

# Three-dimensional finite element analysis of immediate loading mini over denture implants with and without acrylonitrile O-ring

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## ABSTRACT

**Aim of the study:** The aim of the study was to check the stress absorbed by the bone around mini over-denture dental implant with and without acrylonitrile O-ring under two different loading conditions. The initial stress absorbed by the implant plays a significant role in the success of the immediate loading implants.

**Materials and Methods:** A three-dimensional finite element analysis using Pro-E mechanical finite element software was used to check the stress absorbed by the bone with and without acrylonitrile O-ring. The implant and the mandible were modeled from the data obtained from C.T. scan and optical projector using reverse engineering process. Two different loading conditions of 80 N and 220 N were determined and the analysis was done.

**Results:** The result showed at lower loads (80 N), there was not much difference in the stress absorbed by the cancellous bone with or without acrylonitrile O-ring, but at higher loads (220), there was difference in the stress absorbed by the cancellous bone with (0.03508 Mpa) and without acrylonitrile O-ring (3.874 Mpa) which showed that significant stress was absorbed by the acrylonitrile O-ring.

**Conclusion:** This study proves that higher loads during parafunctional movement were absorbed by the acrylonitrile O-ring increasing the success of the implants.

**Key words:** Acrylonitrile O-ring, finite element analysis, mini dental implant

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Increasing life expectancy of patients requires them to wear dentures for longer periods of time causing considerable resorption of the supporting bone, resulting in decreased retention and stability of dentures especially the mandibular denture. The treatment options available for such patients is either surgery or over-denture implants.<sup>[1]</sup> Mini over-denture dental implants are immediate loading and use the patient's old denture as the permanent prosthesis. Mini<sup>[2]</sup> O-ball bearing implants come as a single unit with the O-ball abutment attachment to it. It has a metal housing and acrylonitrile O-ring. The acrylonitrile O-ring acts as a shock absorber.

## Aim of the study

The aim of the study was to check the stress absorbed by the bone around mini over-denture dental implant with and without acrylonitrile O-ring under two different loading conditions.

## MATERIALS AND METHODS

Two immediate loading mini O-ball bearing over-denture implants were used for the study. The implant and abutment are a single unit and it is made up of titanium alloy (Ti<sub>6</sub>Al<sub>4</sub>V). Titanium alloy has 62.5% higher tensile strength than the strongest commercially pure grade IV titanium. The pitch of the thread 0.53 mm, diameter 1.72 mm and height 19 mm. It has a titanium alloy housing and acrylonitrile O-ring.

The O-rings are categorized as static or dynamic, based on the relative motion. The dynamic movement O-ring is a resilient or mobile type of attachment. The food and drug administration (FDA) of the U.S.A has issued guidelines for O-ring meant for use in humans. The elastomeric materials satisfying the guidelines include (1) Silicone (2) Acrylonitrile (3) Fluorocarbon, (4) Ethylene propylene. Acrylonitrile is

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one of the most widely used elastomer in implant O-ring. The O-ring acts as a shock absorber and limits the load placed on the implant and bone.

Finite element analysis (FEA) is a sophisticated engineering tool which has been used extensively in design optimization and structure analysis. It represents one of the most significant developments in the history of computational methods. This method originated in the aerospace industry as a tool to study stresses in complex airframe structures. The method has gained increased popularity among both researchers and practitioners.

In this method, a body or a structure in which the analysis to be carried of material out is subdivided into smaller elements of finite dimensions called finite elements, called discretization. Then the body is considered as an assemblage of these elements connected at a finite number of joints called nodes. Mechanical properties such as Young's modulus (modulus of elasticity) and Poisson's ratio of materials can be utilized by computer generated analysis to describe the mechanical behavior and induced stress of a structure. Calculation of these stresses allows the investigator to determine areas of high stresses or large deformations which could lead to fracture or failure of the structure. General purpose finite element software provides the necessary tools to perform such analyses on a wide variety of problems without compromising accuracy. Here we have used Pro Engineering (Pro-E) Mechanical finite element analysis software which helps us to make the model using Pro-E interface software and then do the analysis.

The modeling process can be subdivided into two broad steps, geometric modeling and finite element modeling. Geometric modeling is the step in which an accurate model of the components to be analyzed is generated using Pro-E interface software. It requires accurate inputs of data regarding the design features and dimensions of the components to produce accurate geometric models. Model must be accurate like the components to be analyzed by the FEA software.

Finite element modeling is described as the representation of the geometric model in terms of finite number of elements and nodes which are the building blocks of the numerical representation of the model. Any element which may consist of triangular or quadrilateral shapes is a mathematical matrix of the collective interactions among degrees of freedom whose sides are connected by nodal points.<sup>[3]</sup> A node is a coordinate in space where degree of freedom (displacement) and actions (forces) of a structure under load are considered to exist. In addition, this model also contains information about material and other properties, loading and boundary conditions. Once a structure is numerically created and material properties are assigned, it can be analyzed for stress distributions during force application using FEA. The

stresses are expressed as color codes with numerical values in  $N/mm^2$ . The global (x, y, z directional axes) combination of the absolute values squared of all stresses is known as Von Mises stresses. This study was done at Rolta India Limited, Chennai.

Loading conditions for the finite element analysis was based on Boucher.<sup>[4]</sup> He stated that 80 N is the maximal functional load for complete denture patient and 220 N was used to simulate loads in complete denture during parafunctional movements which is also the maximum functional load for natural teeth.

The analysis was done to check the stress distribution on cancellous bone. The loads of 80 N and 220 N are placed axially, before and after placement of the metal housing and O-ring to evaluate the amount of force absorbed by the acrylonitrile O-ring.

### Method followed

A CT scan data of the patient was taken to generate an accurate model for the geometric modeling of the mandible. The dental CT of 1 mm by 1 mm slice was taken from a Siemens CT scan machine. The CT data is available as dicom format. The dicom format has to be converted to IGES format which is a universal platform for any FEA software. This interface conversion is done by 3D doctor software which converts dicom files of CT/MRI data to IGES files which can be imported into Pro-E Mechanical FEA software to model the mandible [Figure 1].

The accurate geometric modeling of the acrylonitrile O-ring and titanium housing was done using the reverse engineering process.[Figure 2] Reverse engineering is the scientific method of taking something apart to figure how it works. Reverse engineering has been used by innovators to determine interoperable products i.e., going from the product to the design of the product, to make a new or same product. The same principle was used for implant modeling.

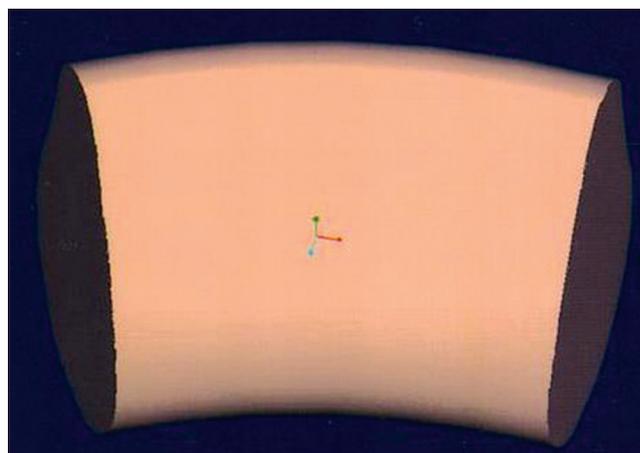


Figure 1: 3D model of mandible geometry

The implant was used on an optical projector [Figure 3] to accurately determine the size and pitch of the threads. This data was used to develop the model in Pro-E interface software. The model was then converted to IGES format. The IGES data is then converted to three dimensional geometric models by Pro-E Mechanical FEA software. Then the model is assembled for analysis. The Pro-E mechanics auto meshes the model to small elements connected by nodes [Figures 4 and 5]. Triangular and quadrilateral elements were used based on the surface geometry. The contact algorithm used in this FEA analysis is surface to surface contact algorithm.

The Pro-E Mechanical does the preprocessing and postprocessing after the material properties [Table 1] of Young's modulus and Poisson's ratio are entered to the FEA software.

The results are available as gradients of color. Three dimensional models represent the maximal to minimal principal stress in N/mm<sup>2</sup>. Color codes represent the area of stress in model. Any area of the implant model can be visualized for the stress pattern.

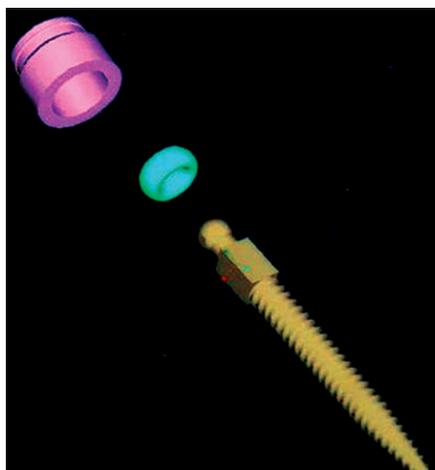
## RESULTS

Three-dimensional finite element stress analysis studies were carried out for the load of 80 N and 220 N. The load of 80 N and 220 N were placed axially in the implant without the metal housing and acrylonitrile O-ring and then with the metal housing and O-ring to evaluate the amount of stress absorbed by the acrylonitrile O-ring.

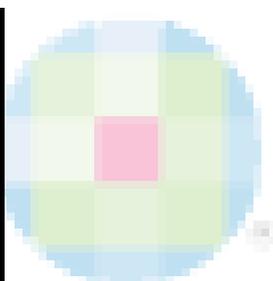
The results for FEA of the implant without housing and O-ring for 80 N load was  $1.680e - 06$  Mpa was the minimal stress and for the implant with housing was 0 Mpa was the minimal stress [Table 2]. The results for the maximum stress for 80 N load was 0.01754 Mpa for implant without metal

**Table 1: Mechanical properties**

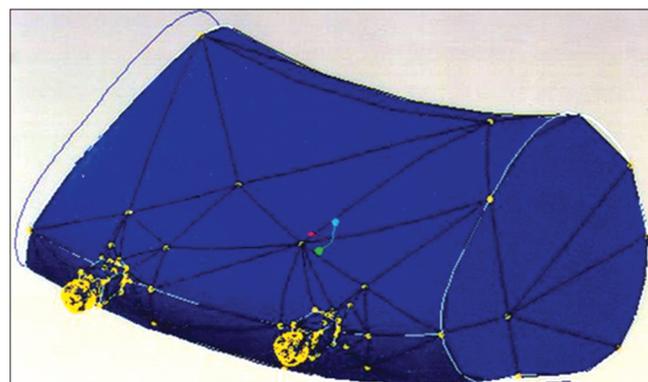
	Young's modulus	Poisson ratio
Cancellous bone	250 (Pa)	0.30
Titanium alloy	$110 \times 10^9$ (Pa)	0.33
Acrylonitrile O-ring	490 (Psi)	0.49



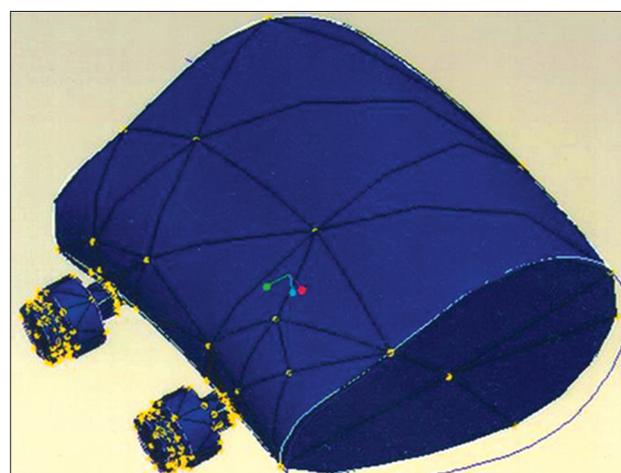
**Figure 2:** Geometric model of minidental implant with metal housing and acrylonitrile O-ring



**Figure 3:** Optical projectors



**Figure 4:** Finite element model of implant and bone without metal housing and acrylonitrile O-ring



**Figure 5:** Finite element model of implant and bone with metal housing and acrylonitrile O-ring

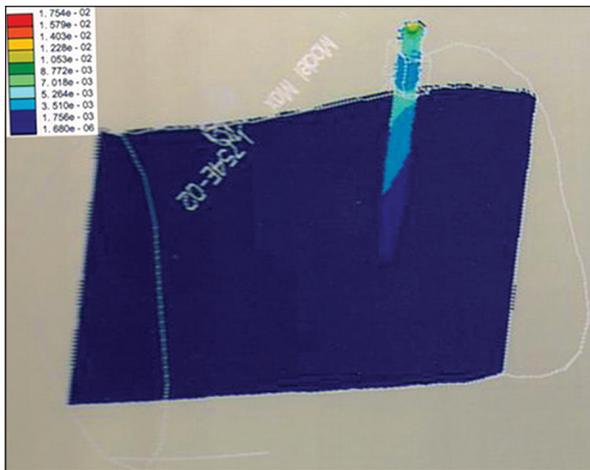
housing and O-ring [Figure 6] and for implant with metal housing and O – ring [Figure 7] the result was 0.01754 Mpa. There was no significant difference in the result showed for 80-N load.

The results [Table 3] for the implant without housing and O-ring for the 220 N load the minimal stress was 5.008e – 04 MPa and minimal stress for with housing and O-ring showed zero stress distribution. The maximal stress for without housing and O-ring [Figure 8], was 3.847 MPa and with housing and O-ring the maximal stress was 0.03508 Mpa for 220-N load [Figure 9].

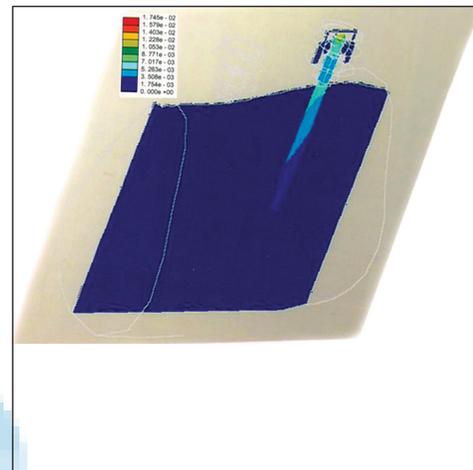
There is no difference in the stress value at 80 N for with and without metal housing and O-ring and are significant at 220 N for with and without metal housing and O-ring this may be due to the surface to surface contact algorithm used in the FEA which allowed the complete transfer of the stress to the bone.

### DISCUSSION

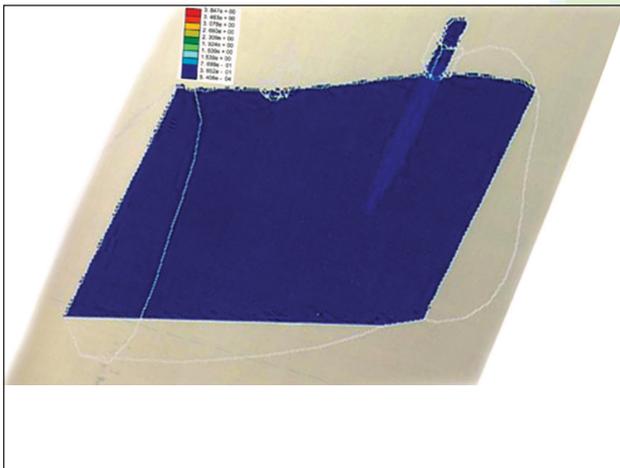
The immediate loading O-ball bearing mini over-denture implant<sup>[5]</sup> is a unique implant system for the treatment of



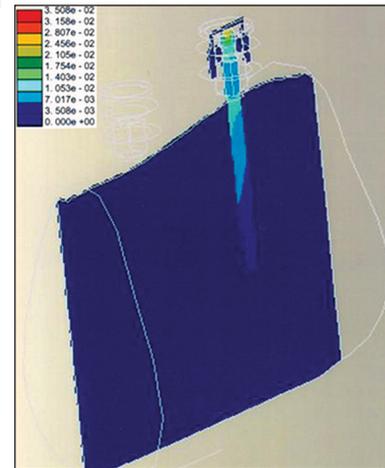
**Figure 6:** Finite element analysis of implant without metal housing and acrylonitrile O-ring for 80 N load



**Figure 7:** Finite element analysis of implant with metal housing and acrylonitrile O-ring for 80-N load



**Figure 8:** Finite element analysis of implant without metal housing and acrylonitrile O-ring for 220-N load



**Figure 9:** Finite element analysis of implant with metal housing and acrylonitrile O-ring for 220-N load

**Table 2: Von Mises Stress distribution on the cancellous bone with and without, metal housing and O-ring for 80-N load**

Load	Maximal stress Mpa	Minimal stress Mpa
80 N without housing and O-ring	1.754e – 02	1.680e – 06
80 N with housing and O-ring	1.754e – 02	0.00

**Table 3: Von Mises Stress distribution on the cancellous bone with and without, Metal housing and O-ring for 220-N load**

Load	Maximal stress Mpa	Minimal stress Mpa
220 N without housing and O – ring	3.847	5.008e-04
220 N with housing and O – ring	0.0350	0.00

compromised mandibular ridge. Advantages of mini dental implant.

- No surgical flap required.<sup>[6]</sup>
- No osteotomy site created.
- Only one drill used.
- Unique self-tapping design.
- Immediate fixation is equal to immediate loading.
- Multiple restorative options.

This immediate loading implant improves the stability and retention of the denture many folds. It evolves a simple technique for the placement of the implant. These implants are loaded immediately<sup>[7]</sup> after the placement the stress distribution on the implant and bone plays an important role for the success of the implant.

The maximal load on the bone was found around the neck of the implant. Meijer. HJ *et al.*<sup>[8]</sup> The most extreme principal stress were always located around the neck of the implant.

The maximal stress for 80-N load with and without O-ring was found to be the same i.e., 0.01754 Mpa, but when it was evaluated for a maximal load of 220 N the implant without O-ring showed 3.874 Mpa and while implant with O-ring showed 0.03508. the difference of 3.472 Mpa is the amount of the stress absorbed by the O-ring. Himmlová<sup>[9]</sup> *et al.* masticatory forces acting on dental implants can result in undesirable stress in adjacent bone, which in turn can cause bone defects and the eventual failure of the implant.

The stress absorbed by the acrylonitrile O-ring for lower loads is insignificant but when the loads are increased, like parafunctional loads, the acrylonitrile O-ring acts as a resilient shock absorber reducing the loads on the implants This aids in the reducing the stress being applied at the implant bone interface during the initial stages of osseointegration. Overloading factors that may negatively influence on implant longevity include large cantilevers, parafunctions,<sup>[10]</sup> improper occlusal designs and premature contacts. The stress absorption during the initial stages of osseointegration of the implant becomes the major factor for the success of the implant as over denture implants fail more during the initial period<sup>[11]</sup> than the following years.

## CONCLUSIONS

Three-dimensional finite element stress analysis was used to evaluate the stress absorption by a mini dental implant acrylonitrile O-ring and the distribution of stress patterns on the peri – implant bone. Implants of dimension

1.72 × 19 mm were tested with and without metal housing and acrylonitrile O-ring.

According to the results of this study, acrylonitrile O-ring was not stressed at lower loads which prolong the longevity of the life of the O-ring. The presence of O-ring made a large difference when higher loads are applied to the implant. The acrylonitrile O-ring plays a vital role in absorbing the stress directed to mini dental implant and the surrounding bone at higher loads

The limitation of this study is that, the superstructure was not taken into consideration during stress distribution. Hence further study can be done along with the superstructure following the same protocol.

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