacement are interpreted from color coded images seen in the 3D finite element models.

Results

The observations were statistically analysed to comparatively evaluate the values obtained. The Stress analysis executed by the Ansys software provided results that enabled visualization of Compressive stress, Von-Mises stress fields in the form of Colour coded bands along with the Displacement. Each colour band represented a particular range of stress value which is given in Newton-mm^2. The displacement values were observed in mm.

Analysis of Stress Induced In Bone With Three Different Implant Positions (N/Mm²)

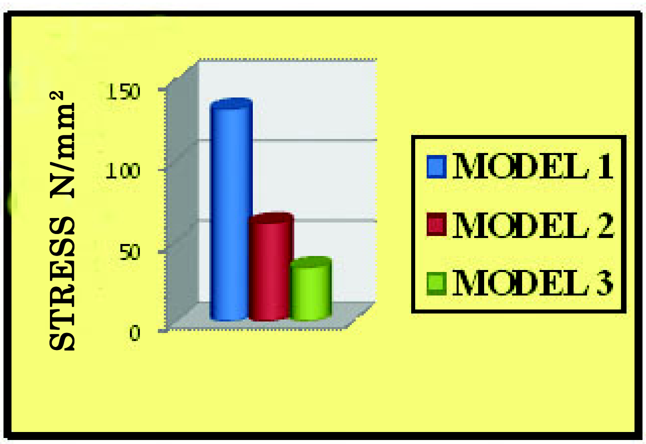
Model	Compressive Stress 325N Vertical Load	Von Misses Stress 325N Vertical 10N Oblique Load	Von Misses Stress 10N Oblique Load	Resultant Von Misses Stress of 325N Vertical Load (Rounded)
Model 1	Max. Upto 132	0-352	0-1.2	351
Model 2	Max. Upto 60	0-261	0-0.9	260
Model 3	Max. Upto 33	0-160	0-1.1	159

Displacement of Denture Base (Mm)

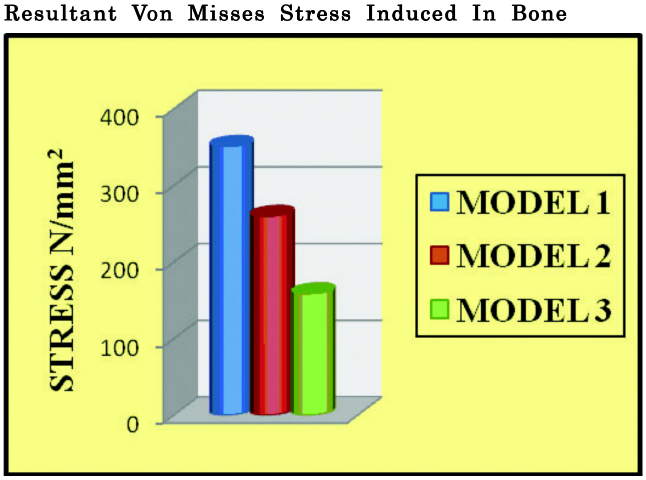
Model	Displacement of Plate With 325N Vertical And 10N Oblique Load	Displacement of Plate With 10N Horizontal Load
Model 1	93	0.079
Model 2	46	0.026
Model 3	20	0.018

Graphs:

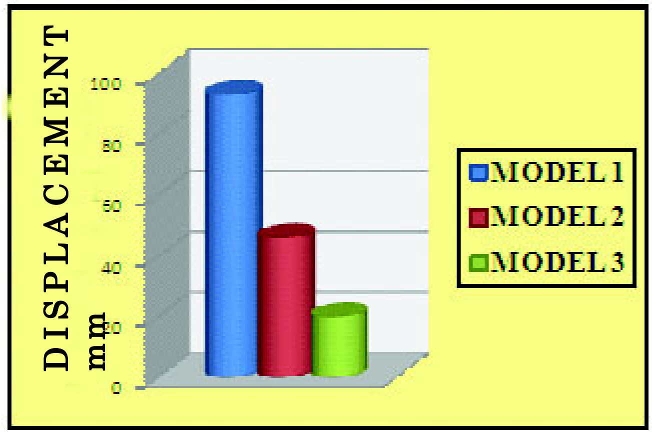
Compressive Stress Induced In Bone



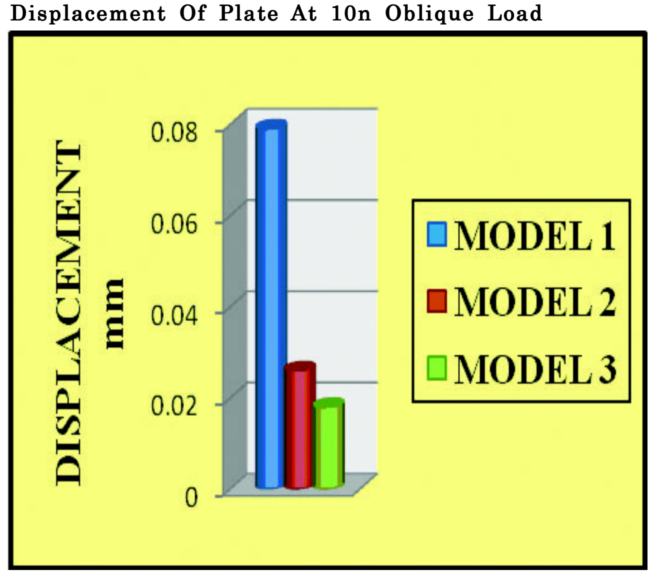
Resultant Von Misses Stress Induced In Bone



Displacement Of Plate At 325n Vertical And 10n Oblique Load



Displacement Of Plate At 10n Oblique Load



Discussion:

Edentulous patients require replacement of teeth for performing function of mastication, speech and esthetics. With advancing age, the rate of resorption increases leaving the patient a dental cripple. The placement of implants for such patients will overcome the problems of retention, stability, comfort and preservation of tissues. Fixed restoration with multiple implants may be the first choice for these patients, but with the deteriorating conditions of the alveolar ridge, placing multiple implants may not be possible. We need to take the maximum advantage of what remains of the patient's oral condition. Complete over dentures with few implants could be the treatment option for these patients in order to fabricate prosthesis that the patient appreciates without overloading the poor denture foundation.

The placement of implant overdentures has become a popular line of treatment. Factors such as location, number, size and distribution of implants over the edentulous arch have been a subject of much debate.

This study was 3-D finite element study planned with the two lengths of Nobel Biocare Mk III implants having two different diameters and lengths and three different positions on the edentulous mandible.

The finite element model of the mandible was modeled and the bone density was incorporated as suggested by Perrishard, Hure, Barquins, Chappard1. For simulation of the overdenture a SHELL element was modeled and was two dimensional. The material properties were assigned according to the literature and the models were meshed. The selection of implants was done to simulate different situations.

For Model 1 two implants of Nobel Biocare 3.75mm x 13mm were placed in the lateral incisor region which according to Hong, Choi, Bak and Kwon[2], was the best position for placing them for overdentures.

For Model 2 four implants of Nobel Biocare 3.75mm x 13mm were placed in central and canine region as suggested by Misch[3].

For Model 3 the two anterior implants of Nobel Biocare 3.75mm x 13mm were placed as in Model 1 in lateral incisor region and two posterior implants of Nobel Biocare 5mm x 7mm were placed in posterior region as suggested by Gherke, Spanel, Degidi, Piatelli, and Dhom[4].

Occlusal forces were applied to simulate the vertical forces (y axis) and the oblique load was applied at 150 angle as suggested by Chun et al[5] to simulate the anterior component of the load that bought about the tipping of the denture when tongue comes in contact with the lingual surface of the anterior teeth6 (x-axis). A combination of occlusal and oblique load simulated the masticatory load in the model. The amount of load applied was in accordance with Kampen, Bitt, Cune, Bosman, and Bozkaya, Muftu[7]. the stresses were observed and analyzed.

It was found that irrespective of the positions of implant the concentration of stresses was near the attachment of the O-ball head to the implant. Less stresses were seen in model with four implants as compared to model with two implants which is contradictory to the studies carried out by different researchers i.e Meijer, Starmans, Steen, Bosman[8] and Visser, Raghoebar, Meijer, Batenburg, Vissink[9]. Maximum stresses and displacement of denture base were observed in model with two implants placed anteriorly which may be attributed to less support. Least stresses were seen in the model with two long implants placed anteriorly and two short implants placed posteriorly along with least displacement of denture base. This may be attributed to the increased number of implants and also their wide distribution and spread across the arch.

The Finite Element Method has proven to be an extremely accurate and precise method for analyzing structures. Although it is not a substitute for clinical experimentation, the use of this method of analysis is warranted as it simulates experimental results, reduces experimentation costs and avoids destructive experimentation.

Conclusion

The study was conducted to evaluate the stress distribution in bone and displacement of the denture base with varied implant positions. Within the limitations of the 3D finite element study the following conclusions were drawn:

1. The stresses were maximum with two implants placed in the anterior region.
2. The stresses were minimum when the implants were spread anteriorly and posteriorly i.e. two implants in the anterior region and two short implants in the posterior region.
3. The stresses with four implants in the anterior region were less than the two implants placed in the anterior region but more than the four implants spread anteriorly and posteriorly.
4. Maximum displacement of the denture base was observed with two implants placed in the anterior region.
5. Minimum displacement of the denture base was observed with implants spread anteriorly and posteriorly.
6. The displacement with four implants placed in the anterior region showed less displacement as compared with two implants placed in the anterior region but more as compared to the four implants placed anteriorly and posteriorly.
7. When the implants were spread across the arch both anteriorly and posteriorly, the stress induced in the bone and displacement of the denture base was seen to be less.

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